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Land Suitability Analysis for Sustainable Agricultural Development in Rajshahi District of Bangladesh

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PhD Dissertation

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Certification

This is to certify that the dissertation titled "Land Suitability Analysis for Sustainable Agricultural Development in Rajshahi District of Bangladesh" has been carried out by Md. Asadul Islam under my supervision. The research work presented here is original and standard enough for the fulfillment of the degree of Doctor of Philosophy.

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Declaration

I am pleased to declare that this research work is my own and original work. Any part or the whole of this study has not been published earlier anywhere. The GIS, Multi-Criteria Evaluation (MCE), and Benefit-Cost Analysis (BCA) approaches have been used to examine land suitability analysis with appraisal of economic viability in Rajshahi district of Bangladesh, which is a pioneer work in land suitability and economic viability analysis.

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Abstract

Importance of land suitability analysis for sustainable agricultural development is unnoticed in Bangladesh for long time resulting in the stagnation of profit margin, economic benefit, yield, crop diversification and development in agriculture sector as well as socio-economic, political and cultural development of Bangladesh. However, the purposes of the present research were land suitability analysis for sustainable agricultural development in Rajshahi district of Bangladesh analyzing the current soil, irrigation water, climate, topography, floodability, and accessibility attributes and many other aspects of the study area. Besides, economic viability of currently cultivated major crops and cropping patterns and land suitability based cropping patterns are assessed. Land use changing patterns are analyzed and farmers' perception levels are also measured for agriculture development.

In this study, Rajshahi district of Bangladesh was the study area and Godagari upazila was selected through simple random sampling (SRS) which covers about 20 per cent area of the district. Soil, irrigation water, topography, and floodability samples and respondents for questionnaire survey and land suitability model output and classified image verification samples were selected using sample size determination formula and union wise samples were selected following probability proportional to size (PPS) sampling. Climate data were used for 40 years (1975-2014) of the study area and accessibility data were generated using multiple ring buffer and Euclidian distance method in GIS technique. Data of economic viability of agricultural crops and farmers' perception regarding land suitability and agriculture development were collected through questionnaire survey. Land use changes were analyzed considering soil properties of 1991 and 2015, crop cultivation areas of 1983-84, 1996, and 2008 by agriculture census data, agriculture land use changes using 5 images of 1977, 1988, 1996, 2008, and 2016 and cultural changes in different aspects of agriculture of the study area. Total six case studies- two from each of onion seed, cauliflower, and Thai guava cultivation were conducted to support the data.

All properties of soil except pH and boron are below from the optimum value in the study area. Irrigation water attributes are within normal range though not in optimum level. Temperature is not a major problem but rainfall is insufficient for crops production. High land area dominates in the study region and flooding problem is very trifling. Accessibility is a major problem for Char Ashariadaha union which is separated by mighty river the Padma.

Soil and climate are moderately suitable; irrigation water and floodability are predominantly suitable for agriculture in the study area. Topography and accessibility are found mainly low and moderate suitable for agriculture. The study locale is dominated by agriculture and agriculture is dominated by a few crops mainly rice. All unions are found moderately suitable for rice, wheat, maize, potato, chili crops cultivation and the whole study area is found moderately suitable for general agriculture. On the other hand, lentil, mustard, and onion crop cultivation are found moderately suitable in Basudevpur, Deopara, Gogram, Matikata, Rishikul, Godagari, Mohanpur, and Pakri union which cover 92.34 per cent land area and marginally suitable is found only in Char Ashariadaha union which covers only 7.66 per cent land. In land suitability model output, the accuracy figure was found from 87.50 to 92.85 per cent in field verification.

Yield of almost all crops is lower in the study area than that of Northern Bangladesh. Among the generally cultivated 15 crops, per 33 decimals net returns from onion seeds and cauliflower cultivation are found worth about BDT 97574 and 26090 respectively which are very profitable and much more than rice which (rice) is cultivated in about 79 per cent land both in the study area and in Bangladesh. The next economically viable five crops are onion, brinjal, tomato, maize, and potato respectively on the basis of net return. On the other hand, rice is the economically least viable crop and next least viable five crops are mustard, wheat, lentil, chili, and pulses respectively. However, the dominance of rice in cropping patterns in the study area and Bangladesh is not economically viable and a key obstacle for the development of agriculture, socio-economic development of farmers as well as rural areas of Bangladesh. Land suitability based cropping patterns are highly profitable than presently cultivated rice based cropping patterns. It is possible to increase net returns about BDT 511.74, 2398.54, 9512.49, and 97930.14 crores for the study area, Rajshahi district, Rajshahi division, and Bangladesh respectively changing only cropping patterns and agriculture sector alone could contribute a lot to develop Bangladesh if land suitability based cropping patters are followed. Case studies of onion seed, cauliflower, and Thai guava cultivation show that these three crops cultivation are profitable but cauliflower has low sustainability risks and onion seed and Thai guava cultivation have high sustainability risks.

pH, organic matter, and zinc level have been increased but nitrogen, phosphorus, sulfur, and boron of soil have decreased significantly in the study area from 1991 to 2015. HYV *aus*, HYV *boro* rice, maize, jute, potato, spices, fruits, oil seeds, and vegetables cultivation area have been increased but HYV *aman*, wheat, sugarcane, pulses cultivation area are decreasing. Agriculture land cultivation areas have been increased noticeably from 1977 to 2016. The classification error matrix of 2016 Landsat 8 image in 56 spots, field verification shows that the classification accuracy is 87.50 per cent. Chi-square value was found 285.430, Kendall's tau .758 and Kappa statistic was .809 that show good agreement between classified image and field data. Cultural changes are occurred noticeably in agriculture in the study area. Farmers hold medium and low level of perception regarding land suitability and agriculture development in the study area which are not conducive for sustainable agricultural development and need to be elevated for the development of agriculture.

The study area has immense potentialities of Thai guava, *bablah*, moringa, flowers, mango etc. cultivation in agriculture land and fish cultivation in 1162 ha low land area. Land suitability based crop cultivation, crop diversification and cropping pattern changes, emphasis on cultivation of profitable non-traditional crops, application of GIS and RS, e-agriculture, use of organic and green manure fertilizer, fish cultivation and other practices in 1162 ha low lands, establishing agriculture market and cold storages, elevation of farmers' perception level etc. are few important ways for sustainable agricultural development in the study area.

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List of Abbreviations and Symbols

BADC	= Bangladesh Agricultural Development Corporation
BCA	= Benefit- Cost Analysis
BCR	= Benefit- Cost Ratios
BDT	= Bangladesh Taka
BMDA	= Barind Multi-Purpose Development Authority
DPHE	= Department of Public Health Engineering
ERDAS	= Earth Resources Data Analysis System
ESRI	= Environmental Systems Research Institute
FAO	= Food and Agricultural Organization
GIS	= Geographic/Geographical Information System
Ha/ha	= Hectare/hectare
KAP	= Knowledge, Attitude, and Practice
Kg	= Kilogram
LIS	= Land Information System
LSA	= Land Suitability Analysis
LUT	= Land Utilization Type(s)
MAY	= Maximum Attainable Yield
MCE	= Multi-Criteria Evaluation
MoA	= Ministry of Agriculture
MoL	= Ministry of Land
RS	= Remote Sensing
SMCE	= Spatial Multi-Criteria Evaluation
SRDI	= Soil Resource Development Institute
%	= Percentage
=	= Equals to
<	= Less than
>	= Greater than
°	= Degree
°c	= Degree Celsius
°N	= Degree North
°S	= Degree South
n	= Sample Size
N	= Population

Chapter One
Introduction

1.1 Prelude

Land is the most valuable and important of all the natural resources of a country. It provides food, clothes, residence and shelters, raw materials for industries, essential medium for development of agriculture, aquaculture, forestry, industry, communication, vegetation, employment, business, recreation, growth and development etc. It is the ultimate source of wealth and the foundation on which almost all economic activities are based. Possibly the best form of land resources' inventory of Bangladesh is land use map based on land suitability analysis for various uses. The land use maps and their interpretations are essential tools in agricultural development.[1]

Land suitability analysis is very important for Bangladesh as the country has only14.84 million hectares of land with 149.77 million population, the density of population was 976 per sq. km of which 24.26 per cent (3.60 million hectares) land are at present used for non-agricultural purposes.[2] Besides, the country is adding about 2 million new mouths every year, which need additional food and lands. On the other hand, cultivable land is decreasing by about 58 thousand hectares annually on an average. Land suitability analysis for various uses is the perfect tool for the proper land use planning and land management. The present time of highly densely populated Bangladesh leads to the conclusion that the central concern in proper land use is the proper selection for maximum production and benefits from every piece of land. Hence, the concern is to examine what really happens in practice and what should be practiced for maximum beneficial outcome in all respects.

Land suitability analysis is a prerequisite for sustainable agricultural development. Sustainable agriculture integrates three main goals- environmental health, economic

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[1] M. Aminul Islam and R. M. Ahsan,"Land Use Study in Bangladesh," *Environment, Land Use and Natural Hazards in Bangladesh* ed. M. Aminul Islam (Dhaka: Dhaka University, 1995), 214.

[2] Sk. Ghulam Hussain, M. Khalequzzaman A. Chowdhury and M. Abeed Hossain Chowdhury, *Land Suitability Assessment and Crop Zoning of Bangladesh* (Dhaka: Bangladesh Agricultural Research Council, 2012), 2.

profitability, and social and economic equity.[3] Nevertheless, this field is neglected for long time, especially in sweet water areas and sweet water area covers about 81 per cent area of Bangladesh. In any discussions of agricultural sustainability, it is important to clarify what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria.[4] So, we should work out a land use suitability analysis whereby it becomes possible to predict the rational type of land use for sustainable agriculture and other purposes which ought to be pursued in all areas of Bangladesh.

Geographical Information System (GIS) is a system of hardware, software, and procedures designed to support the use, manipulation, analysis, display, and management of spatially referenced data for solving complex planning and management problems.[5] The main purpose of the Multi-Criteria Evaluation (MCE) techniques is to investigate a number of alternatives with respect to multiple criteria and conflicting objectives for maximum benefits. The MCE and GIS jointly could be very useful in taking proper decisions in conflicting situations in spatial context and it is a very powerful approach to land suitability analysis.[6]

Land suitability is the fitness of a certain piece of land for a defined use.[7] The land suitability is a function of agricultural crops requirements and land characteristics for the maximum benefits. The firm's objective is the choice of the optimal way of increasing its output, to maximize its profits.[8] The comparison of benefits and costs plays a major part in the determination of land suitability. Agriculture is the single largest producing sector of the economy and it contributes about 17.22 per cent to the total Gross Domestic Product (GDP) of the country and accommodates around 45.60 per

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[3] Jennifer A. Elliot, *An Introduction to Sustainable Development*, 4th ed. (New Delhi: Syam Lal Chattergy Trust, 2013), 9.

[4] Niels Roling and Jules N. Pretty, *Extension's Role in Sustainable Agricultural Development,* Chapter 20 of *Improving Agricultural Extension: A Reference Manual* (Rome: Natural Resources Management and environment Department, 1997), 3.

[5] C.P. LO and Albert K. W. Yeung, *Concepts and Techniques of Geographic Information Systems* (New Delhi: Prentice-Hall of India Private Limited, 2002), 2.

[6] Florent Joerin, Marius Theriault and Andre Musy, "Using GIS and Outranking Multi-Criteria Analysis for Land-Use Suitability Analysis," *International Journal of Geographical Information Science* 15, no. 2 (2001), 154. doi:10.1080/13658810051030487 (accessed August 14, 2014).

[7] Food and Agricultural Organization, "A Framework for Land Evaluation," *FAO Soil Bulletin* 32 (1976), 16.

[8] A. Koutsoyiannis, *Modern Microeconomics*, 2nd ed. (London: Macmillan Education Ltd, 1979), 92.

cent of labor force.[9] Bangladesh is mainly an agrarian country, about 60 per cent of the total population is directly or indirectly involved in this sector for their livelihood, and this sector is fully related to land use. Urban area means 6 per cent area and 23.3 per cent population of Bangladesh are connected to village and agriculture who are not separated like distinctive urban areas of the Western World. Therefore, it is possible to bring significant changes in the whole spectrum of the socio-economy of Bangladesh only by using land based on suitability. In this way, we can either solve or at least mitigate the problems of Bangladesh, which are created by the growth of population on its diminishing limited lands. In this study, a model is to be constructed which will be helpful to predict what should be done in a specific pieces of land in Godagari upazila of Rajshahi district which would act as a catalyst for the land suitability based crop cultivation in the whole country.

1.2 Statement of the Problem

One of the essential factors which restricts the growth of mankind and their necessary activities is the limited land. Land is a precious resource and various human activities cannot be carried out simultaneously on the same piece of land. On the other hand, the cultivable land area in Bangladesh is declining and is under threat due to increasing uses of diverse types.

The rapidly growing population exerts noticeable pressure on the limited cultivable land of Bangladesh. According to the census 2011, the total population of Bangladesh is 149.77 million against the total area of 1,47,570 sq. km which is about 2.20 per cent of the world population but only 0.099 per cent of the total land surface area (148951000sq km). Bangladesh is one of the most densely populated countries in the world with a density of 976 persons per sq. km in 2011. Average annual population growth rate (2001-2011) is about 1.37 per annum, which is high and these people need additional food and lands. The projected population for the 2020, 2030, and 2040 would be 16.95, 18.98 and 20.51 crores respectively and the estimated food, especially rice and wheat, requirements would be 25.94, 27.63 and 32.38 million tons.[10] About 25 per cent of the total area is occupied by

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[9] Bangladesh Bureau of Statistics, *Statistical Year Book Bangladesh 2014* (Dhaka: Statistics and Informatics Division, Ministry of Planning, 2016), xxv.

[10] Hussain, Chowdhury and Chowdhury, *Land Suitability Assessment and Crop Zoning of Bangladesh*, 1.

homesteads, urban centers, industries, various institutions, and inhabited lands which are not available for agriculture. During 1971 the net cropped area of Bangladesh was 8.24 million hectares which declined to 7.94 million hectares in 2009. During the last decade, on annual average decline rate in net cultivable area is 0.735 per cent which is more than 57,800 hectares per year. Besides, 0.23 million hectares are classified as cultivable waste which is not available for cultivation.

The available per capita land in India is about 0.4 hectare, more than 0.9 hectare in China and 8.4 ha in USSR. But in Bangladesh, the per capita available land is about 0.065 hectare which is very low and not enough in any consideration. A census on land resources reported that everyday about 220 ha of arable land had been converting for other uses like construction of houses, roads, industries, and for other non-agricultural activities which is an alarming indication for Bangladesh.[11] If these causes of land resources declination continued, it is estimated that per capita arable land would be reduced from 0.065 ha to 0.025 ha by 2050. Following population rise and incessant increase in land use, Bangladesh will confront a grave situation from which there is virtually no scope to be escaped. With the development and diversification of increasing economic activities, the competition and necessity of proper use of land increases rapidly, creating more and more problems and urgency of feasible solutions.

Yield of different crops in Bangladesh is still considered very low in comparison to many other countries of the world.[12] One of the main reasons of low yield in Bangladesh compared to other countries of the world is the use of land for crops cultivation without assessing its suitability. A comparison is presented below between Bangladesh and neighboring country India for three crops of the study area.

Table 1.1. Comparison of Yield of Wheat, Sugarcane, and Root and Tuber Crops Between Bangladesh and India (2012)

(Tones per hectare)

Country	Wheat	Sugarcane	Root and tuber crops
Bangladesh	2.4 (14 % low)	43.8 (34 % low)	17.7(16% low)
India	2.8	66.1	20.9

Source: Statistical Data Book for Agricultural Research and Development in SAARC Countries- 2012 (P. 15, 17)

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[11] Ministry of Land, *Land Zoning Report: Sarankhola Upazila, Bagerhat District* (Dhaka: Ministry of Land, 2011), ii.

[12] Mohammad Monirul Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2015), 149.

The picture between Bangladesh and other developed and developing countries is appalling. The average yield per hectare of rice in the world is 4250 kg. The highest yield of 10040 kg has been registered in Egypt, followed by 7940 kg in USA, 6540 kg in Japan and 6490 kg in China. Rice yield (per hectare/ kg) is also found, India: 2967, Myanmar: 3187, Pakistan: 3071, Indonesia: 4376, Republic of Korea: 4040, and Vietnam: 4105.[13] On the other hand, per hectare yield of rice in Bangladesh is found in the last agriculture census 2907 kg,[14] which is much lower than abovementioned countries.

The present crop cultivation without suitability analysis may lead to stagnation in production increase and economic benefits. In view of above, the present situation demands an in-depth land suitability analysis for cultivation of proper and economically viable crops for agriculture development of Bangladesh.

1.3 Literature Review

A number of studies have been carried out regarding land suitability analysis in Bangladesh. But no study in particular has been carried out so far regarding the sweet water areas in an integrated way. Most of the studies are devoted to saline water vis-a-vis fish and crops production in coastal saline areas. A few studies have been done in other countries of the world. But, soil, irrigation water, climate, topography, floodability, accessibility and other conditions of those countries are totally different from the study area and Bangladesh. Economic viability analysis of land suitability is crucial to switching from present land use to suitability based land uses, but these are not done in any study. The pertinent research works done in Bangladesh and abroad reviewed for the analytical guidance, footing for conceptions and research gap which are presented below country wise (alphabetically ordered).

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[13] Muhammad Parvez Wasim, "A Study of Rice in the Major Growing Countries of the World: Their Growth, Instability and World Share," *Pakistan Economic and Social Review* XL, no. 2 (2002), 156-157. http://pu.edu.pk/images/journal/pesr/PDF-FILES/3%2520WASIM%2520A%(accessedOctober 28, 2015).

[14] Bangladesh Bureau of Statistics, *Census of Agriculture 2008; Zila Series: Rajshahi* (Dhaka: Statistics and Informatics Division, Ministry of Planning, 2011), 37.

Bangladesh: Khondaker Md. Shariful Huda conducted a study named "Geographical Information Systems and Agriculture in Bangladesh" in 1997. Rainfall, temperature, land type, soil type, flood and salinity have been taken into consideration under existing physical environment, irrigation, use of fertilizers; pesticides and improved seed distribution are considered as improved agricultural inputs for locating suitable areas for rice, jute, wheat, and sugarcane crops. GIS techniques have been used for data capture, presentation, analyses and for final output of results to generate crop suitability maps with suitable areas. The research findings show that greater districts of Bangladesh Barisal, Patuakhali, Chittagong, Comilla, Noakhali, Dhaka, Faridpur, Jamalpur, Kishoreganj,Mymensingh, Tangail, Khulna, Kushtia, Bogra, Dinajpur, Pabna, Rajshahi, and Rangpur have been found to be suitable areas for rice, wheat, maize and sugarcane crops.

Soil Resources Development Institute (SRDI) prepared reports in 1999-2009 'Land and Soil Resources Utilization Guide' of different *Thana*s of Rajshahi district. Land type, soil structure, soil color, soil series, soil reaction, drainage, biological components, soil salinity, climate, communication etc. are considered in these reports with particular reference to land use and agriculture. Its main purpose is to present the soil condition for different crops' optimum production in concerned areas. Land, soil and water resources, present cropping pattern, fertilizer recommendation for specific crops, land use constraints, crop rotation etc. have been discussed in this guide. These are helpful for optimum use of land and use of fertilizers for mitigating soil nutrients deficiencies leading to production increase.

Mst. Farida Parveen et al. (2005) carried out a study on crop-land suitability analysis using multi-criteria evaluation and GIS approach in Haripur upazila of Thakurgaon district of Bangladesh. The aim of this study is to determine physical land suitability for rice crop using multi-criteria evaluation and GIS approach and to compare present land use versus potential land use. The study results showed that agricultural practice in the study area did not match with the potential suitability in the marginally suitable area. This research provided information at the local level that could be used by farmers to select cropping patterns and suitability.

Sk. Ghulam Hussain, M. Khalequzzaman A Chowdhury and M. Abeed Hossain Chowdhury (2012) worked on land suitability assessment and crop zoning of Bangladesh. In this work, the agro-edaphic and agro-climatic data were used for land suitability assessment. The agro-edaphic and agro-climatic suitability of crops have been assessed separately based on each individual soil and climatic factor with respect to crop requirements and thus produced crop suitability maps for different crops mentioning the potential areas under different classes. The crop zoning maps were also produced considering the percentage of the total cultivable area of the upazila under each crop suitability classes.

Md. Abeed Hossain Chowdhury (2013) conducted a study on land suitability assessment for chickpea and lentil in Bangladesh applying GIS tool. In this study, an attempt has been made for spatial analysis to produce maps of most suitable areas for growing chickpea and lentil pulse and performing spatial analysis to produce maps of constraints. Land suitability maps of chickpea and lentil growing area were produced by overlaying the climate and soil suitability maps. The evaluation of spatial variability is carried out in terms of suitability ratings from highly suitable to not suitable.

China: Jiansheng Ye et al. (2010) studied about the access to agricultural land use potential on the Loess Plateau of China. The study considered six variables viz., slope, altitude, precipitation, temperature, soil organic matter and distance to water which are important for agriculture in the study area. The used MCE approach, which integrates spatially explicit maps of six variables using GIS serves as proxies for the agricultural potential of the study area. An analysis of the agricultural suitability indices (ASI) found that certain variables are correlated with the spatial distribution of crops yield, farming population density, gross agricultural output, and farmers' income. The study also indicated that ASI is a useful tool for accessing agriculture land use in Gansu Province and it may have value throughout the greater Loess Plateau of China.

Ethiopia: Alemmeta Assefa Agidew (2015) conducted a study on land suitability evaluation for sorghum and barley crops in south Wollo Zone of Ethiopia. The study was done to assess the physical land suitability of south wollo zone for sorghum and barley crops and to produce suitability maps for each crop following land suitability guideline of FAO. Data of climate, topography, length of growing period and crops requirement were used to produce suitability maps for sorghum and barley crops. Results of the study revealed that most of the land in the study area is suitable for the cultivation of two crops. The suitability map of sorghum crop shows that 237.58 sq km of the research area are highly suitable; 14492.57 sq. km are marginally suitable. On the other hand, the suitability map of barley crop shows that 649 sq. km are highly suitable, 7169 sq. km are moderately suitable, and 122 sq. km are found unsuitable for economic reasons.

Ghana: Eric K. Forkuo and Abrefa K. Nketia (2011) conducted a study on digital soil mapping through GIS for cropland suitability analysis. The purpose of this study was to produce a digital soil map and an interactive geo-database with cropland suitability analysis on the growth and production requirement of oil palm, cassava, and citrus of the study area. For this, soil attributes and climate data were used to make model for cropland suitability. The developed soil map has the ability to upload the soil map, and perfumes suitability analysis on three different soil series for three selected crops namely, oil palm, cassava, and citrus.

India: Prakash T.N. (2003) studied land suitability analysis for agricultural crops using fuzzy multi-criteria decision-making approach. In this study, soil, terrain, socio-economic, market and infrastructure criteria were evaluated and ranking, rating, multi-criteria decision-making techniques were employed for suitability analysis. This research focuses on addressing uncertainty in the process of land suitability analysis for agricultural crops. AHP (Analytical Hierarchy Process), IVA (Ideal Vector Approach) and Fuzzy AHP were used to analyze the suitability of the rice crop in the Doiwala Block of the Dehradun district, Uttaranchal, India. It is seen that Fuzzy AHP performs better than AHP and IVA to identify suitable land for agriculture crop. Alpha cut and lambda values provide and facilitate good sensitivity analysis and three methodologies are implemented to analyze the suitability of rice crop in the Doiwala block of the Dehradun district, Uttaranchal of India.

R.M. Bhagat et al. (2009) conducted a study on land suitability analysis for cereal production in Himachal Pradesh of India using Geographical Information Systems (GIS). In this study, precipitation, temperature, elevation, soil type, and land cover (land use) have been used for land suitability evaluation for cereal food-grain crops in the study area. The suitability analysis was done through digital processing of geo-referenced data namely, elevation, climate, soil, and land cover and calculating potential production areas by combining different types of geographical data through decision rules framed for each crop. Suitable areas have been delineated for cereal crops in the form of land suitability maps. In comparison to the actual area under cereal crops, the possibility of further expansion under each cereal crop was determined.

A Sathis and K. V. Niranjana (2010) carried out a study on land suitability analysis for major crops in Pavagada Taluk, Karnatk of India using RS and GIS techniques. The study was carried out using remote sensing data along with field survey and laboratory analysis for assessing the potentials and limitations of soil. The soil suitability maps were prepared using Arc GIS software based on soil, climate and topographic data for the crops' requirement of groundnut, paddy and finger millet. The study revealed that about 48 per cent of the total area was moderate to marginally suitable and 13 per cent area was not suitable for both groundnut and finger millet. Lowland area covering 12 per cent of the area was highly suitable, 15 per cent was moderate to marginally suitable and 20 per cent land was not suitable for paddy cultivation.

A. A. Mustafa et al. (2011) conducted a study on land suitability analysis for different crops using RS and GIS based multi-criteria decision making approach in Kheragarah tehsil, Agra of India. The databases of soil and land use were generated from RS derived data and soil survey and chemical and physical parameters of soil were evaluated for different crops. Subsequently all data were integrated using multi-criteria decision making and GIS to generate land suitability maps for different crops. The study revealed that 55 per cent area is highly suitable for sugarcane and 60 per cent, 54 per cent and 48 per cent of the area are moderately suitable for cultivation pearl millet, mustard and rice respectively. Fifty per cent of the study area is found marginally suitable for growing maize.

Jadab Chandra Halder (2013) conducted a study on land suitability assessment for crop cultivation in Ghatal Block, West Medinipur district of West Bengal in India by using GIS and Remote Sensing (RS) for rice and wheat cultivation based on four pedagogical variables namely, nitrogen-phosphorous-potassium (NPK) status, soil reaction (pH), organic carbon (OC) and soil texture, which are mandatory input factors for crop cultivation. The study proposes an integrated methodology for analyzing and mapping of land suitability using RS and GIS techniques. The result indicated that only 12.71 per cent of agricultural land could be demarcated as highly suitable for rice cultivation whereas only 7.78 per cent of agricultural land as highly suitable for wheat cultivation in the study area.

Iran: Nasim Megdadi and Benham Kamkar (2011) conducted a study on land suitability analysis for cumin production in the North Khorasan Province of Iran using geographical information system (GIS). For this purpose, DEM (Digital Elevation Model) data were used for digital maps and surface analysis functions were used to create topographic layers. Multiple regression models were used and tested to create rainfall, average temperature and extreme temperature layers for cumin growing seasons. Based on these, three scenarios (scenarios 1, 11,111) were prepared to determine land suitability of the study area for cumin production. Only 6.2 and 21.9 per cent of total agricultural lands were found as favorable areas for cumin production based on scenarios 1 & 11 respectively. The study also revealed that GIS based plans could help create a shortcut for conscious decision making in large scales, which is a necessity for new crops, especially medicinal plants such as cumin.

Mexico: Alejandro Ceballos- Silva and Jorge Lopez- Blanco (2003) conducted a study on delineation of suitable areas for crops using MCE approach and land use mapping in Central Mexico. Climate, relief, and soil databases were used to integrate GIS raster coverage to define suitability levels and relevant criteria for crops. A 1996 Land sat TM image was processed using GIS capabilities by means of a supervised classification to obtain land use map. Land use and suitability maps were prepared to identify differences and similarities between the present land uses in the suitable areas for the maize and potato crops.

Nigeria: Jonah Kunda Joshua, Nneoma C Anyanwu and Abubakar Jarere Ahmed (2013) conducted a research work on land suitability analysis for agricultural planning using GIS and multi-criteria decision analysis approach in Nasarawa State of Nigeria. The central theme of this study is to explain the process of developing a prototype GIS application to provide a system for supporting location decisions with respect to the implementation of agricultural planning. GIS was used based on a set of criteria derived from the spatial and environmental aspect. In this study, a model was developed to determine the suitability of the area for agricultural production using soil, slope, water bodies and geological maps to support decisions making for sustainable agricultural production.

USA: Robin Lambert Graham (1994) conducted a study analyzing the potential land base for energy crops in the conterminous United States. Suitability was assessed on the basis of assumption that the land must be capable of energy crop yields of at least 11.2 Mg $ha^{-1}yr^{-1}$ with current technology. Most of the suitable land is in the North-Central, South Central and South Eastern region of the United States. The study defined the land suitable for energy crop production and estimated the yield production of that land. Of the capable land base, 91.1 million ha is suitable for SRWC (short-rotation woody crops), and 131.1 million ha is suitable for HEC (herbaceous energy crops).

Vietnam: Nguyen Thi Dieu and Truong Van Canh (2013) conducted a research work on land use suitability analysis in Hao Vang district of Da Nang City in Vietnam integrating GIS and AHP techniques. The study was done using fieldwork methods for soil characteristics, water, and land use status and assessment procedures applying multi-criteria to evaluate land adapted for land use of agricultural land. Integration of GIS and AHP was done to evaluate and support a decision to use each land unit.

Nguyen Zuan Hai et al. (2014) studied land suitability for Nang Xuan rice variety combining Hanoi soil database and climate change scenario to identify the suitable area for each unique plant in order to have a good development planning. To identify the suitable areas for good planning and land management, soil classification was combined with temperature and rainfall in order to sketch the changes in suitable areas for rice, the most important plant in Vietnam. The results of this study could be beneficial in land use management and ensure food security of the study area of Vietnam.

Yemen: Mohammad Hezam Al- Mashreki et al. (2011) studied about land suitability evaluation for sorghum crop in the IBB Governorate of Yemen using remote sensing and GIS techniques. The study aimed to detect the types of potential land suitability of agriculture applying remote sensing and GIS technologies as well as designing an information system for land resource assessment. The study reveals that nearly 5 per cent of the study area is highly suitable, 25 per cent area is moderately suitable, 31 per cent land are marginally suitable, 24 per cent area currently unsuitable as well as 15 per cent area permanently not suitable for the production of sorghum.

1.4 Research Questions

In the light of the literature review and from the analysis of the problem statement, some relevant questions have appeared which need to be answered. The specific questions to be answered in the present study are as follows:

a. What is the present land use pattern in the study area?

b. What are the production and economic losses of the present land use pattern?

c. What would be the possible benefits, if lands were used according to suitability?

d. What are the present practices of cultivation by farmers?

e. What is the perception level of farmers about land suitability and agricultural development?

f. What are the implications of land suitability analysis for agricultural sustainability in Rajshahi district and other areas of Bangladesh?

1.5 Objectives

1.5.1 General Objective

On the basis of above discussion, the general objective of this study is to analyze the land suitability for sustainable agricultural development in Rajshahi district.

1.5.2 Specific Objectives

In order to fulfill the general objective, the following specific objectives are set for the present study.

1. To analyze the existing land characteristics and land suitability variables in the study area;
2. To prepare composite land suitability maps of major agricultural crops in the study area;
3. To analyze the economic viability of currently cultivated major crops and cropping patterns and also of land suitability based cropping patterns;
4. To assess farmers' perception about land suitability and agriculture development; and
5. To find policy suggestions for the development of agriculture in the study area.

1.6 Justifications of the Study

1.6.1 Research Gap

Land suitability analysis is an advanced and relatively new issue in agriculture. A number of studies regarding land suitability analysis have been done on the South Western region of Bangladesh, especially on coastal saline belt, but no study in particular has been carried out so far in the sweet water areas in a comprehensive way. Most of the studies are devoted to saline water vis-à-vis fish and crop production. However, the study area is situated in the fresh water areas and about 81 per cent area of Bangladesh are of fresh water areas. A few studies have been conducted in many countries of the world. But soil, irrigation water, climate, topography, floodability, accessibility and other conditions of those countries are not similar to the study area. Moreover, the difficulties with such studies are the homogeneity assumptions across the countries that are unrealistic due to variations in agronomic, and socio-cultural conditions.

Besides, economic viability analysis of present land uses and suitability based land uses are not done in any study that is very necessary to see the benefits of suitability based land uses in terms of net economic returns. In addition, region and country specific studies are needed to throw more lights on policy issues. So, there is research gap and it becomes very necessary to conduct a comprehensive study about the land suitability analysis for sustainable agricultural development of Rajshahi district highlighting on economic viability. The main view in this regard is to see whether the lands are used according to suitability or not and to explore the economic benefits and increase crops production from Rajshahi district and other sweet water areas of Bangladesh.

1.6.2 Significance of the Study

Bangladesh is a highly dense populated country in the world with only 14.84 million hectares of land. Agriculture is the main sector of our country. This sector contributes about 17.22 per cent of our present total GDP and about 60 per cent population are dependent on this sector. Therefore, development of this sector is very much important for the development of the country. About 81 per cent area of Bangladesh are sweet water area. Coastal Bangladesh consists of 19 districts that comprise 2.85 million hectares (7.6 million acres) in area which are mainly saline area. The rest areas about 14 million ha are sweet water areas. In addition, significant portion of upper part of many districts in 19 districts costal Bangladesh have same agricultural characteristics like sweet water areas. So, development of this sector will contribute a lot in the whole sweet water areas. Rajshahi district is an expanding urban center of the North Western region of Bangladesh and demands of agricultural products are increasing day by day. Rajshahi is the fourth largest and populous city of Bangladesh. Godagari upazila is the largest and agriculture intensive upazila of the district. So, land suitability analysis for sustainable agricultural development of Rajshahi district will contribute a lot for the whole sweet water areas of Bangladesh.

1.7 Scope of the Study

The proposed study focuses on land suitability analysis of Rajshahi district based on texture, moisture, pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron of soil and P^H, electrical conductivity (EC), and temperature of irrigation water and temperature, and rainfall of climate for sustainable agricultural development. Land type, and drainage condition of topography and depth of flooding, and duration of flooding of floodability and distance from highway, and distance from local markets of accessibility attributes are evaluated for land suitability analysis. Three hundred eighty one (381) respondents' opinion have been analyzed as to economic viability of present land uses and suitability based projected land uses and farmers' perception regarding land suitability and agriculture development. The study also encompassed different farming, social and environmental aspects of the study area.

1.8 Utility of the Study

The researcher believes that the following categories of the stakeholders will hopefully use the findings of this research work.

(a) **Farmers and Entrepreneurs:** The farmers and entrepreneurs of Rajshahi district could utilize the findings of this research work to enhance their production and net profit significantly and use their land following land suitability analysis.

(b) **Policy Makers and Concerned Officials:** This research may help the policy makers and concerned officials take proper decisions, measures and policies for the development of agriculture sector of the whole sweet water areas of Bangladesh.

(c) **Educationists, Scholars and Researchers:** This work could also be helpful to the educationists, scholars and researchers of the relevant fields. It can also be used as a secondary source of data by the future researchers for the research of land suitability and economic viability of agriculture sector in the sweet water areas.

(d) **Extension Professionals:** Agriculture extension officials can use the findings to increase the production and help farmers select crops to cultivate in their farms. This will develop the agriculture sector of Godagari upazila as well as all sweet water areas of Bangladesh.

1.9 Limitations of the Study

The present study is by no way a comprehensive one covering the entire gamut of land suitability analysis vis-a-vis all other sectors of the study area of Rajshahi district such as, livestock, forestry, recreational use, housing, business, communication, infrastructure requirements, size and configuration of land holdings, land tenure system, management systems etc. Not only that, four crops- jute, cotton, sugar cane, and fruits that cover about 1100 acres of gross cropped area of the study area are not included in this study. Besides, not all attributes of soil, irrigation water, climate, topography, floodability, and accessibility are analyzed in this work due to time and resource constraints.

The study area of Rajshahi district has 390 *mauzas*. 76 *mauzas* are selected from 390 by sample size determination formula and probability proportional to size sampling (PPS) for questionnaire survey. Only 381 respondents out of 33513 farm holdings from 76 *mauzas* have been interviewed from the study area that may not be fully typical of the whole population of the study area. 78 samples each from soil, irrigation water, topography, and floodability attributes have been analyzed from 78 *mauzas* from total 390 *mauzas* of the study area, which may not be fully archetypal of Rajshahi district.

1.10 Profile of the Study Area

Rajshahi district was established in 1772 and ranks 27th among 64 districts of Bangladesh in terms of area. The district consists 9 upazilas which are Bagha, Bagmara, Charghat, Durgapur, Godagari, Mohanpur, Paba, Puthia, and Tanore. The district is the basic unit of administration and the focal point of all- economic, social, cultural, and development activities.[15] Rajshahi district is mainly agriculture dominated. Profile of the study area are discussed below emphasizing on agriculture related aspects.

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[15] S. A. Akand, ed., *The District of Rajshahi: It's Past and Present* (Rajshahi University: Institute of Bangladesh Studies, 1983), 113.

1.10.1 Location and Area

Rajshahi district lies between 24°27′ and 24° 43′ north latitudes and 88°17′ and 88°58′ east longitudes. The district is bounded by Naogaon district on the north, West Bengal of India, the Padma and Kushtia district on the south, Natore district on the east, and Chapainawabganj district on the west.

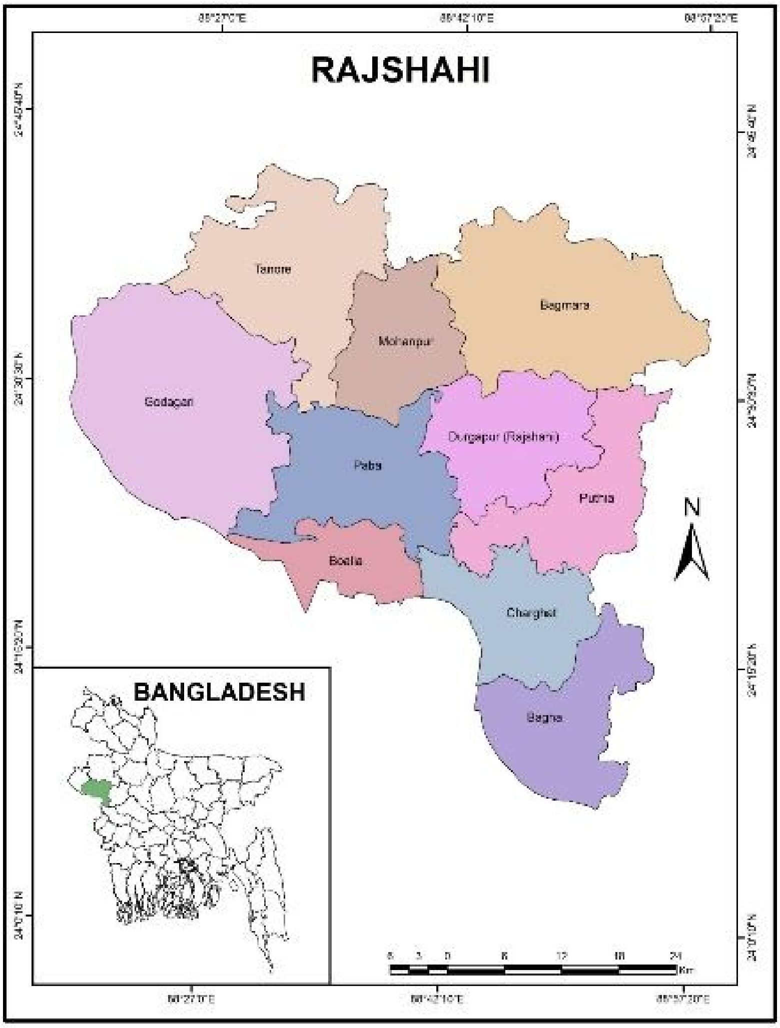

Figure 1.1. Study Area Rajshahi District

The southern boundary is the river Padma which separates Rajshahi district from Murshidabad district (West Bengal) of India and Kushtia district of Khulna division. The total area of the district is 2425.37 sq. km. The region consists of Barind Tract, Diara and C*har* lands. The area of Rajshahi City Corporation is 96.72 sq. km.

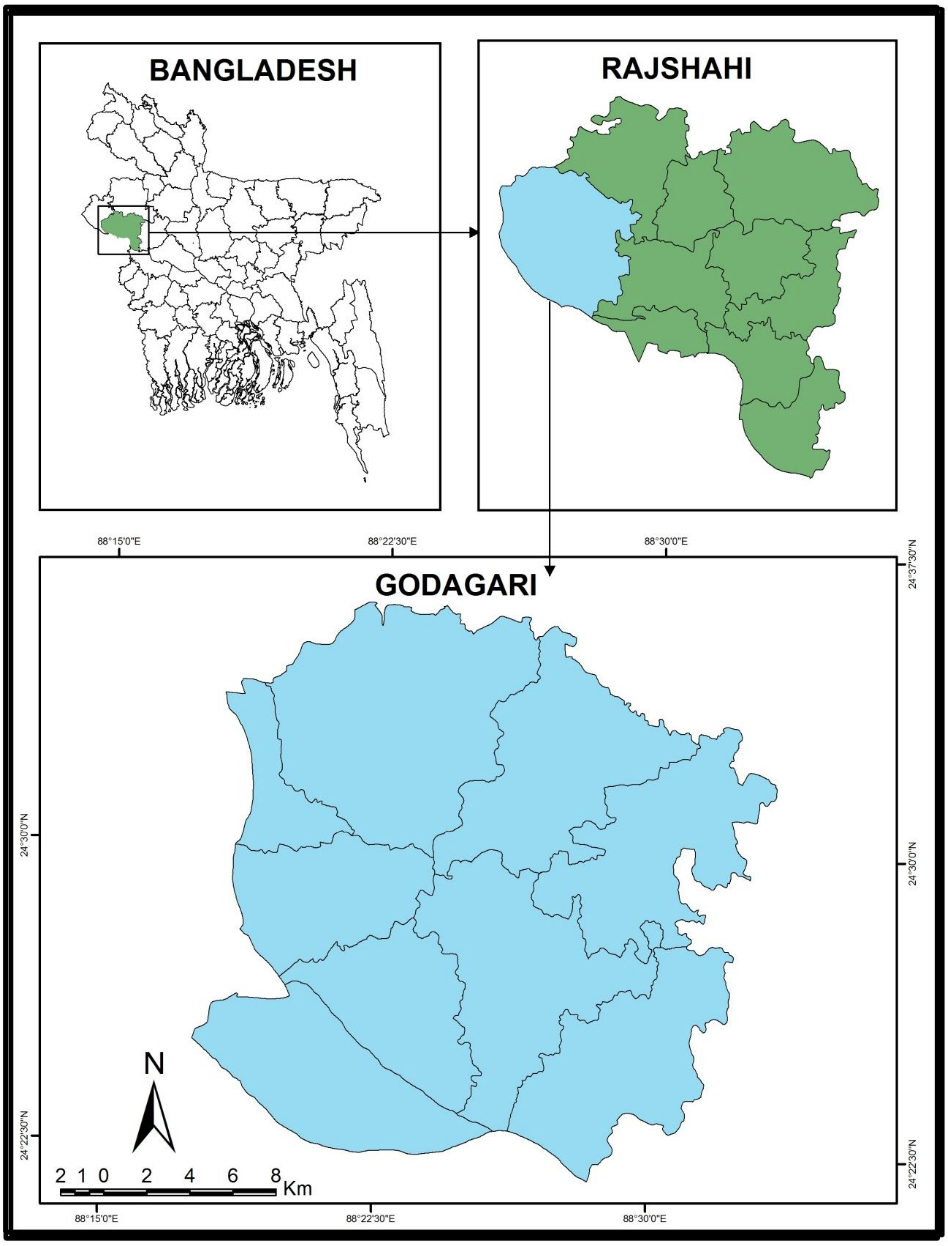

Figure 1.2. Location of Godagari Upazila

Below the district level, other layers of administrative division are upazilas and unions. Rajshahi district consists of 9 upazilas and 71 unions. The district houses 1 City Corporation and 14 pourasavas. Rajshahi district has total 1686 revenue villages (*mauzas*). Among 9 upazilas, Godagari is the largest upazila of Rajshahi district. Godagari upazila is comprised by 9 unions and the area of the upazila is about 472 sq. km.

Godagari upazila covers about 20 per cent area of the district which has 9 unions, 2 pourasavas, and 390 revenue villages. On the other hand, the district has 71 unions,14 pourasavas, and 1686 revenue villages which are presented below.

Table 1.2. Union, Pourasava and Revenue Villages of Rajshahi District by Upazila

Sl	Name of Upazila	No of Unions	No of Pourasavas	Number of Revenue Villages
1	Bagha	06	02	96
2	Bagmara	16	02	292
3	Charghat	06	01	93
4	Durgapur	07	01	114
5	Godagari	09	02	390
6	Mohanpur	06	01	167
7	Paba	08	02	187
8	Puthia	06	01	135
9	Tanore	07	02	212
Total		71	14	1686

Source: Deputy Commissioner's Office, Rajshahi

The study area has significant riverine areas and some forest exists mainly in Bagha upazila. Upazila wise total area, riverine, and forest area of Rajshahi district are presented below.

Table 1.3. Upazila Wise Area (in sq. km) of Rahshahi District

Sl	Name of Upazila	Total Area	Percentage of District	Riverine Area	Forest Area
1	Bagha	184.25	7.65	-	14.48
2	Bagmara	363.30	15.09	-	-
3	Charghat	164.52	6.83	6.89	-
4	Durgapur	195.03	8.10	-	-
5	Godagari	472.13	19.61	9.25	-
6	Mohanpur	162.65	6.76	-	-
7	Paba	280.42	11.65	31.75	-
8	Puthia	192.64	8.00	-	-
9	Tanore	295.39	12.28	-	-
-	City Corporation	97.18	4.03	-	-
District total		2407.51	100.00	47.89	14.48

Source: Census of Agriculture 2008 Zila Series: Rajshahi (P.1)

1.10.2 Physiography

Most of the lands of Rajshahi district is of recent origin and appears to be a flat uniform alluvial plain. The study area is comprised of three distinct physiographical areas, which are,

1. Barind Region;
2. Alluvial Deposits or Riparian Tract; and
3. Marshy or *Beel* Areas**.**

About 60 per cent area of Rajshahi district is constituted by Ganges-Floodplain. Barind Tract is also important in this district which has distinct characteristics. Statistics of area wise physiographic region of the study area are presented below.

Table 1.4. Area Wise Physiographic Region by Upazila of Rajshahi

Sl	Upazila	Barind Tract		Ganges Floodplain		Tista Floodplain		Active Ganges Floodplain		Atrai Floodplain		Others		Total area
		Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	
1	Bagha	-	-	18426	100	-	-	-	-	-	-	-	-	18426
2	Bagmara	-	-	25470	69.7	-	-	-	-	3456	9.4	7642	20.9	36568
3	Charghat	-	-	14751	89.6	-	-	1707	10.4	-	-	-	-	16458
4	Durgapur	-	-	16556	84.9	-	-	-	-	-	-	2948	15.1	19504
5	Godagari	35712	75	6687	14	-	-	-	-	-	-	5163	11	47562
6	Mohanpur	602	3.7	12507	76.9	715	4.4	-	-	-	-	2441	15	16265
7	Paba	694	2.33	24528	82.36	-	-	4561	15.31	-	-	-	-	29783
8	Puthia	-	-	19264	100	-	-	-	-	-	-	-	-	19264
9	Tanore	24202	81.8	874	3	1430	4.8	-	-	-	-	3074	10.4	29580
Rajshahi		61210	26.22	139063	59.58	2145	0.92	6268	2.69	3456	1.48	21268	9.11	233410

*Source: Land and Soil Resources Utilization Guides (Guides of 9*upazilas*) of SRDI*

Notes: Area in hectare, others = water body, char land, and river

Bangladesh comprises hill, terrace, and floodplain areas. The hills occupy about 12 per cent, the terrace areas about 8 per cent, and the floodplain the remaining 80 per cent. The Barind Tract of terrace area spreads about 7727 sq. km which constitutes about 5.33 per cent of the country.[16] Barind Tract constitutes about 26 per cent land area of Rajshahi district which mainly falls in Godagari and Tanore upazila. The Barind Tract is a distinct physiographic unit characterized by its comparatively high elevation, reddish

[16] Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh 2012* (Dhaka: Statistics and Informatics Division, Ministry of Planning, 2013), 15.

and yellowish clay soils, entrenched dendritic stream pattern, and a relative paucity of vegetation. The Barind Tract of Rajshahi district is depicted below.

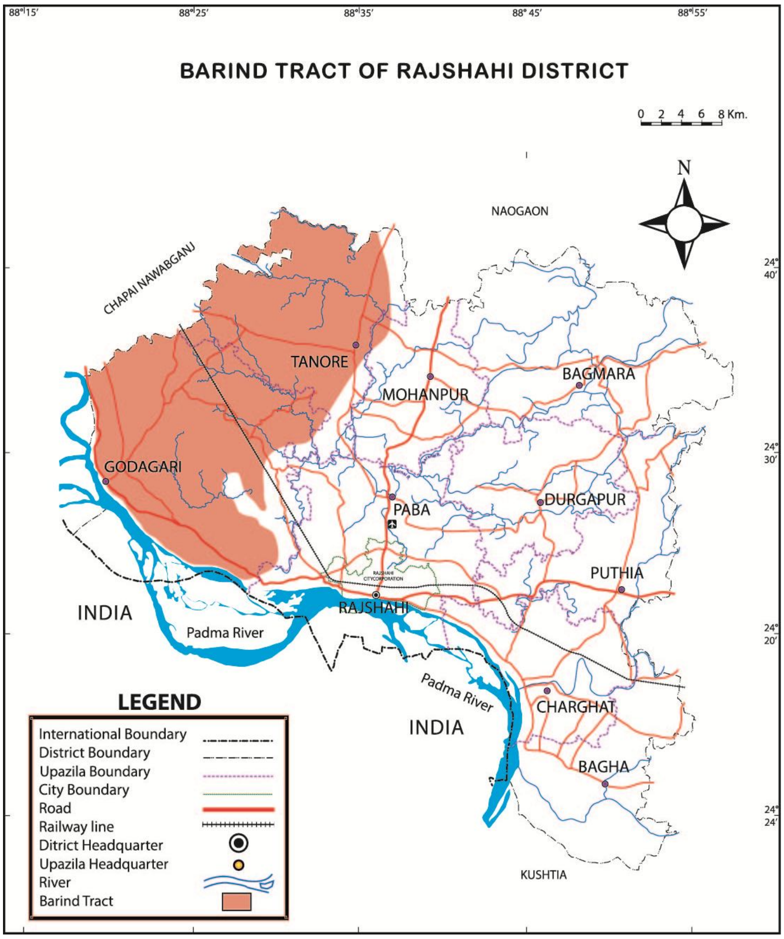

Figure 1.3. Barind Tract of Rajshahi District

1.10.3 Soil Condition

The Barind tract is the important physiographic features of Rajshahi district which governs many things including agriculture. It is mainly level with slowly permeable soils. The red soil of the Barind contains an excess of iron and lime. However, this soil is deficient in siliceous matter, as it gets no deposits of sand from floodwater. The northern part of the district is mainly formed of grey brown clay loam of the dissected terrace of Barind tracts. The eastern part is covered by pale brown silt clay loam of meander floodplain of the older Ganges and the southern part, by brown silt loam alluviums of the active and very young Ganges meander floodplain. Characteristics of general soil types and soil classification of Rajshahi district are given below.

Table 1.5. General Soil Type of Rajshahi District

Sl.	General Soil Type	Characteristics
1	Calcareous Alluvium	Calcareous alluvium is slightly to moderately calcareous due to presence of calcites derived mostly from Gangetic sources
2	Acid Basin Clays	Very strongly acid, grey to dark grey heavy plastic clays
3	Non-calcareous Dark Grey Floodplain Soils	Structured dark grey loamy soils on old flood plain ridges and clay in basins. Slightly acid to somewhat alkaline in reaction. The basin clays have heavy consistence
4	Calcareous Brown Floodplain Soils	Calcareous, brown silt loams to light silt clays, occurring in the Ganges river flood plain
5	Shallow Grey Terrace Soils	Whitish grey, slightly to strongly acid, friable, somewhat porous silt loams to silt clays
6	Deep Grey Terrace Soils	Whitish grey, speckled with brown or red mottles, slightly to strongly acid, friable and highly porous silt loams to silt clay loams

Source: Statistical Yearbook of Bangladesh 2014 (P.3-6)

Soil texture is important for agriculture. The type of crops grows well significantly depend on soil texture. The soil classes of Rajshahi district is given below.

Table 1.6. Soil Classes of Rajshahi District by Upazila

Upazila/CC	Broad Soil Classification (Area in acre)					
	Loam	Sand	Clay	Kankar[17]	Others	Total
Bagha	5200	4509	3522	0	31277	40647
Bagmara	28793	17557	22824	18610	2	81636
Charghat	19874	7950	11924	0	0	35769
Durgapur	47553	0	0	0	0	41074
Godagari	72945	8316	27354	0	5765	80337
Mohanpur	4512	195	7308	0	3875	34870
Paba	25016	4569	19670	0	0	49561
Puthia	26762	89	14104	0	0	41963
Tanore	16063	0	56942	0	0	59347
RCC	0	0	0	0	0	11870
Total	246718	43185	163648	18610	40919	477074

Source: District Statistics- 2011: Rajshahi (P. 35)

Note: RCC = Rajshahi City Corporation, CC = City Corporation

[17] Kankar is nodular calcareous concretions.

It is found in above that soil classes of Rajshahi district is dominated by loam and clay soil. Loam soil is good for most crops but clay soil is not good for potential yield. On the other hand, sandy soil also constitutes a good portion which is not good for most crops.

1.10.4 Land Type

Topographical condition determines the suitability level. It also governs drainage condition. The land type of Rajshahi district is mainly highland. The land type classes of Rajshahi district are presented below in table 1.7.

Table 1.7. Land Type Classes of Rajshahi District

District	Cultivated Land (ha)						Miscellaneous Land	Grand Total
	HL	MHL	MLL	LL	VLL	Total		
Rajshahi	120751	43803	21479	7916	258	194207	39204	233411
	52%	19%	9%	3%	0%	83%	17%	100%

Source: Statistical Yearbook of Bangladesh- 2012 (P. 9)

Note: Miscellaneous land means settlement, ponds, water bodies, river, channel etc. HL=High land MHL=Medium high land MLL=Medium low land LL= Low land VLL=Very low land

Godagari upazila is Barind tract and high land dominated upazila. The high land area covers about 80 per cent area of the upazila which governs agriculture. The area of different land type classes of Godagari upazila is presented below. It is worth to mention that high land area has also different agriculture potential.

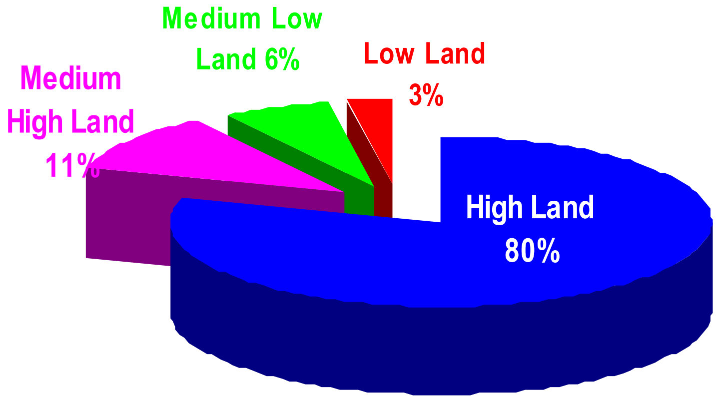

Figure 1.4. Land Type Classes of the Study Area (Godagari Upazila)

1.10.5 Ground Water Level

Ground water level is very important for agriculture as the agriculture in the study area is highly dependent on underground irrigation. Ground water level in the study and adjoining areas are declining which are found in many studies. As such, the irrigation cost is increasing which has important bearing on total cost and profitability. The static water level of a point (Figure 1.5) in Godagari union of the study area from 2004 to 2015 is presented below in table 1.8.

Table 1.8. Static Water Level of Godagari Upazila in Rajshahi District

Upazila: Godagari, Union: Godagari, *Mauza*: Amtoli. J. L. No: 193, Plot No: 95

Year	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	1st week	last week	1st week	last week	1st week	last week	1st week	last week	1st week	last week	1st week	last week	1st week	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test
2004	58'10"	63'6"	68'8"	67'10"	69'0"	70'1"	70'1"	68'9"	67'0"	66'10"	66'3"	65'5"	64'4"	64'4"	59'2"	56'6"	49'1"	40'0"	48'8"	57'0"	61'2"	61'3"	61'4"	61'5"
2005	62'2"	64'8"'	68'9"	69'10"	70'3"	68'10"	68'10"	69'4"	67'7"	67'0"	68'7"	69'0"	67'9"	66'8"	65'8"	56'11"	47'1"	43'2"	52'6"	55'7"	55'6"	56'6"	57'4"	58'1"
2006	58'8"	62'9"	66'9"	67'1"	68'10"	69'1"	70'4"	68'4"	67'7"	66'9"	64'3"	63'5"	62'0"	63'4"	63'5"	63'11"	41'1"	38'9"	55'6"	56'2"	54'0"	54'7"	58'11"	64'1"
2007	66'1"	67'1"	68'0"	68'1"	70'2"	71'1"	71'0"	71'0"	70'0"	69'1"	69'0"	68'2'	68'1"	67'1"	66'2"	66'0"	65'0"	63'2"	62'0"	61'1"	61'1"	61'2"	61'2"	61'0"
2008	58'0"	58'5"	58'9"	60'0"	62'2"	63'0"	64'2"	65'4"	64'8"	64'0"	55'0"	53'7"	50'2"	48'3"	48'2"	48'1"	48'3"	48'5"	48'7"	48'11"	49'0"	49'3"	52'0"	55'7"
2009	61'6"	62'7"	63'0"	63'7"	63'9"	64'4"	63'3"	63'10"	63'0"	60'1"	63'1"	64'9"	65'2"	65'11"	64'10"	63'9"	61'5"	69'6"	65'5"	65'1"	64'5"	64'0"	64'2"	63'8"
2010	64'6"	65'7"	66'8"	68'10"	70'0"	70'9"	59'2"	61'3"	65'3"	58'2"	57'3"	65'9"	65'5"	63'9"	62'8"	61'6"	67'9"	68'3"	66'4"	67'3"	66'1"	65'9"	65'6"	65'9"
2011	69'1"	69'10"	70'7"	71'6"	70'10"	68'3"	67'0"	67'0"	66'0"	65'6"	63'10"	62'5"	67'2"	68'8"	68'5"	67'10"	66'11"	65'8"	65'3"	65'0"	67'5"	68'7"	68'11"	69'6"
2012	70'10"	71'5"	71'9"	72'7"	72'10"	73'6"	73'9"	74'7"	75'1"	75'7"	75'2"	74'10"	744'5"	74'0"	74'3"	74'6"	75'0"	75'6"	75'3"	75'5"	75'8"	75'11"	76'10"	77'6"
2013	78'6"	79'3"	79'10"	80'2"	81'7"	82'2"	82'8"	83'2"	82'6"	81'6"	78'2"	76'9"	75'3"	74'1"	73'9"	73'6"	79'10"	78'11"	78'6"	78'1"	73'5"	78'10"	79'0"	79'30"
2014	79'7"	79'11"	79'7"	79'11"	81'6"	82'9"	84'5"	85'9"	84'4"	83'7"	81'5"	80'7"	84'5"	85'9"	84'0"	80'0"	84'5"	84'9"	82'9"	83'4"	83'11"	84'7"	82'11"	83'4"
2015	85'11"	86'4"	82'7"	82'7"	83'11"	84'7"	82'7"	82'1"	81'2"	80'10"	80'4"	80'11"	80'0"	79'6"	79'5"	79'1"	80'3"	80'6"	82'2"	83'1"	80'9"	80'11"	77'6"	78'6"

Source: Barind Multipurpose Development Authority (BMDA), Rajshahi, 2016

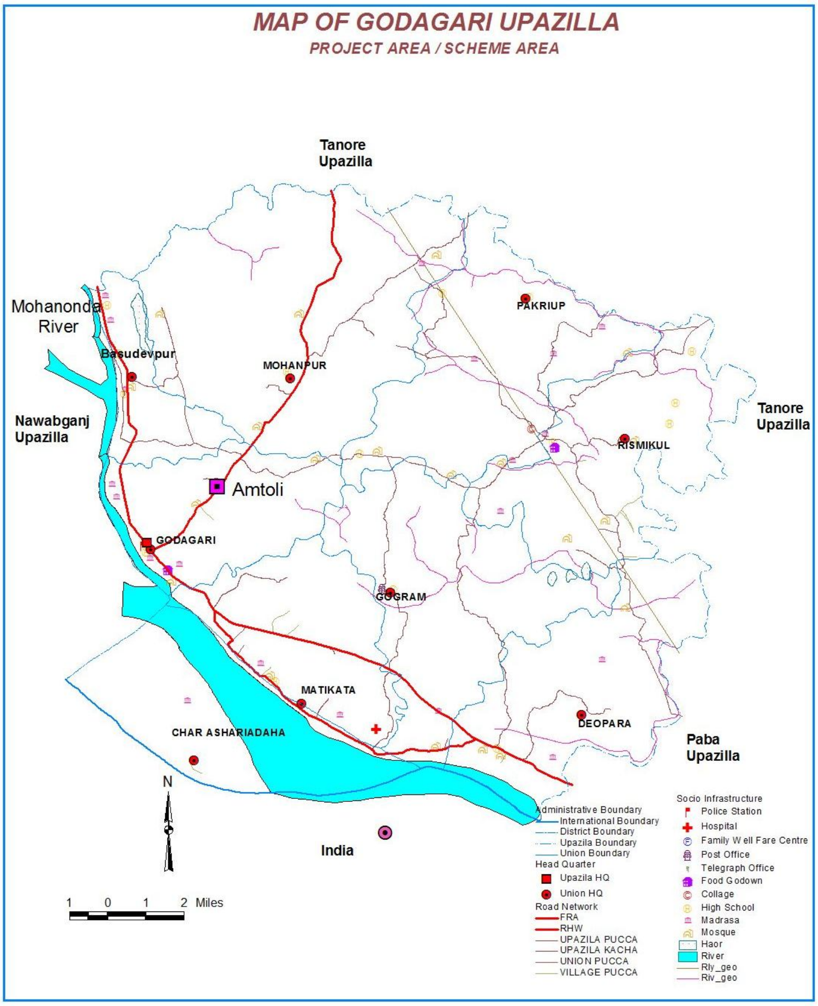

Figure 1.5. Amtoli Ground Water Level Recording Point

1.10.6 Climate

The climate of Rajshahi district is marked with a tropical monsoon climate with high temperature, considerable humidity and scanty rainfall. The dry winter season starts from November and continues up to the end of February. The maximum temperature 45.1°c was recorded in Rajshahi on 18.05.1972, which is so far highest temperature in Bangladesh. The minimum temperature was 3.4°c recorded on 23.01.2003. The maximum and minimum annual temperature were 42.6°c and 7°c in 2014. The rainy season comes at the end of May and stays up to September. Annual total rainfall was 1192.5 mm and total rainy days were 97 in 2014. The maximum rainfall 1068.61 mm is generally observed during the month of June to September that accounts about 73 per cent of the year (1456 mm). The last 10 years' (2005-2014) highest and lowest temperature and rainfall scenarios of the study area are presented in Table 1.9.

Table 1.9. Temperature and Rainfall Scenarios of Rajshahi

Year	Max Temp	Min Temp	Total Rainfall	Total Rainy Days	Total Rainless Days
2005	42.8°c	7.5°c	1421.4 mm	108	257
2006	39.6°c	6.5°c	1152.4 mm	100	265
2007	42.2°c	6.2°c	1505.9 mm	107	258
2008	40.0°c	6.7°c	1158.9 mm	99	266
2009	41.8°c	6.1°c	1047.6 mm	90	275
2010	42.5°c	6.5°c	803.5 mm	94	271
2011	38.0°c	4.8°c	1477.7 mm	105	260
2012	42.0°c	6.4°c	1164.3 mm	102	263
2013	41.2°c	4.4°c	1247.5 mm	90	275
2014	42.6°c	7.0°c	1192.5 mm	97	268
Average	41.27°c	6.21°c	1217.7 mm	99.20	265.80

Source: Bangladesh Meteorological Department (BMD), Rajshahi

Sunshine is an important factor for accelerating transpiration of plants and intensity and duration of sunshine affect plants in many ways.[18] Soil temperature, grass minimum temperature, evaporation, and humidity are also important factor and affect crops production. Six parameters of climate and soil temperature at five different depths of the study area are depicted below for the year 2014.

Table 1.10. Agriculture Important Climate Factors Scenario of Rajshahi District, 2014

Months	SH	GMT	MxT	MnT	ST(5cm)	ST:10cm	ST:20cm	ST:30cm	ET	RH	WR
Jan.	5.2	NA	22.825	11	18.3	17.875	18.25	19.2	2.0025	83	326.09
Feb.	6.87	10.01	25.225	12.7	20.6	20.45	20.325	21.075	2.705	77.75	298.295
Mar.	8.245	13.575	32.15	17.05	26.025	26.225	25.35	25.6	4.5875	67.25	366.435
Apr.	9.06	19.2	37.85	22.875	31.475	31.8	30.9	31.125	5.695	65.5	256.48
May	7.705	22.05	37.35	25.375	33.375	33.75	33.175	32.85	5.985	69.5	404.455
Jun.	3.6375	25.05	35	26.375	31.725	32.1	31.55	32.075	3.4175	84.5	370.6
Jul.	4.355	25.625	35.45	26.875	31.475	32.05	31.075	31.575	3.1225	86.5	544.22
Aug.	3.385	25.175	33.775	26.375	31	31.425	30.875	31.475	2.98	84.25	409.7
Sept.	5.955	24.925	34.175	26	31.225	31.55	30.95	31.475	3.735	85	354.13
Oct.	7.265	21.55	32.675	22.675	29.05	29.725	29.4	30.1	3.1225	83	150.075
Nov.	6.93	13.725	30.275	16	24.55	24.925	24.95	26.225	2.625	78.25	157.12
Dec.	3.6575	9.85	24.675	12.25	20	19.8	20.1	21.35	1.785	84.25	259.992
Average	6.02	19.16	31.78	20.46	27.4	27.64	27.24	27.84	3.480	79	324.799

Source: Bangladesh Meteorological Department (BMD), Rajshahi

Notes: All Temperature in °c; SH= Sunshine Hours; GMT=Grass Minimum Temperature ST=Soil Temperature; MxT=Maximum Temperature; MnT=Minimum Temperature ET= Evapotranspiration in millimeter; RH=Relative Humidity in millimeter; WR=Wind Run in kts

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[18] Jasbir Singh and S. S. Dhillon, *Agricultural Geography* (New Delhi: New Age International Private Limited), 70.

The level of humidity was found about 77 per cent in April and about 88 per cent in July of 2014.

1.10.7 Agro-Ecological Zone (AEZ)

Bangladesh is divided into 30 agro-ecological zones (AEZ) on the basis of physiography, soils, land levels in relation to flooding, and agro-climatology. The study area Godagari upazila lies in AEZ-11(High Ganges Floodplain) and AEZ-26 (High Barind Tract Zone). High Ganges River Floodplain includes the western part of the Ganges river floodplain which is predominantly highland and medium highland. High Barind Tract Zone includes the western part of Barind tract where the underlying Madhupur clay has been uplifted and cut into by deep valleys. General fertility status is low having low status of organic matter. The percentages of land in the study area Godagari upazila according to agro-ecological zones are depicted below.

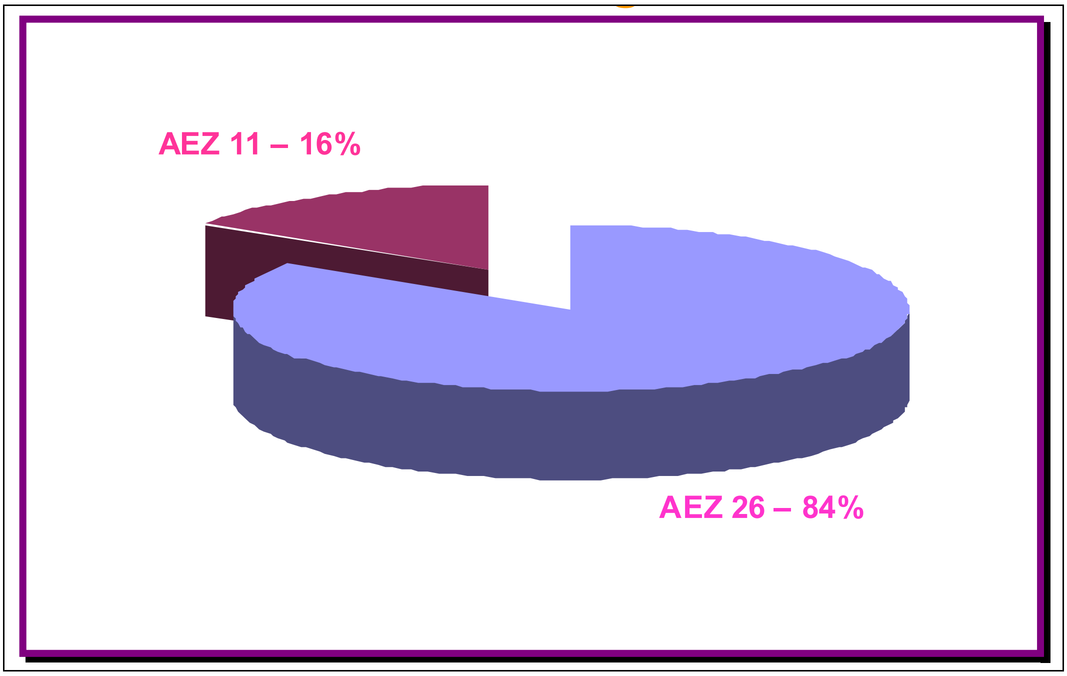

Figure 1.6. Land Percentage According to Agro-Ecological Zone (Godagari Upazila)

1.10.8 River System

The main rivers flowing through the study area are the Padma, the Mahananda, and the Baral.

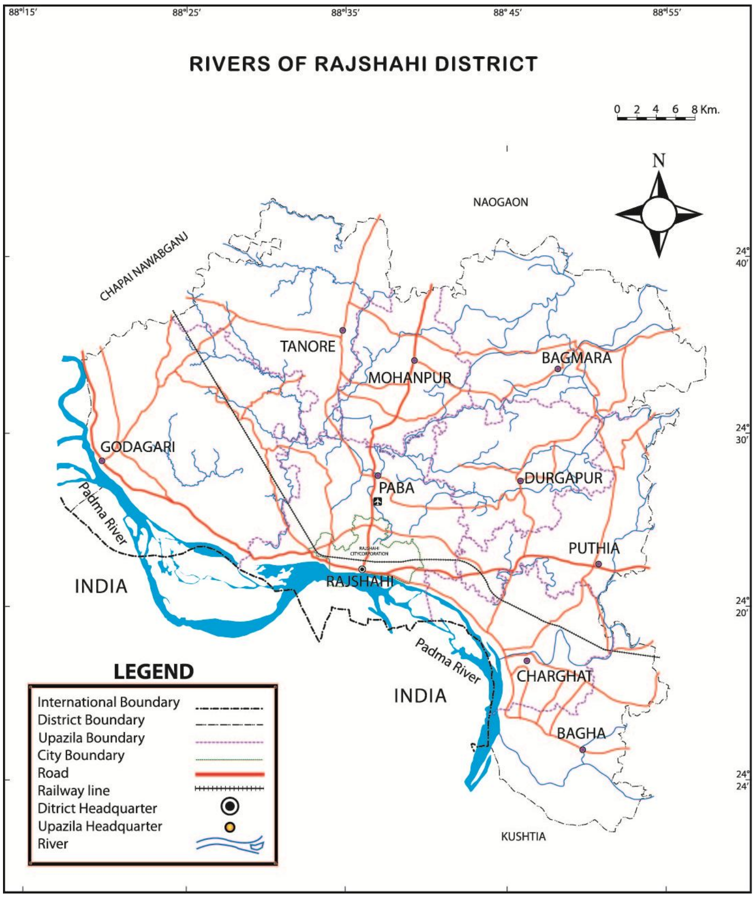

Figure 1.7. River System of Rajshahi District

All the rivers except the Padma are of little importance in navigation because they become active flowing channels during the rainy seasons only. The few channels are several miles apart and have tightly meandering courses. Most of the area is shallow flooded by rainwater in the monsoon, but occasional flash floods in the Padma, the Mahananda, and the Baral river spread water over adjoining Barind areas. The rivulets Kakrani, Barnai, Narad, Mushakan, Shibu, and Hoja play an important role in irrigating soil. All the channels flowing through the district are non-tidal and most of them are distributaries. The total area of the rivers and rivulets within the boundary of the district is about 47.89 sq. km, which is about 01.99 per cent of the total area of the district.

1.10.9 Households and Population

According to the Population Census 2011, total number of households of Rajshahi district was 633758 and total enumerated population was 2595197 which are about 1.80 per cent of the country. Upazila wise distribution of the enumerated households and population in 2011 is given below.

Table 1.11. Household and Population by Upazila

Upazila	Population Census 2011(Enumerated)						
	Household	Population			Sex Ratio(M/F)	Average Size of Household	Density (sq. km)
		Male	Female	Total			
Bagha	46711	92010	92173	184183	100	3.94	995
Bagmara	94050	177157	177507	354664	100	3.77	968
Charghat	51783	1104138	102650	206788	101	3.95	1257
Durgapur	48530	93551	92294	185845	101	3.83	939
Godagari	72186	166260	164664	330924	101	4.57	696
Mohanpur	43984	85236	84785	170021	101	3.87	1045
Paba	76622	159452	154744	314196	103	4.08	924
Puthia	52922	105071	102419	207490	103	3.92	1077
Tanore	47425	94041	97289	191330	97	4.03	648
RCC	93545	232974	216782	449756	107	4.81	4318
Total	633758	1309890	1285307	2595197	101	4.03	1070
Bangladesh	32173630	72109796	71933901	144043697	100.3	4.40	976

Sources: Population and Housing Census 2011, Vol. 1(P. xiii-xiv) and District Statistics 2011; Rajshahi (P. 4)

Note: RCC=Rajshahi City Corporation

1.10.10 Agriculture

Rajshahi district is predominantly an agricultural area and agriculture remains the principal source of earning and employment for majority of the population. The major crops of the study area are, *aus, aman, boro*, wheat, maize, jute, cotton, sugar cane, potato, vegetables, pulses, oil seeds, fruits, and spices. *Aus, aman, boro*, wheat, maize, potato, vegetables, pulses, oil seeds, and spices cover 650769 acres that constitute about 93 per cent area while jute, cotton, sugar cane, fruits etc. cover only 48213 acres, which is only 7 per cent area of the district.[19]The farm holdings and type of ownership of the study area are presented below.

[19] Bangladesh Bureau of Statistics, *Yearbook of Agricultural Statistics of Bangladesh 2011*(Dhaka: Statistics and Informatics Division, Ministry of Planning, 2011), 387.

Table 1.12. Farm and Non-Farm Holdings of Rajshahi District by Upazila

Name	All Holdings	Non-Farm Holdings	Number of Farm Holdings				Number of Holdings			Agri. Labor Holdings
			Small	Medium	Large	Total	Owner	Owner-Cum-Tenant	Tenant	
Bagha	43559	16071	22918	4087	483	27488	32287	7044	4228	20829
Baghmara	88557	26182	54626	7329	420	62375	58012	27200	3345	40559
Charghat	47896	19698	24575	3316	307	28198	34005	10541	3350	19370
Durgapur	45700	13000	29076	3383	241	32700	28636	13851	3213	17756
Godagari	66226	27304	28825	9006	1091	38922	37002	21447	7777	23154
Mohanpur	39899	11299	25450	2933	217	28600	25335	11324	3240	17106
Paba	69629	33016	31595	4665	353	36613	45820	14397	9412	28230
Puthia	49847	17361	28456	3731	299	32486	30426	13896	5525	16297
Tanore	43980	15509	21046	6386	1039	28471	24277	15096	4657	22424
Rural	495293	179440	266567	44836	4450	315853	315750	134796	44747	205725
Urban	77072	71544	4696	677	155	5528	54984	3154	18934	2464
Total	572365	250984	271263	45513	4605	321381	370734	137950	63681	208189

Source: Census of Agriculture 2008 Zila Series: Rajshahi (P. 45)

Net cultivated area is important for agriculture development. Besides, irrigated area, intensity of cropping, owned area, and operated area are also important for any planning of agriculture development. The area under different uses of Rajshahi district is presented below.

Table 1.13. Area Under Different Uses of Rajshahi by Upazila

(in acres)

Name	Owned Area	Operated Area	Homestead Area	Net Cultivated Area	Temporary Crops Net Area	Irrigated Area	Temporary Crops Gross Area	Intensity of Cropping(%)
Bagha	38365	40647	2632	33602	25054	14360	45764	183
Baghmara	79557	81636	5596	69918	66099	62346	126548	191
Charghat	33520	35769	2353	30657	26578	21443	46240	174
Durgapur	39987	41074	3294	33211	29886	24360	57047	191
Godagari	59496	80337	4875	71199	70273	45705	129715	185
Mohanpur	32176	34870	2317	29399	26550	23691	57460	216
Paba	44257	49561	3874	41582	38731	34984	71978	186
Puthia	39418	41963	2903	34623	30755	22726	51011	166
Tanore	45558	59347	3027	53347	52710	47820	114721	218
Rural	412332	465204	30872	397537	366637	297435	700483	191
Urban	39736	11870	3189	6877	5300	3276	8832	167
Total	452068	477074	34062	404413	371937	300711	709315	191

Source: Census of Agriculture 2008 Zila Series: Rajshahi (P. 45)

The study area is mainly rice dominated like most areas of Bangladesh. Rice constitutes about 79 per cent area found in last agriculture census 2008. HYV *aman* and *boro* also dominate different rice type. Wheat, maize, pulses, and oil seeds also occupy significant area of Rajshahi district. Area under different crops of Rajshahi district and upazila wise distribution are mentioned below in table 1.14.

Table 1.14. Area under Different Crops of Rajshahi by Upazila

Name of Upazila	Area (in acres)													
	Local Aus	HYV Aus	Local Aman	HYV Aman	Local Boro	Hybrid Boro	HYV Boro	Wheat	Maize	Jute	Pulses	Oil Seeds	Sugar cane	Potato
Bagha	612	571	2102	1244	940	632	914	7194	417	4432	5944	3012	6507	672
Baghmara	2748	22070	642	894	2774	16634	18483	809	17162	2241	434	12853	111	19602
Charghat	529	392	2942	1998	1534	292	1835	8390	624	1106	8033	4651	8585	338
Durgapur	1198	6849	2157	3745	1663	6568	7061	1606	4914	2583	1092	4816	222	3661
Godagari	6430	17473	10641	32310	3682	1652	30358	3319	3754	815	6407	3349	225	539
Mohanpur	1690	11437	948	4184	1192	4174	10658	364	4700	353	267	3595	140	9505
Paba	630	2341	3869	14146	997	915	13087	4586	6203	3436	3323	1174	2486	6716
Puthia	209	379	1240	7146	500	2278	7324	4471	3318	3767	4307	2394	4025	492
Tanore	4030	20110	8975	34030	4631	2876	29665	1551	2010	42	276	1317	29	2450
Rural	23587	81622	33515	99696	17912	36022	119387	32291	43101	18775	30083	37162	22330	43976
Urban	612	481	914	565	672	568	881	751	660	218	611	200	379	468
Total	24199	82102	34429	100261	18584	36590	120268	33042	43761	18993	30694	37361	22709	44444

Source: Census of Agriculture 2008 Zila Series: Rajshahi (P. 46)

Though the study area is mainly rice dominated, a lot of crops grow in three crop growing season. Most crops are low value crops and only a few are high value crops. The major crops cultivated in the study area and crop wise area and yield are mentioned below.

Table 1.15. Cultivated Area and Yield of Crops

Sl.	Crops	Production Year					
		2012-13		2013-14		2014-15	
		Cultivated Area(ha)	Yield(m.t.)	Cultivated Area(ha)	Yield(m.t.)	Cultivated Area(ha)	Yield(m.t.)
1	*Boro*	15,150	54,175	15890	64513	16100	61799
2	*Aus*	10,630	27,866	12,225	31367	12215	35393
3	*Aman*	24,411	77,626	24,730	77899	26650	84112
4	Wheat	6,530	22,528	7360	23298	7715	25462
5	Mustard	4,775	5,724	5070	6236	5800	7134
6	Potato	1,380	30038	1375	33000	1375	35098
7	Tomato	2,760	68,995	3340	85170	3040	70540
8	Blackgram	1,980	2,178	1800	1980	1280	1304
9	Lentil	630	658	1200	1320	1865	2051
10	Chickling Vetch	240	288	160	192	120	144
11	Linseed	35	21	15	9	5	3
12	Onion	490	4710	580	6395	770	7260
13	Garlic	182	1183	185	1202	130	975
14	Sesamum	460	462	310	341	120	120
15	Gram	1950	2338	1910	2231	1680	1963
16	Jute	860	9050 Bail	860	9356 Bail	745	8195 Bail
17	Turmeric	25	300	40	480	35	490
18	Chili	350	4,900	370	5180	375	3975
19	Vegetables	1525	22,030	1205	18822	725	11324
20	Green Gram	90	117	125	125	115	103
21	Mango	350	9450	440	12180	470	13630
22	Moringa	170	1360	180	1440	290	2320
23	Guava	5	60	35	420	450	8550
24	*Latiraj* Arum	--	--	--	--	8	200
25	Sweet potato	--	--	--	--	5	30

Source: Bangladesh Agriculture Development Corporation, Rajshahi, 2016

Apart from abovementioned 25 crops, a lot of crops are grown in the study area. These are different type of vegetables, fruits, pulses etc. The cultivated area is dominated by rice which is less profitable crop. *Boro* rice covers a significant area of rice which needs much irrigation resulting of groundwater depletion and other environmental degradation.

1.10.11 Crop Production Seasons and Crop Calendar

Crop calendar is important for agriculture. It is a tool that provides timely information about planting, sowing, and harvesting periods of crops in specific agro-ecological zones. The Present cropping pattern in the study area is characterized with three cropping seasons which are *rabi* (16 October-15 March), *kharif* 1(16 March-15 July), and *kharif* 2 (16 July-15 October). The crop calendar of the study area as well as of Bangladesh is depicted below.

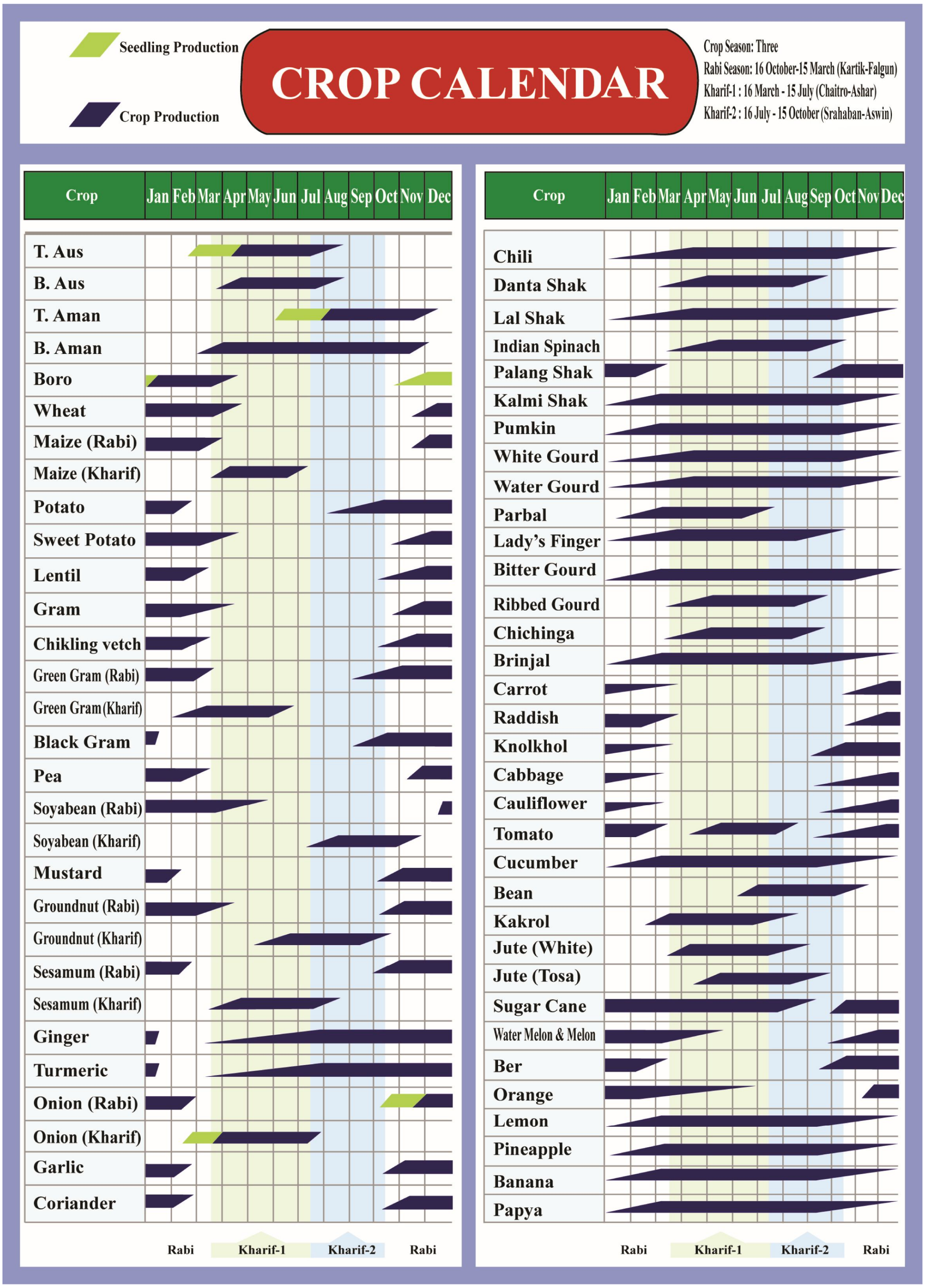

Figure 1.8. Crop Calendar of Rajshahi District and Bangladesh

Source: Bangladesh Agriculture Development Corporation

1.10.12 Economic Situation

The economy of Rajshahi is predominantly agricultural. Out of total 572365 holdings of the district, about 56 per cent holdings are farms that produce varieties of crops, namely, local and HYV paddy, sugarcane, wheat, vegetables, spices, jute, pulses, and other minor cereals. Various fruits like mango, banana, jackfruit, guava, coconut etc. are grown here. Almost all kinds of vegetables are cultivated and a few are abundantly grown.

Pisciculture, livestock rearing, and poultry add an additional income to the rural households. Fish of different varieties grows abound in Rajshahi. Moreover, varieties of fish are caught from rivers, tributaries, channels, and even from paddy fields during the rainy season. Some valuable timber and forest trees are grown in the district. Out of total 2407.51 sq. km of the district, organized forestry is 14.48 sq. km and riverine areas occupy about 47.89 sq. km.

1.10.13 Flora

In the farmlands, varieties of crops namely rice, jute, vegetables, spices, pulses, oil seeds, beans etc. are produced. Sugarcane and mango are the major cash crops. Among rice crops, *aman* covers the largest area followed by *boro* and *aus* in 2008.[20] Minor crops include barley, potato, motor etc. Litchi, melon, watermelon, and other fruits are also cultivated.

In the villages, bamboo, and tree growths are numerous. In the Barind, palm is grown widely. Common trees found in this area include:

bablah, shet khoiyer, chakua koroy, shiris, bilati siris, batul, akashmoni, catechu,
raktachandan, wood apple, motor koroy, ata, kadam, pitraj, betel-nut, jackfruit, kamranga,
margosa, hijal, cotton, bastard-teak, papaya, sonalu, jambura, coconut, barun, krisnochura,
tamal, gab, olive, mandar, kodbel, batgas, dumur, ashatha, chila, jarul, bhadia, mendi,
neem pitali, mango, sajna, tut, debdaru, guava, dalim, herenda, boroi, kadbadam, arjun,
tatul, starapple, black berry, bara mehogoni, talla bans, beora bans, choibans etc.

Besides, the floating macrophytes like water hyacinth, topa pona, lotus, water lily, bind weed, helencha etc. are commonly seen in the village ponds and *beels*.

[20] Bangladesh Bureau of Statistics, *Census of Agriculture-2008; Zila Series: Rajshahi*, 403.

1.11 Outline of the Dissertation

The study has been designed to meet the objectives in particular. Accordingly, outline of the dissertation has been framed for the purpose of sequential settings which are described below.

Chapter one provides introductory matters that include prelude, statement of the problem, review of literature, research questions, objectives, research gap, significance, scope, utility, and limitations of the study and a brief account of the study area. Outline of the dissertation are also described at last.

Chapter two is regarding methodology of the study. This chapter describes the materials and methods in details that are used for the research work. It includes data sources, data collection tools and techniques of soil, irrigation water, climate, topography, floodability, accessibility, remotely sensed images, questionnaire survey, field observation, case study, opinion survey, and opinion of experts about reclassify value and percentage of influence. Selection of the study area and sampling of study population and different attributes namely, soil, irrigation water, topography, and floodability are discussed herein. Afterwards, data analysis and interpretations techniques are discussed including GIS analysis, image analysis, economic viability analysis of major crops and cropping patterns through net return analysis and benefit-cost ratios (BCR), data analysis of farmers' perception and multi-criteria evaluation (MCE). Finally, citation style and English are mentioned.

Chapter three investigates the land characteristics and land suitability variables of the study area that include present state of soil, irrigation water, climate, topography, floodability, and accessibility attributes of the research area. Hypotheses, tests of normality and calculation of data of soil, irrigation water, climate, and accessibility attributes are discussed here. Union wise mean values of various attributes of the study area are also calculated and presented.

Chapter four is concerned with land suitability analysis model, its specification, weight calculation and validation. It discusses selection of suitability value and classes of soil, irrigation water, climate, topography, floodability, accessibility data and justification, workflows of model builder (analysis procedures) for land suitability analysis, reclassified value calculation of soil, irrigation water, climate, topography, floodability, accessibility attributes, percentage of influence of weighted overlay for overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops and weighted overlay procedures. Validations of the model are also discussed.

Chapter five deals with the analysis of land suitability for major agriculture crops of the study area. Analyses of soil, irrigation water, climate, topography, floodability, and accessibility attributes are discussed elaborately. It also includes analysis of overall land suitability, land suitability for rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation based on present soil, irrigation water, climate, topography, floodability, and accessibility attributes of the study area. This chapter also includes land suitability model output verification description.

Chapter six pertains to assessing economic viability of major agricultural crops and cropping patterns of the study area. With a view to economic viability analysis, area and percentage of major agricultural crops and cropping patterns, yields, gross revenue and total costs of major crops, net return and benefit-cost ratios (BCR) of major crops, economic viability analysis of presently followed cropping patterns and land suitability based cropping patterns through net return analysis and BCR. Net return increase through changing cropping pattern of the study area, Rajshahi district, Rajshahi division and Bangladesh are also calculated in this chapter. Case studies of economically viable two crops namely, onion seed and cauliflower cultivation are also discussed focusing on causes of higher profitability and sustainability.

Chapter seven discusses land use changing pattern and sustainable agriculture. Land use changing pattern are discussed based on changes of soil properties, crop cultivation areas for different crops, land cover areas for different uses focusing on agriculture land, error matrix analysis of 2016 image, cultural changes of agriculture in respect of different seed varieties, chemical fertilizer and insecticide, food culture, health risks, agriculture farm working culture, costumes, and foods of farm workers and household working culture. Opinion of 6 agriculture officials on 7 themes regarding land suitability and agriculture development for the study area are also discussed in this chapter. Case study results of immense potential Thai guava cultivation are described throwing light on factors of higher profitability and sustainability risks.

Chapter eight pertains to farmers' perception about land suitability and agriculture development. This chapter includes description of perception, knowledge, attitude, and practice, statements and scales for perception assessment, validation of statements, perception assessment procedure, results of perception study and perception level of farmers. Coefficient of variation of statements, correlation, ANOVA, and regression analysis are also done in this chapter.

Chapter nine deals with concluding matters. It includes major findings, policy suggestions and limitations of the present study and need for further research. Finally, this chapter ends with a conclusion.

1.12 Conclusion

The present study is regarding land suitability analysis of Rajshahi district in Bangladesh incorporating various aspects of land suitability. Land suitability analysis is very important for Rajshahi district as well as for the country as Bangladesh is a land scarce country. Godagari upazila is selected as study unit which is the largest upazila and constitutes about 20 per cent of the district. Since there is hardly any scope for horizontal expansion of agriculture land, land suitability based land uses is the proper answer to surmount problems of high value and cereal crops production, employment generation, and socio-economic development. The study area is dominated by agriculture, and any development in agriculture based on land suitability will change the total scenario of socio-economy of the area.

Chapter Two
Materials and Methods

2.1 Introduction

The present study used a mixed method approach. Primary and secondary data have been used in this study. The primary data were collected and used mainly for the purpose of economic viability of major agricultural crops and cropping patterns and farmers' perception about land suitability and agriculture development. Secondary data were collected and used mainly for the purpose of theoretical grounding, exploring the real state of existing land characteristics and land suitability variables and land suitability analysis for major agricultural crops of the study area. Geographical Information System (GIS), Multi-Criteria Evaluation (MCE), and Benefit-Cost Analysis (BCA) techniques have been used in this research work. To fulfill the objectives of the research taking into account the mixed method approach, primary and secondary data, Geographical Information System (GIS), Multi-Criteria Evaluation (MCE), and Benefit-Cost Analysis (BCA) techniques as mentioned above the methodology used in this study are graphically presented in the following diagram. It may be mentioned here that chapter four titled "Land Suitability Analysis Model" provides methodology and workflows related to land suitability analysis model in details is also a part of the methodology.

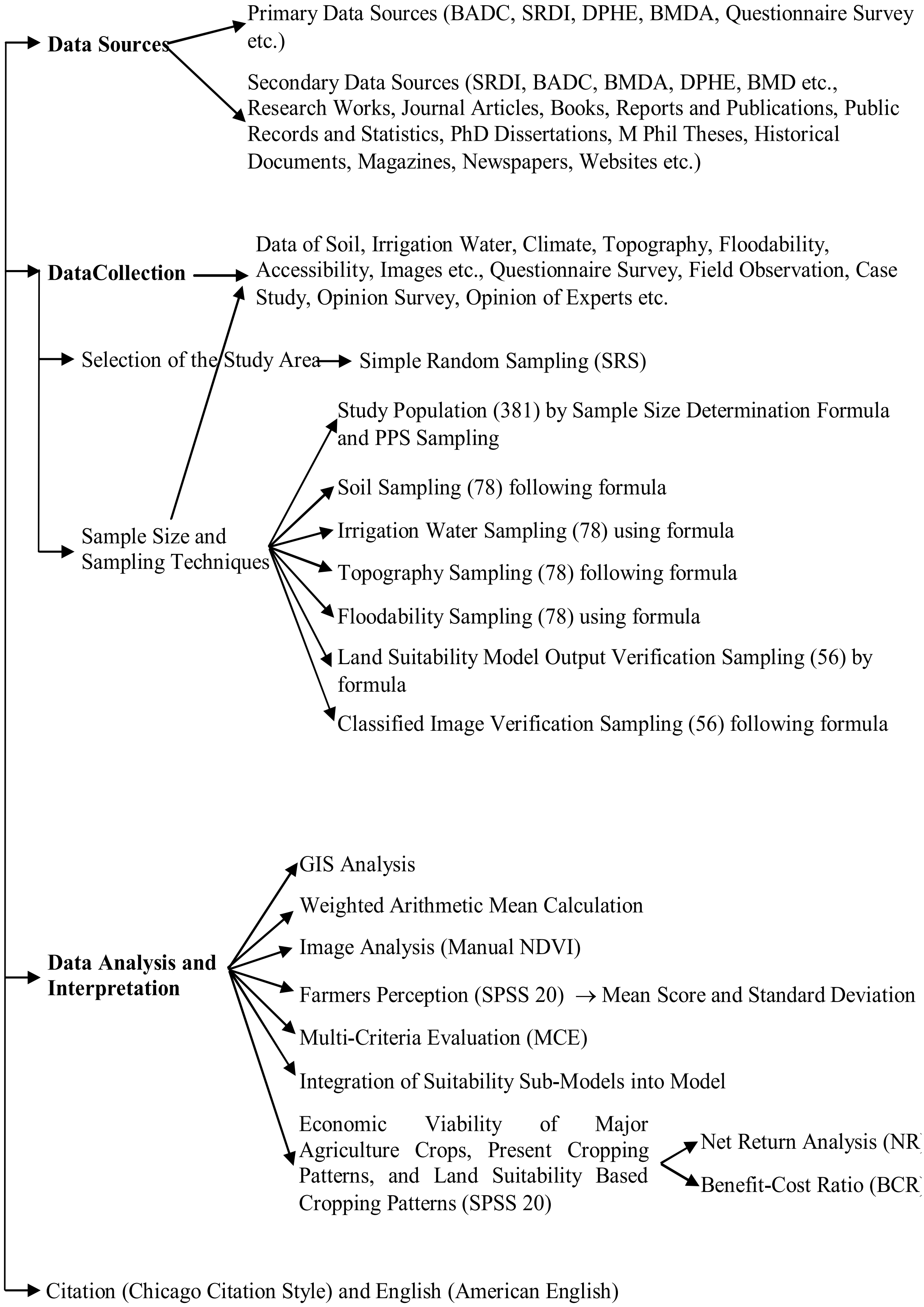

Figure 2.1. Used Methods at a Glance

In this study, 8 crops - rice, wheat, maize, vegetables (potato), pulses (lentil), oil seeds (mustard), and spices (onion and chili) have been taken under investigation that cover about 99 per cent[1] of gross cropped area (126732 acres) while rest crops constitute about only 1 per cent (1100 acres) gross cropped area in the study area Godagari upazila.[2] The materials and methods graphically presented in figure 2.1 are described below.

2.2 Data Sources

Both primary and secondary data have been used in this study. The sources of primary and secondary data are described below.

2.2.1 Primary Data

Primary data of irrigation water of few unions have been collected by laboratory tests in the Bangladesh Agriculture Development Corporation (BADC: Small Irrigation) laboratory, Rajshahi. Primary information pertaining to assessing economic viability of major agricultural crops and farmers' perception about land suitability and agriculture development were collected through questionnaire survey in January to March 2016. The highway and local markets data were collected from Godagai upazila map prepared by SRDI in 2015.

2.2.2 Secondary Data

To reveal the existing scenarios of the present land uses and land suitability analysis of the study area, secondary data of soil of 2015 have been collected from Soil Resource Development Institute (SRDI). Irrigation water data of 2014 and 2015 have been collected from Bangladesh Agricultural Development Corporation (BADC: Small Irrigation), Barind Multipurpose Development authority (BMDA), Department of Public Health Engineering (PHE), Rajshahi. Temperature and rainfall data of Climate from 1975 to 2014 were collected from Climate Division, Bangladesh Meteorological Department (BMD), Dhaka. Data of maximum and minimum temperature, total rainfall, total rainy and rainless day, and agriculture important few climate factors from 2005 to 1014 have been collected from Rajshahi Meteorology Office. Topography and floodability data of

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[1] Including species of those crops.

[2] Bangladesh Bureau of Statistics, *Yearbook of Agricultural Statistics of Bangladesh 2011*(Dhaka: Statistics and Informatics Division, Ministry of Planning, 2011), 403.

2015 were taken from SRDI, Rajshahi. Remote sensing data of land uses (land cover) of the study area of 1977, 1988, 1996, 2008, and 2016 are collected from open source United States Geological Survey (USGS) website (glovis.usgs.gov).

Besides, research works, journal articles, books, reports and publications, public records and statistics, PhD dissertations, MPhil theses, historical documents, magazines, newspapers, websites etc. were used to collect secondary data.

2.3 Data Collection: Tools and Techniques

Data collection tools and techniques are very important to collect the data systematically. The tools and techniques to be employed to collect data largely depend on the objectives of the study.[3] The present study uses both primary and secondary data. The methods of collecting primary and secondary data differ, as primary data are to be collected originally, while secondary data collection is merely that of compilation.[4] Another important consideration of data collection techniques is whether the data are quantitative data or qualitative data. Keeping these in view, the data collection techniques of this study were selected which are described below.

2.3.1 Soil

Data of texture, moisture, pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron of soils have been collected from Soil Resource Development Institute (SRDI), Rajshahi. The SRDI tested soil samples in Regional Laboratory, SRDI, Dinajpur and test results were prepared on 30.03.2015. Mean values of upazila and 9 unions of pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron of soils have been calculated from values of soil attributes of 78 soil samples.

2.3.2 Irrigation Water

Data of pH, electrical conductivity (EC), and temperature of irrigation water have been collected from Bangladesh Agricultural Development Corporation (BADC: Small Irrigation), Barind Multi-Purpose Development Authority (BMDA), Department of Public Health Engineering (DPHE), Rajshahi, and laboratory tests. Irrigation water

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[3] M. Nurul Islam, *An Introduction to Research Methods: A Handbook for Business and Health Research* (Dhaka: Mullick & Brothers, 2008), 147.

[4] C. R. Kothari, *Research Methodology: Methods and Techniques,* 2nd ed. (New Delhi: New Age International Private Limited, 1999), 95.

samples were collected and tested in the laboratory of BADC (Small Irrigation), BMDA, DPHE, Rajshahi in the dry period (January to April and October to December) of 2014 and February to April of 2015. A few samples of few unions were collected and tested in BADC laboratory in January-April of 2015.

2.3.3 Climate

Temperature and rainfall data of Rajshahi Meteorological Station have been used in this study. Data have been collected from Climate Division, Bangladesh Meteorological Department (BMD), Dhaka for the period of 1975 to 2014. Monthly average temperature and monthly total rainfall of 40 years (1975-2014) have been used for analysis and to see their suitability for agricultural crops in the study area. Data of agriculture related few climate factors were collected from Rajshahi Meteorological station for the period of 2005 to 2014.

2.3.4 Topography

Land type and drainage data of topography of the study area have been collected from SRDI in 2015. Land type and drainage data of 78 points out of 390 *mauza*s are analyzed to see the different land types and drainage condition and their relationship with land suitability and agriculture.

2.3.5 Floodability

Floodability data of Godagari upazila of Rajshahi district have been collected from SRDI, Rajshahi in 2015 to see the depth of flooding in 78 points from 390 *mauza*s. Duration of flooding data is also collected from SRDI. The data are used to see the depth and duration of flooding and its relation to sustainable agriculture for agricultural crops of the study area.

2.3.6 Accessibility

Accessibility is analyzed through measurements of distance from highway and distance from local markets. The highway and local markets data were extracted from SRDI map prepared in 2015. The extracted one highway and seven local markets data were used for creating buffers to calculate distances. Geo-processing tool of ArcGIS 10.1 has been used for multiple rings buffer creation of one highway and seven local markets with the specified distances of ≤ 0.5 km, 0.5 – 2 km, 2 - 4 km, 4 - 6 km, and > 6 km for highway and ≤ 2 km, 2 - 4 km, 4 - 6 km, 6 - 8 km, and > 8 km for local markets.

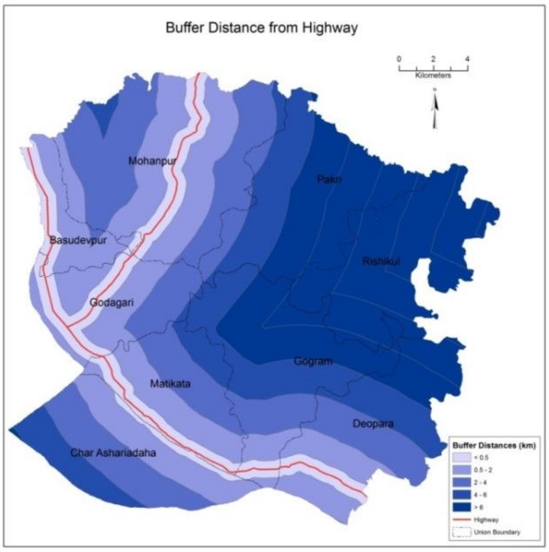

Figure 2.2. Buffer Distance from Highway

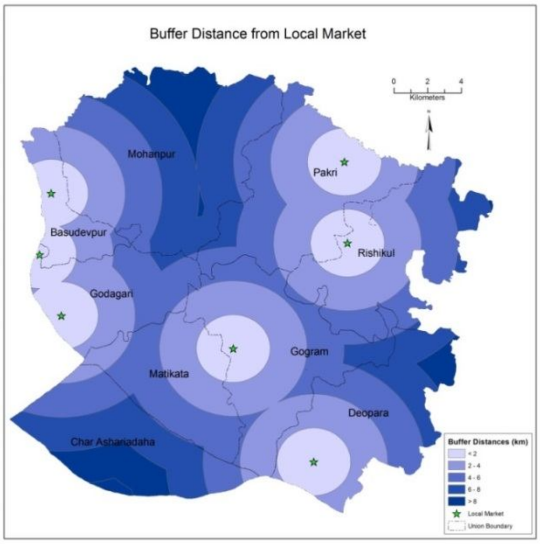

Figure 2.3. Buffer Distance from Local Markets

Source: Produced in ArcGIS 10.1 Model through Multiple Ring Buffer

Distances are computed through Euclidean distance method in ArcGIS. Mean distances are calculated and used for weighted values which are used in land suitability analysis. Mean values of accessibility attributes (distance from highway and distance from local markets) of each union were calculated and weights of mean values were converted from polygon to raster throughout the study area unit (unions).

2.3.7 Remote Sensing Data

Landsat MSS (Multispectral Scanner), Landsat TM (Thematic Mapper), and Landsat OLI (Operational Land Imager) images of the study area for the year of 1977, 1988, 1996, 2008, and 2016 have been collected from US Geological Survey (USGS) website named USGS Global Visualization Viewer (glovis.usgs.gov). Landsat provides the inventory of the global land surface over time for both natural and human induced changes.[5] The paths are 148 and 138 and row is 43. Table 2.1 presents general information about collected five Landsat images.

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[5] Gyanesh Chander, Brian L. Markham and Dennis L. Helder, "Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI Sensors," *Remote Sensing of Environment* 113 (2009), 893. www.pancroma.com/downloads/Landsat_Calibration_Summary.pdf. (accessed August 14, 2016).

Table 2.1. General Information of Collected Images

Sensor	Mission	Year	Month	Day	Band	Spectral Range
MSS	2	1977	January	5	5	0.607–0.710
MSS	2	1977	January	5	6	0.697–0.802
TM	5	1988	January	9	3	0.626–0.693
TM	5	1988	January	9	4	0.776–0.904
TM	5	1996	January	31	3	0.626–0.693
TM	5	1996	January	31	4	0.776–0.904
TM	5	2008	January	16	3	0.626–0.693
TM	5	2008	January	16	4	0.776–0.904
OLI	8	2016	February	23	4	0.64–0.67
OLI	8	2016	February	23	5	0.85–0.88

Source: Images

Landsat 7 images are not used for 1996 or 2008 because after May 30, 2003, Landsat 7's sensor developed a problem called SLC (Scan Line Corrector) failure that cause stripping from a lack of data on both sides of the scene.

2.3.8 Data of Questionnaire Survey

Primary information pertaining to economic viability of major agricultural crops and farmers' perception about land suitability and agriculture development are collected through questionnaire survey. Questionnaire consists of three sections. Section-A is about the basic information of the respondent. Section-B is the appraisal of economic viability of agricultural crops, and Section-C is assessing of perception of farmers regarding land suitability and agriculture development comprised of 23 statements/ questions (19 for perception and 4 for demographic and educational features). One statement was designed reverse. Statement questionnaire was close-ended and response options for different aspects of perception were five-point Likert scale. The five-point response categories ranged from strongly agree to strongly disagree with the neutral point neither agree nor disagree. These ordinal scales measure the levels of agreement/ disagreement. Five-point Likert scale was selected for statements as five point statements (five alternatives from which to choose) yield a normal distribution.

Questionnaire was developed considering the required data relating to all production costs and total revenues for economic viability analysis of major agricultural crops and perception about different aspects of land suitability and sustainable agriculture of the study area. The developed questionnaire was pre-tested in Deopara union two times and opinion was taken of Sub-Assistant Agriculture Officers (SAAO) of mentioned union. After modification, pilot survey was conducted. Then final questionnaire was prepared after necessary modifications for survey. The survey was conducted from January to March 2016 by the researcher himself. The study area is about 20 km away from the Institute of Bangladesh Studies, University of Rajshahi. Face-to-face interview survey method was employed in this study for questionnaire survey. Sample size (381) and union wise respondents and small farmers, medium farmers, and large farmers from each union were selected using sample size determination formula and PPS sampling. Farmers are the respondents and they were selected randomly.

2.3.9 Field Observation

Direct observation is a good method of collecting real data. The possibility of coming false information through observation is low than questionnaire survey and interview as opined by many scholars. Direct observation technique was used in this study to collect field data of land suitability model outputs and classified images to check the validity and truthiness of model outputs and classified images. Local farmers and union agriculture officials were present and participated in the process of collecting field data through direct observation. Observation was done in 56 sites. The sample size was selected following sample size determination formula and union wise sample sizes were selected following PPS sampling.

2.3.10 Case Study

The case study is a careful and complete observation, efforts are made to study all aspects of concerning unit intensively, and from the case data, generalizations and inferences are drawn.[6] The goal of the case study in this research is to find out the factors that responsible for the conversion of rice farms into Thai guava, onion seed, and cauliflower cultivation and their sustainability. It is seen during the questionnaire survey that farmers are switching from rice cultivation to Thai guava cultivation in the study area. From the opinion of agriculture officials, the immense potentialities of Thai guava cultivation have also found in the research area. After processing of questionnaire survey data, it is also seen that the highest two economically viable crops are onion seed and cauliflower. To find

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[6] C. R. Kothari, *Research Methodology: Methods and Techniques*, 113.

out the factors that responsible for the switching from rice cultivation to Thai guava cultivation and higher economic viability of onion seeds and cauliflower to associate with other data to make generalization and inferences, investigation of Thai guava cultivation, onion seeds and cauliflower cultivation is deemed necessary. Case studies are considered the proper ways in this situation and two cases for each (Thai guava, onion seeds, and cauliflower) are selected in the study area for investigation. Two case studies for each were considered enough for this study as the nature of data is homogenous and there are other data and this method is used simultaneously with other methods. Farms were selected taking advice from the agriculture officials so that they become representative and illustrative of the whole study area. The case study was done in the month of May in 2016. Case studies were conducted through repeated informal interview and observation. The case study results are presented in chapter six and seven following indention style.

2.3.11 Opinion Survey

Agriculture experts' opinions are very important in decision making to develop agriculture. Agriculture experts can give scientific advice and they have scientific, indigenous, in-depth, and practical knowledge regarding the ways and means of agriculture development. Six officials' opinions are collected on seven themes regarding the ways and means of sustainable agricultural development. Six officials comprise of Additional Deputy Director, Department of Agriculture Extension (DAE), Rajshahi who was Upazila Agriculture Officer of Godagari upazila few months back, present Upazila Agriculture Officer, present Upazila Agriculture Extension Officer, present Assistant Engineer of Barind Multipurpose Development Authority (BMDA), Godagari Zone, Rajshahi who is irrigation and agriculture expert and two Sub-Assistant Agriculture Officers of two unions.

2.3.12 Opinion of Experts about Reclassify Value and Percentage of Influence Value

For reclassify value and percentage of influence value, attributes' classes and their value ranges for soil, irrigation water, climate, topography, floodability, and accessibility attributes for analysis of overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili cultivation in this study, nine Sub-Assistant Agriculture Officers (Union Agriculture Officers) from nine unions (the study area comprises nine unions), one Agriculture Extension Officer, one Scientific Officer of Soil Resource Development Institute (SRDI), Rajshahi, one Agronomist, one Agro-economist, and one agriculture and irrigation specialist of BMDA (BMDA is an autonomous specialist institution that provides irrigation in this region), Rajshahi total 14 officials opinion regarding reclassified value of 6 attributes and 21 sub attributes were taken. The selection criterion of officials was the officials who have more than 12 year's field experience in their respective fields.

To reduce the subjectivity and to reach a near consensus for weights, at the time of agriculture officials' monthly meeting in upazila office the researcher arranged group discussions for final weights and took corrected versions from them. Then discussions were done with scientific officer, agronomist, agro-economist, and irrigation expert and took their corrected versions. The nature of corrected data was centered; therefore, there was no need to use standard deviation. Thus, the mean values of 14 officials corrected opinion were calculated and used in this study for concerned purposes.

2.4 Selection of the Study Area

Rajshahi is the major district of the North Western region of Bangladesh with an area of 2425.4 sq. km, which is about 1.64 per cent of the total area of Bangladesh. Rajshahi district is intensively used for agriculture, majority of the population depend directly or indirectly on agriculture, and the economy depends primarily on the productivity of agricultural crops.[7] Rajshahi district is selected purposively, which lies between 24°07′ and 24°43′ north latitudes and 88°17′ to 88°58′ east longitudes. The district has 9 upazilas.

For this study, Godagari upazila (Figure 2.4) has been selected by lottery method of simple random sampling (SRS) from homogenous characteristics' 9 upazilas of the Rajshahi district. The selected upazila has large areas (19.61 per cent area of the district), intensive agricultural activities, data availability, and accessibility. Besides, it is comprised of three distinct physiographical areas, viz., Barind region, Alluvial deposits or Riparian Tract, and Marshy or *Beel* areas.[8] These distinct physiographical

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[7] S. A. Akand, ed., *The District of Rajshahi: It's Past and Present* (Rajshahi: Institute of Bangladesh Studies, University of Rajshahi, 1983), 186.

[8] Ashraf Siddiqui ed., *Bangladesh District Gazetteers: Rajshahi* (Dhaka: Bangladesh Government Press, 1976), 3.

areas are closely related with the type of agricultural products and yield which are necessary for this research.

The study locale, which has an area of about 472.13 sq. km covers about 19.61per cent of the total area of Rajshahi district (2425.4 sq. km). It has 9 unions and 390 *mauza*s. To place an accurate portrait of the study area, it lies between 24°21′ and 24°36′ north latitudes and 88° 18′ to 88° 33′ east longitudes.

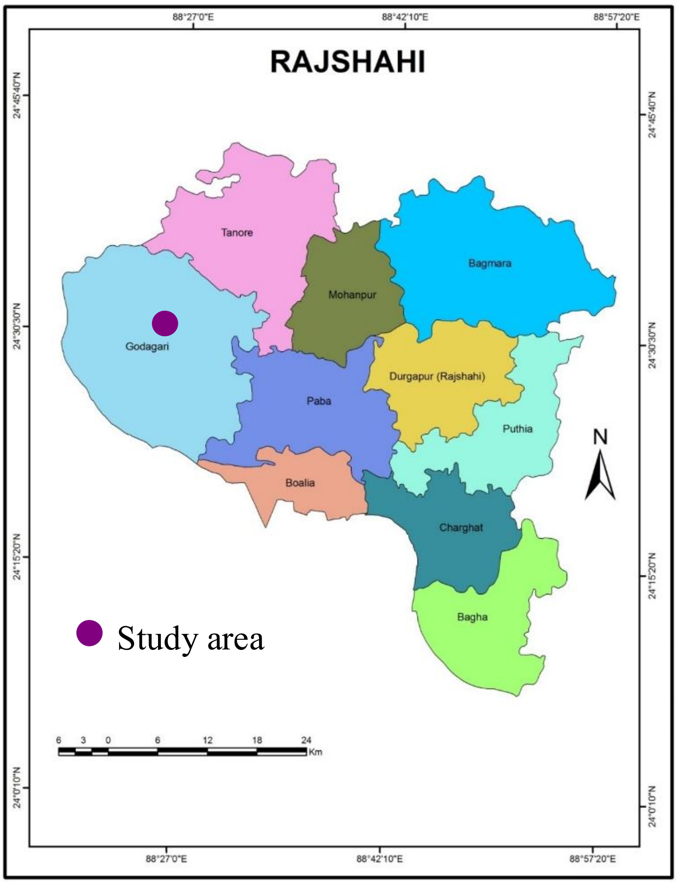

Figure 2.4. Study Area

Source: Produced as of ArcGIS 10.1 Model

2.5 Sample Size and Sampling Techniques

Multi-stage stratified random sampling has been employed in this study. Statisticians discussed usefulness of multi-stage sampling techniques for agricultural and crop surveys, such as Mahalanobis, Cochran, and Lahiri.[9]

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[9] Daroga Singh and F. S. Chaudhary, *Sample Survey Designs* (New Delhi: New Age International Private Limited, 1997), 223.

Table 2.2. Selection of Multi-Stage Sampling Scheme of the Study Area

Stage	Sampling Unit	Referred to as
1	Upazila	Primary Sampling Unit (PSU)
2	Union	Secondary Sampling Unit (SSU)
3	*Mauza* or Revenue Village	Penultimate Sampling Unit (PSU)
4	Farm Household	Ultimate Sampling Unit (USU)

2.5.1 Study Population

Rajshahi district is the population or the study area. The district consists of 9 upazilas. The upazilas are Bagha, Bagmara, Charghat, Durgapur, Godagari, Mohanpur, Paba, Puthia, and Tanore. All the 9 upazilas of the district are almost homogenous and have the same physical and climatic characteristics.

Hence, considering all the upazilas are homogenous according to desired characteristics, one upazila has been selected from 9 upazilas in the 1st stage. The process used for selection was simple random sampling (SRS) based on lottery method and the selected upazila is Godagari.

Godagari upazila has 9 unions and all the unions have been selected in the 2nd stage (complete enumeration).

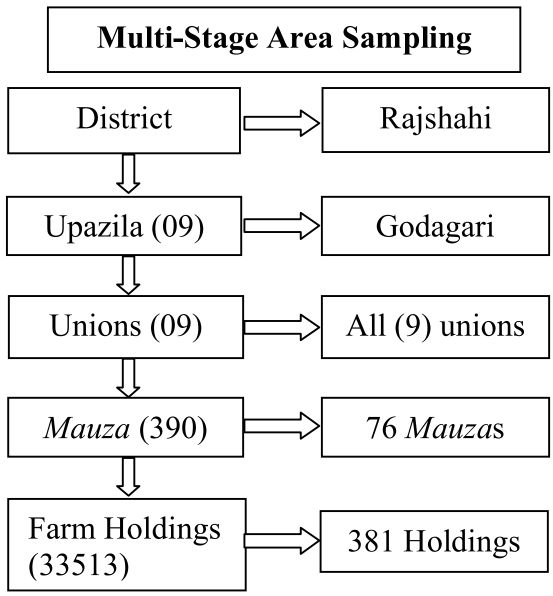

Figure 2.5. Multi-Stage Area Sampling

The study area Godagari upazila is divided into 390 *mauza*s or revenue villages. The estimating formula for sample size is,

$$n_0 = \frac{z^2pq}{d^2} = \frac{(1.96^2)(0.6)(0.4)}{0.1^2} = 92.1984 \approx 93 \text{ (next round figure is taken in sampling)}$$

Where, n_0 = desired sample size

z = standard normal deviate set at 1.96, which corresponds to the 95% confidence level

p = assumed proportion in the target population estimated to have farm holdings = 0.6

q = 1- p (q is the proportion not having farm holdings)

d = degree of accuracy desired in the estimated proportion = .10

Here, N = 390. Hence, our estimate of n is as follows:

$$n = \frac{N.n_0}{N + n_0} = \frac{390 \times 93}{390 + 93} = 75.09 \approx 76$$

Thus, 76 *mauza*s have been selected and they have been selected from 9 unions based on stratified sampling with probability proportional to size (PPS) sampling in the 3rd stage. It is noted that each of the unions is treated as a stratum. The sample size is determined by using the following formula.

$$n_i = \left(\frac{n}{N}\right)Ni$$

Table 2.3. Selection of *Mauza* from Unions

Union No	Union Name	No. of *Mauza* (N_i)	n_i
1	Basudevpur	19	04
2	Char Ashariadaha	9	02
3	Deopara	35	07
4	Gogram	63	12
5	Matikata	54	11
6	Rishikul	36	07
7	Godagari	53	10
8	Mohanpur	83	16
9	Pakri	38	07
Total	**09**	**390**	**76**
N	390		
n	76		

Where,

N = Population Size

n = Total sample size; i= 1, 2,…9

N_i = Number of *mauza* in each union

n_i = Number of sample size in each union

The abovementioned union wise proportions of 76 *mauza*s have been selected from concerned unions randomly.

In order to select respondents for questionnaire survey in this study, the following sample size determination formula has been used.

$$n_0 = \frac{z^2pq}{d^2} = \frac{(1.96^2)(0.5)(0.5)}{0.05^2} = 384.16 \approx 385$$

Where,

n_0 = desired sample size

z = standard normal deviate set at 1.96, which corresponds to the 95% confidence level

p = assumed proportion in the target population estimated to have farm holdings = 0 .5

q = 1- p (q is the proportion not having farm holdings)

d = degree of accuracy desired in the estimated proportion = .05

Here, N = 33513. Hence, estimation of n is as follows:

$$n = \frac{N.n_0}{N + n_0} = \frac{33513 \times 385}{33513 + 385} = 380.63 \approx 381$$

In the above way, 381 respondents have been selected from 76 *mauza*s using stratified sampling with PPS technique in the 4th or last stage where each *mauza* is treated as a stratum.

Respondents are selected from unions using PPS. Farm holdings are divided into three classes or strata viz., small (.05-2.49 acre), medium (2.50-7.49 acre), and large (7.50 acre & above) in the study area as well as in Bangladesh.[10] Respondents from each

[10] Bangladesh Bureau of Statistics, *Yearbook of Agricultural Statistics of Bangladesh-2011*(Dhaka: Statistics and Informatics Division, Ministry of Planning, 2011), 31.

stratum have been selected on the basis of PPS. Union wise type of farm holdings is presented in appendices as appendix 1.

Table 2.4. Selection of Union Wise Respondents from Strata of Farm Holdings

Union No	Union Name	Total Farm Holdings(M_i)	m_i	Respondents from Small Farm Holdings	Respondents from Medium Farm Holdings	Respondents from Large Farm Holdings
1	Basudevpur	2897	33	24	08	01
2	Char Ashariadaha	3133	36	24	11	01
3	Deopara	4712	54	42	11	01
4	Gogram	4244	48	34	12	02
5	Matikata	4762	54	44	09	01
6	Rishikul	3709	42	32	09	01
7	Godagari	2163	25	18	06	01
8	Mohanpur	4251	48	33	13	02
9	Pakri	3642	41	28	11	02
Total	**09**	**33513**	**381**	**279**	**90**	**12**
M	33513					
m	381					

Where,

M = Total no. of selected mauza

M_i = Number of selected respondents from each union

m = Total no. of respondents (381)

m_i = No. of respondents from each selected *mauza*

Respondents from concerned each *mauza* are selected randomly. In this study, farmers are the respondents and all respondents are almost homogenous.

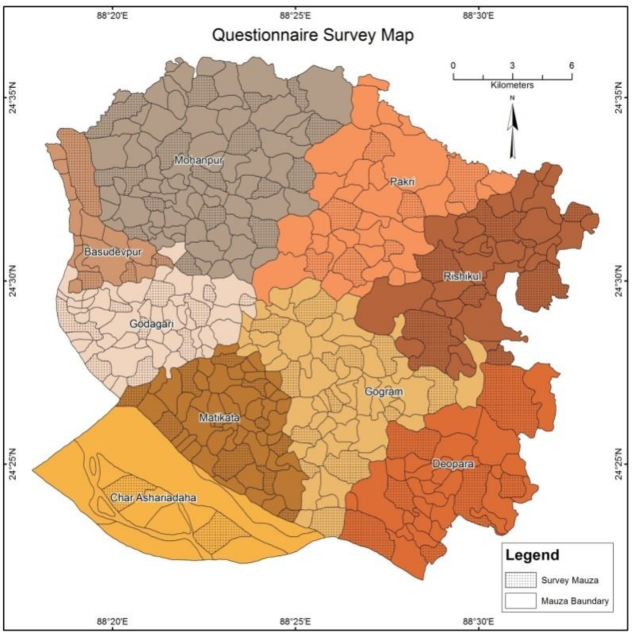

Figure 2.6. Questionnaire Survey Sampling Map

Mauza (revenue village) is the lowest administrative unit having a separate jurisdiction list number (J. L. No) in revenue records and every *mauza* has its well-demarcated cadastral map.[11] On the other hand, villages have no legal existence so far as their demarcation are concerned and village wise maps are not prepared yet in Bangladesh. Besides, the number of village is always increasing and their boundaries are liable to change frequently. As a result, BBS and other departments have been extensively using the concept of *mauza* as the smallest administrative unit in all its statistical programs.[12] Map is a vital part in this research for different spatial analysis. Hence, *mauza* is selected as the last unit in this study.

2.5.2 Soil Sampling

The study area comprised of 9 unions and 390 *mauza*s. From 390 *mauza*s, soil sample sizes have been selected using sample size determination formula, which is,

$$n_0 = \frac{z^2pq}{d^2} = \frac{(1.96^2)(0.5)(0.5)}{0.1^2} = 96.04 \approx 97$$

Where,

n_0 = desired sample size

z = standard normal deviate set at 1.96, which corresponds to the 95% confidence level

p = assumed proportion in the target population estimated to have texture, moisture, P^H, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron attributes of soils = 0 .5

q = 1- p (q is the proportion not having the texture, moisture, P^H, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron attributes of soils)

d = degree of accuracy desired in the estimated proportion = 0.1

Here, N = 390. Hence, the estimate of n is as follows.

$$n = \frac{N.n_0}{N + n_0} = \frac{390 \times 97}{390 + 97} = 77.68 \approx 78$$

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[11] Bangladesh Bureau of Statistics, *Census of Agriculture 2008 Zila Series: Rajshahi* (Dhaka: Statistics and Informatics Division, Ministry of Planning, 2011), 12.

[12] Bangladesh Bureau of Statistics, *Small Area Atlas of Bangladesh: Mauzas and Mahallahs of Rajshahi District* (Dhaka: Statistics Division, Ministry of Planning, 2002), viii.

Thus, 78 soil samples have been selected. 78 samples have been taken from 78 *mauza*s based on probability proportional to size (PPS: size of the unions) sampling which is mentioned below.

Table 2.4. Selection of Soil Samples

Sl	Name of the Union	Area of the Union in hectare (N_i)	No. of Samples (n_i)
1	Basudevpur	1896	03
2	Char Ashariadaha	3646	06
3	Deopara	5234	09
4	Gogram	7026	11
5	Matikata	3956	06
6	Rishikul	5933	10
7	Godagari	3830	06
8	Mohanpur	9647	16
9	Pakri	6395	11
Total =		47, 563	78

Where,

N = 47563 hectare

n = 78

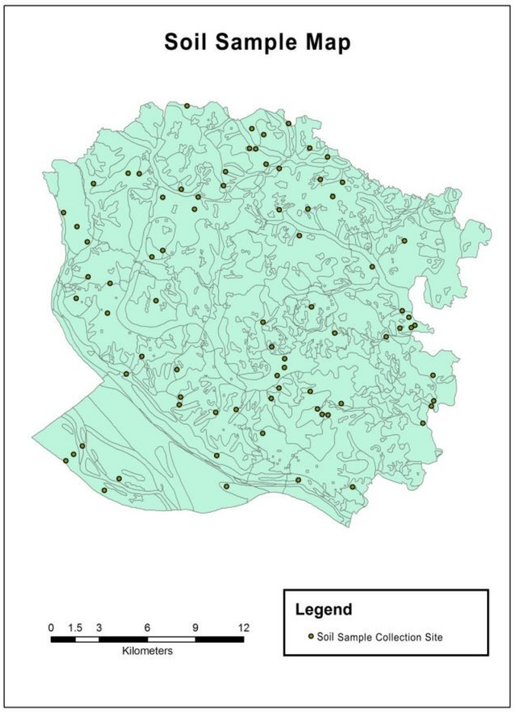

Figure 2.7. Soil Sample Map

2.5.3 Irrigation Water Sampling

The study area consists of 9 unions and 390 *mauza*s. From 390 *mauza*s, irrigation water sample sizes have been selected using sample size determination formula and probability proportional to size (PPS) samplings which are mentioned in soil sampling (2.5.2).

Thus, 78 irrigation water samples have been selected. 78 samples have been taken from 78 *mauza*s based on probability proportional to size sampling (PPS: size of the unions) which is presented below.

Table 2.5. Selection of Irrigation Water Samples

Sl	Name of the Union	Area of the Union in hectare (N_i)	No. of Samples (n_i)
1	Basudevpur	1896	03
2	Char Ashariadaha	3646	06
3	Deopara	5234	09
4	Gogram	7026	11
5	Matikata	3956	06
6	Rishikul	5933	10
7	Godagari	3830	06
8	Mohanpur	9647	16
9	Pakri	6395	11
Total =		47, 563	78

Where,

N = 47563 hectare

n = 78

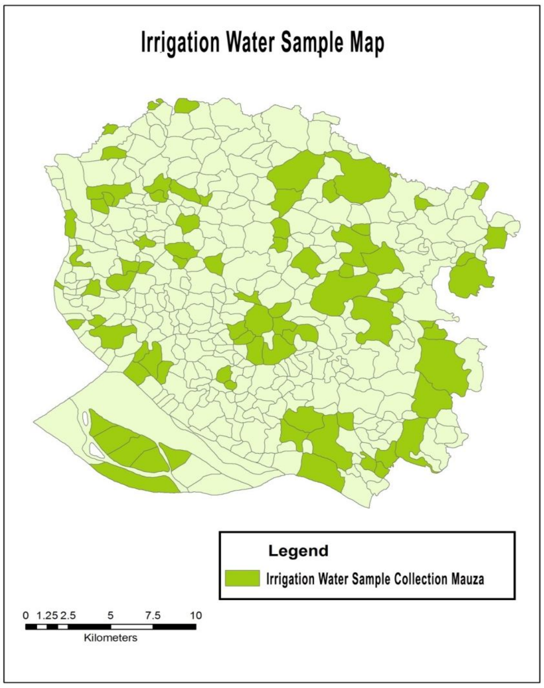

Figure 2.8. Irrigation Water Sample Map

2.5.4 Topography (Topographical Point) Sampling

The study area consists of 9 unions and 390 *mauza*s. From 390 *mauza*s, topography sample sizes have been selected applying sample size determination and probability proportional to size (PPS) sampling formulas which are discussed in soil sampling (2.5.2).

Thus, 78 irrigation water samples have been selected. 78 samples have been taken from 78 *mauza*s based on probability proportional to size sampling (PPS: size of the unions) which is presented below.

Table 2.6. Selection of Topography Samples

Sl	Name of the Union	Area of the Union in hectare (N_i)	No. of Samples (n_i)
1	Basudevpur	1896	03
2	Char Ashariadaha	3646	06
3	Deopara	5234	09
4	Gogram	7026	11
5	Matikata	3956	06
6	Rishikul	5933	10
7	Godagari	3830	06
8	Mohanpur	9647	16
9	Pakri	6395	11
Total =		47, 563	78

Where,

N = 47563 hectare

n = 78

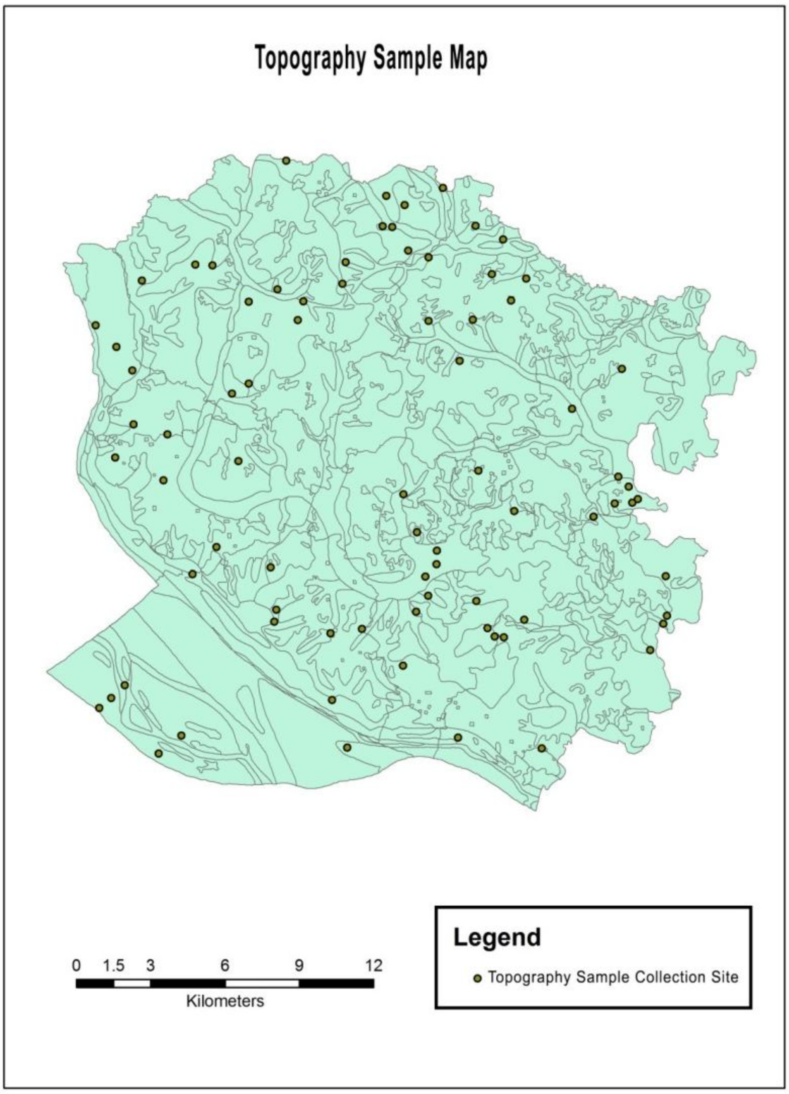

Figure 2.9. Topography (Topographical Point) Sample Map

2.5.5 Floodability (Depth of Flooding) Sampling

The study area comprises of 390 *mauza*s. From 390 *mauza*s, depth of flooding sample sizes have been selected using sample size determination and probability proportional to size (PPS) sampling formula that are mentioned in 2.5.2.

Thus, 78 floodability samples have been selected. 78 samples have been taken from 78 *mauza*s based on probability proportional to size sampling (PPS: size of the unions) which is mentioned below.

Table 2.7. Selection of Floodability (Depth of Flooding) Samples

Sl	Name of the Union	Area of the Union in hectare (N_i)	No. of Samples (n_i)
1	Basudevpur	1896	03
2	Char Ashariadaha	3646	06
3	Deopara	5234	09
4	Gogram	7026	11
5	Matikata	3956	06
6	Rishikul	5933	10
7	Godagari	3830	06
8	Mohanpur	9647	16
9	Pakri	6395	11
Total =		47, 563	78

Where,

N = 47563 hectare

n = 78

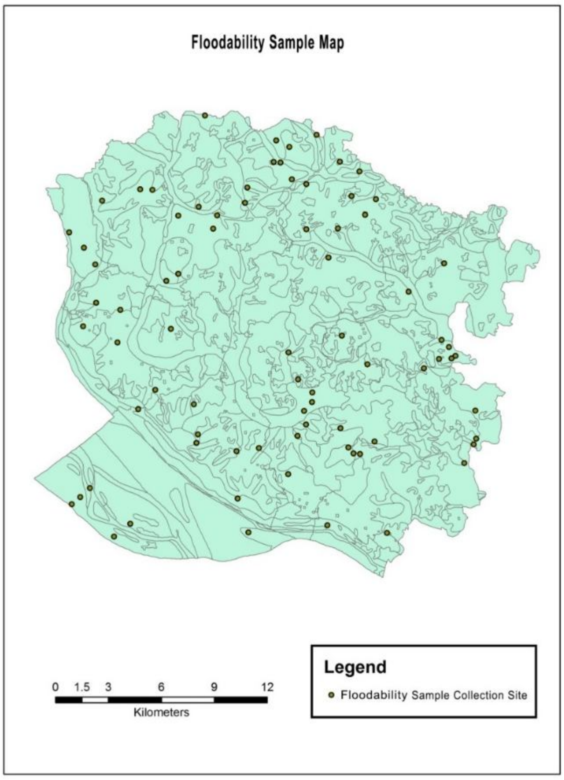

Figure 2.10. Floodability (Depth of Flooding) Sample Map

2.6 Land Suitability Model Output Verification Sampling

The study area Godagari upazila consists of 390 revenue villages. The estimating formula for sample size for land suitability model output verification is,

$$n_0 = \frac{z^2 pq}{d^2} = \frac{(1.64)^2(0.6)(0.4)}{(0.1)^2} = 64.55 \approx 65$$

Where,

n_0 = desired sample size

z = standard normal deviate set at 1.64, which corresponds to the 90% confidence level

p = assumed proportion in the target population estimated to have model output = 0.6

q = 1- p (q is the proportion not having model output)

d = degree of accuracy desired in the estimated proportion = .10

Here, N = 390. Hence, our estimate of n is as follows:

$$n = \frac{N.n_0}{N + n_0} = \frac{390 \times 65}{390 + 65} = 55.71 \approx 56$$

Thus, 56 spots have been selected. These 56 spots have been selected from 9 unions based on stratified sampling with probability proportional to size (PPS) sampling. It is noted that each of the unions is treated as a stratum. The sample size from 9 unions is determined by using the following formula.

$$n_i = \left(\frac{n}{N}\right) N_i$$

Table 2.8. Land Suitability Model Output Verification Sampling

Union No	Union Name	No. of *Mauza* (N_i)	n_i
1	Basudebpur	19	03
2	Char Ashariadaha	9	01
3	Deopara	35	05
4	Gogram	63	09
5	Matikata	54	08
6	Rishikul	36	05
7	Godagari	53	08
8	Mohanpur	83	12
9	Pakri	38	05
Total	**09**	**390**	**56**
N	390		
n	56		

The abovementioned union wise proportions of 56 sites have been selected randomly from concerned unions. Land suitability model output verification points and map are presented in figure 5.49 (chapter five).

2.7 Classified Image Verification Sampling

The study area has 390 revenue villages and the estimating formula for sample size for classified image verification are sample size determination formula and probability proportional to size (PPS) sampling formula which are mentioned above in 2.6.

Thus, 56 spots have been selected. These 56 spots have been selected from 9 unions based on stratified sampling with probability proportional to size (PPS) sampling. It is noted that each of the unions is treated as a stratum. The sample sizes from 9 unions are as follows.

Table 2.9. Classified Image Verification Sampling

Union No	**Union Name**	**No. of *Mauza* (N_i)**	**n_i**
1	Basudebpur	19	03
2	Char Ashariadaha	9	01
3	Deopara	35	05
4	Gogram	63	09
5	Matikata	54	08
6	Rishikul	36	05
7	Godagari	53	08
8	Mohanpur	83	12
9	Pakri	38	05
Total	**09**	**390**	**56**
N	390		
n	56		

The abovementioned union wise proportions of 56 sites for classified image verification have been selected randomly from concerned unions.

2.8 Data Analysis and Interpretation

2.8.1 GIS Analysis

Union wise attributes data of soil, irrigation water, climate, topography, floodability, and accessibility were collected. The soil attributes are texture, moisture, pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron. Irrigation water attributes are pH, EC, and temperature, climate attributes are temperature, and rainfall, topography attributes are land type, and drainage, floodability attributes are depth and duration of flooding and accessibility attributes are distance from highway, and distance from local market.

Collected data were created shape files and converted into raster. The raster value is reclassified to weighted value as 1 to 10-point scale for classes or degrees of suitability. The reclassified values and percentage of influences were selected according to expert opinion and used in reclassify raster. Twenty-one reclassified raster images were weighted overlay to generate 6 themes on the basis of expert given percentage of influences. Six themes were further weighted overlay to produce overall land suitability raster image on the basis of percentage of influence.

To generate crops wise 8 suitability maps, same 21 reclassified raster images were used and model were run separately for each crops. Twenty-one reclassified raster images were weighted overlay on the basis of percentage of influences to produce crops wise 6 themes. Crops wise 6 themes were second time weighted overlay following experts given percentage of influences. Thus, overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation suitability maps were produced. The 5 suitability classes and values in land suitability maps are Very Suitable = 9-10, Suitable = 7-8, Moderately Suitable = 5-6, Marginally Suitable = 3-4, and Not Suitable = 1-2.

ArcGIS 10.1 application by ESRI (Environmental Systems Research Institute Inc. of USA) is used for this analysis. The techniques that employed in analysis procedures are the spatial model creation and flow and weighted overlay. Distance from highway and distance from local markets of accessibility were measured using Euclidian distance method creating multiple rings buffer. BTM (Bangladesh Transverse Mercator) and WGS (World Geodetic System)-1984 were used in map projection. Details of model, workflows, reclassify values and percentages of influences are described in chapter four titled ‘Land Suitability Analysis Model’.

2.8.2 Weighted Arithmetic Mean Calculation of Reclassified Value and Percentage of Influence of Opinion Survey

The weighted mean of a set of n numbers x_1, x_2,………., x_n, whose relative importance is measured by a corresponding set of weights w_1, w_2, …….., w_n is given by the formula,

$$\bar{x}_w = \frac{\sum w_i x_i}{\sum w_i}$$

For weighted value and percentage of influence value of 14 experts are x_1, x_2, x_3…, x_{14}. So, the weighted mean of 14 experts is,

$$\bar{x}_w = \frac{\sum_{i=1}^{14} w_i x_i}{\sum_{i=1}^{14} w_i}$$

2.8.3 SPSS and R Program

IBM SPSS (Statistical Package for the Social Sciences) software (version 20) and R program (version 3.2.0) were used for statistical analyses of data and hypothesis testing.

2.8.4 Data Analysis of Economic Viability

SPSS 20 was used to analyze data. Descriptive statistics namely, mean, maximum, minimum, standard deviation, total cost, total revenue, net revenue (net return) and benefit-cost ratio were used to analyze the data.

2.8.5 Remote Sensing Data (Image) Analysis

Remote sensing is one of the modern techniques to analyze land use/land cover of a certain area. Land use/land cover can be calculated using multiple techniques such as supervised classification, unsupervised classification, Normalize Difference Vegetation Index (NDVI) etc. However, NDVI was employed in this study considering its appropriateness. Remote sensing image classification refers to the task of extracting information from a multispectral raster image collected by sensors. ERDAS (Earth Resources Data Analysis System) Imagine 2014 software is used in this study for remote sensing multispectral satellite image analysis. Data were collected from United State Geological Survey (USGS) website called USGS Global Visualization Viewer (glovis.usgs.gov). Satellite data of 1977, 1988, 1996, 2008, and 2016 were collected from different sensors. The catalogues of data are shown in tables 2.10 and 2.11.

NDVI is a method to analyze land use/land cover of a certain area. There are two ways to calculate NDVI value from a satellite image. One is automated (Software in built) and another is Manual. Manual NDVI is employed in this study as manual NDVI provides result that is more accurate because specific metadata are used to calculate digital number (DN) value to radiance value and again metadata are used to calculate radiance to reflectance value. Following equation is used to calculate NDVI values.

$$\text{NDVI} = \frac{\text{NIR-R}}{\text{NIR+R}}$$

Where,

NDVI = Normalized Difference Vegetation Index

NIR = Near-Infrared

R = Red

Radiance is the flux of radiation emitted per unit solid angle in a given direction by a unit area of a source. Satellite images preserve this electromagnetic radiation energy and provide as digital number (DN) value. So, radiance value is very important for advance analysis of an image. The following equation is used to calculate radiance from digital number value. All necessary values for radiance calculation are provided in table 2.10.

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)(Q_{cal} - Q_{calmin}) + LMIN_\lambda$$

Where,

L_λ = Spectral radiance at the sensor's aperture [W/ (m^2 sr µm)]

Q_{cal} = Quantized calibrated pixel value [DN]

Q_{calmin} = Minimum quantized calibrated pixel value corresponding to $LMIN_\lambda$ [DN]

Q_{calmax} = Maximum quantized calibrated pixel value corresponding to $LMAX_\lambda$ [DN]

$LMIN_\lambda$ = Spectral at-sensor radiance that is scaled to Qcalmin [W/ (m^2 sr µm)]

$LMAX_\lambda$ = Spectral at-sensor radiance that is scaled to Qcalmax [W/ (m^2 sr µm)]

Table 2.10. Values for Radiance Calculation for Landsat Images

Sensor	Mission	Year	Month	Day	Band	Spectral Range	LMAX$_\lambda$	LMIN$_\lambda$	Q_{calmax}	Q_{calmin}	Q_{cal}
MSS	2	1977	January	5	5	0.607–0.710	168.7	-0.6	255	1	Band_5
MSS	2	1977	January	5	6	0.697–0.802	143.6	-2.4	255	1	Band_6
TM	5	1988	January	9	3	0.626–0.693	264	-1.17	255	1	Band_3
TM	5	1988	January	9	4	0.776–0.904	221	-1.51	255	1	Band_4
TM	5	1996	January	31	3	0.626–0.693	264	-1.17	255	1	Band_3
TM	5	1996	January	31	4	0.776–0.904	221	-1.51	255	1	Band_4
TM	5	2008	January	16	3	0.626–0.693	264	-1.17	255	1	Band_3
TM	5	2008	January	16	4	0.776–0.904	221	-1.51	255	1	Band_4
OLI	8	2016	February	23	4	0.64–0.67	618.01416	-51.03581	65535	1	Band_4
OLI	8	2016	February	23	5	0.85–0.88	378.19385	-31.23137	65535	1	Band_5

Source: Chander, Markham and Helder, 2009 (P. 895-897) and 5 Images

ERDAS Imagine model maker tools have been used to formulate the radiance conversion. The model maker conditional algorithm is shown below in figure 2.11.

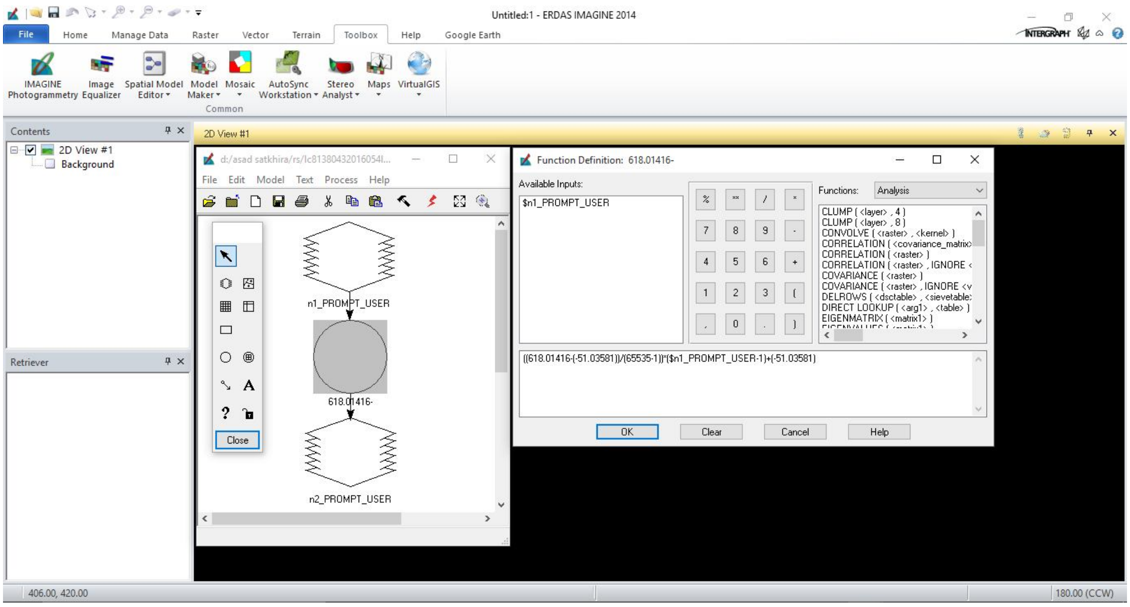

Figure 2.11. Model Maker for Digital Number to Radiance Conversion

Reflectance is the measure of the proportion of light or other radiation striking a surface that is reflected off it. For earth object classification, reflectance value is very necessary. The conversion formula of spectral radiance to reflectance is mentioned below. All necessary values for reflectance calculation are given below in table 2.11.

$$\rho_\lambda = \frac{\pi . L_\lambda . d^2}{ESUN_\lambda . \cos\theta_s}$$

Where,

ρ_λ = Planetary TOA reflectance [unit less]

π = Mathematical constant equal to ~3.14159 [unit less]

L_λ = Spectral radiance at the sensor's aperture [W/ (m^2 sr μm)]

d = Earth–Sun distance [astronomical units]

$ESUN_\lambda$ = Mean exoatmospheric solar irradiance [W/ (m^2 μm)]

θ_s = Solar zenith angle [degrees]

Table 2.11. Values for Reflectance Calculation for Landsat Image

Sensor	Mission	Year	Month	Day	Band	Spectral Range	π	L_λ	d^2	$ESUN_\lambda$	$\cos\theta_s$
MSS	2	1977	January	5	5	0.607–0.710	3.1416	Radiance_B5	0.9832925	1539	30.2309759
MSS	2	1977	January	5	6	0.697–0.802	3.1416	Radiance_B6	0.9832925	1268	30.2309759
TM	5	1988	January	9	3	0.626–0.693	3.1416	Radiance_B3	0.9833559	1536	33.5528868
TM	5	1988	January	9	4	0.776–0.904	3.1416	Radiance_B4	0.9833559	1031	33.5528868
TM	5	1996	January	31	3	0.626–0.693	3.1416	Radiance_B3	0.9851372	1536	32.3538711
TM	5	1996	January	31	4	0.776–0.904	3.1416	Radiance_B4	0.9851372	1031	32.3538711
TM	5	2008	January	16	3	0.626–0.693	3.1416	Radiance_B3	0.98371	1536	37.0314932
TM	5	2008	January	16	4	0.776–0.904	3.1416	Radiance_B4	0.98371	1031	37.0314932
OLI	8	2016	February	23	4	0.64–0.67	3.1416	Radiance_B4	0.9892442	1603	46.7884173
OLI	8	2016	February	23	5	0.85–0.88	3.1416	Radiance_B5	0.9892442	972.6	46.7884173

Source: Chander, Markham and Helder, 2009 (P. 895-897) and 5 Images

For converting radiance value to reflectance value ERDAS Imagine model maker interface is used which is shown above in figure 2.11.

NDVI is a modern method for land use/cover classification using satellite imagery. Mainly vegetation detection is the main purpose for NDVI but it is also used to classify other land use/cover features according to its value. This manual NDVI are also done with modeling using ERDAS Imagine software application. The model is shown below in figure 2.12.

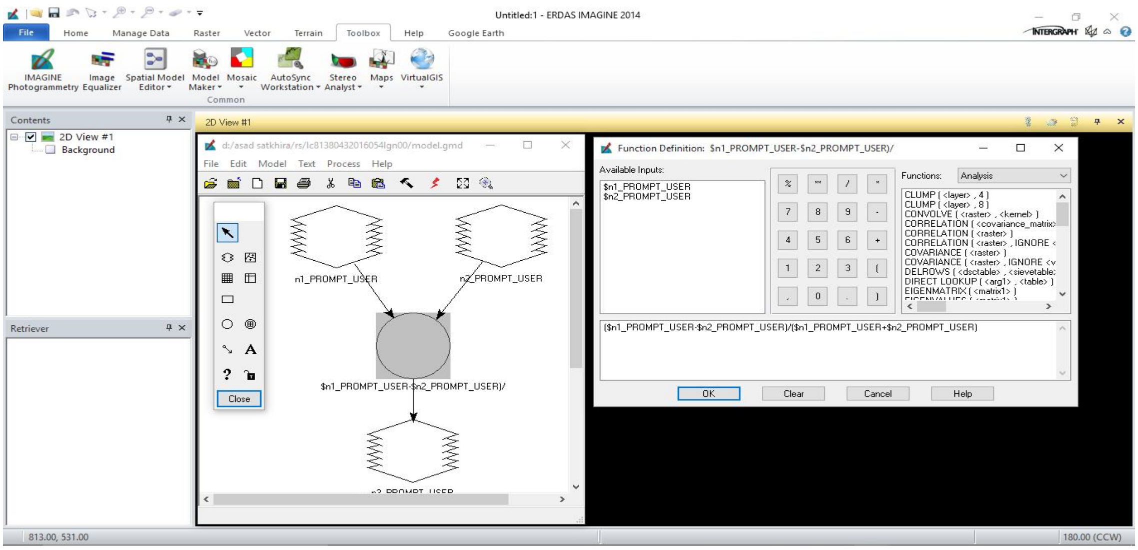

Figure 2.12. Manual NDVI Model for Landsat Images

NDVI value ranges between +1 to -1. +1 is healthy vegetation and -1 is deep water. The value indicates different land use/cover on the earth surface within this range. The NDVI class values used for this study are given in table 2.12.

Table 2.12. NDVI Class Value for Land Use/Land Cover Classes

Class Name	Value for Landsat 2 (MSS)	Value for Landsat 5 (TM)	Value for Landsat 8 (OLI)
Medium Water	-0.17 – -0.30	-0.14 – -0.27	-0.10 – -0.25
Shallow Water	0.05 – - 0.17	0.15 – -0.14	0.17 – -0.10
Sand Bar/Char Land	0.02 – 0.12	0.04 – 0.15	0.04 – 0.17
Barren Land	0.12 – 0.25	0.15 – 0.27	0.17 – 0.28
Agricultural Land	0.25 – 0.30	0.27 – 0.35	0.28 – 0.37
Sparse Vegetation	0.30 – 0.40	0.35 – 0.58	0.37 – 0.65
Moderate Vegetation	0.40 – 0.60	0.58 – 0.70	0.65 – 0.75

Sources: Based on Various Published Inoframtion and Field Observation.

The land use/cover classification was done according to the model builder process. First input raster image (single band) in the conditional class then finally output a thematic color layer for land cover classes. Noise and haze correction were done and cloud correction were not needed because virtually cloud free images were taken. Images were classified into 7 classes namely, agricultural land, sparse vegetation, moderate vegetation, barren land, sand bar, shallow water, and medium water.

2.8.6 Data Analysis of Farmers' Perception

Data of farmers perception were analyzed using SPSS 20. Descriptive statistics namely, frequencies, percentage scores, cumulative percentage, mean scores, standard deviation, coefficient of variation (CV), weighted mean, correlation, analysis of variance (ANOVA), and multiple regression were used to analyze the data.

2.9 Multi-Criteria Evaluation (MCE)

Multi-criteria evaluation approach is an important and spatial support tool that focuses on specifying and creating a comprehensive set of evaluation criteria that incorporates the criteria pertaining to the decision. A scoring method of 1 to 10 is chosen; 9-10 for highly suitable, 7-8 for suitable, 5-6 for moderate suitable, 3-4 for marginally suitable, and 1-2 for not suitable for agricultural development in Godagari upazila of Rajshahi district. In this stage, the decision makers' preferences with respect to the evaluation criteria are incorporated into the decision model. These are assessed in terms of the relative importance (weights) assigned to the evaluation that expresses the importance of each criteria relative to other criteria. In the final stage, the criteria layers and their weights have been integrated to provide an overall assessment of the alternatives in which weights and scores of each of the layers are used combined and include a description of the best alternative or group of alternatives.

Group discussions for final weight consensus procedures have been followed to lessen the subjectivity and to reach a consensus for weights. The MCE procedure requires that the weights sum to 100, when the weights are multiplied by the 6 sub-models (score from 1 to 100), the overall and composite land suitability maps of 8 crops for sustainable agriculture retains within the 1 to 10 suitability score range. In the light of FAO Framework for Land Evaluation, 1976, the study area Godagari upazila of Rajshahi district is divided into 5 classes: (1) S1: Highly Suitable; (2) S2: Suitable; (3) S3: Moderately Suitable; (4) S4: Marginally Suitable; and (5) N1: Not Suitable on the basis of the requirement for the agriculture development of the study area. Brammer also followed five suitability ratings for crops with respect to crop suitability assessment in Bangladesh; (1) Very Suitable: >80 per cent of MAY (Maximum Attainable Yield) (2) Suitable: 60-80 per cent MAY (3) Moderately Suitable: 40-60 per cent MAY (4) Poorly Suitable: 20-40 per cent MAY, and (5) Not Suitable: < 20 per cent MAY.[13] Bangladesh Agricultural Research Council (BARC) also followed abovementioned five classes for different studies such as land suitability assessment and crop zoning of Bangladesh.[14] The present study is based on six base layers viz., soil, irrigation water, climate, topography, floodability, and accessibility attributes (thematic maps) which are developed for agricultural crops. The weighted value and percentage of influence score for suitability rating of each level of a factor are determined by judgments of 14 experts.

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[13]Hugh Brammer, *Agricultural Development Possibilities in Bangladesh* (Dhaka: The University Press Limited, 1997), 340.

[14] Sk. Ghulam Hussain, M. Khalequzzaman A Chowdhury and M. Abeed Hossain Chowdhury, *Land Suitability Assessment and Crop Zoning of Bangladesh* (Dhaka: Bangladesh Agriculture Research Council, 2012), 29.

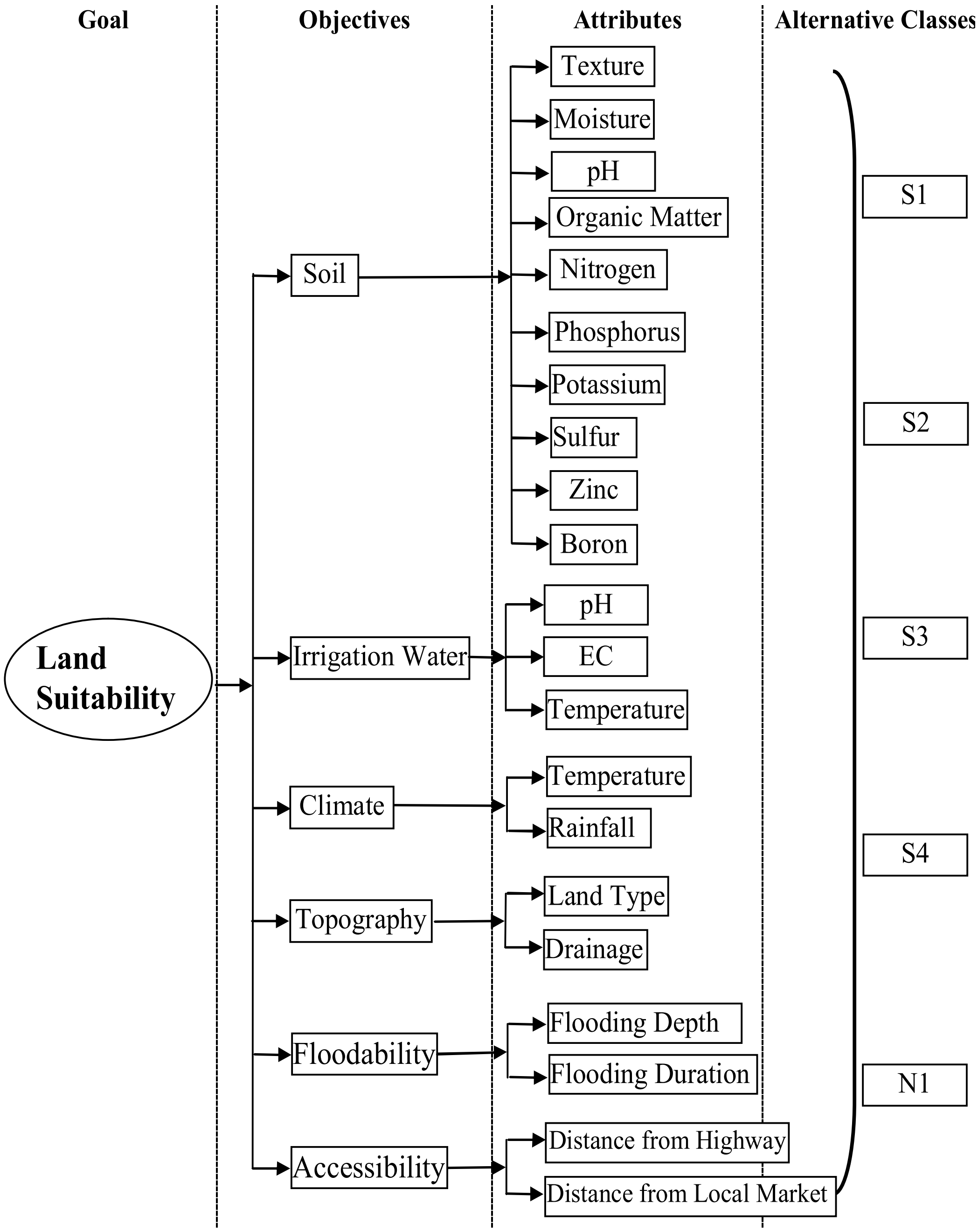

Figure 2.13. Hierarchical Organization of the Criteria Considered for the Study

2.10 Integration of Land Suitability Sub-Models into Model

The model structure for selecting the suitable sites for different crops in the study area are built based on hierarchical structures. The land suitability analysis for agriculture site selection for overall land suitability and rice, wheat, maize, potato, lentil, mustard, onion, and chili crops of Godagari upazila in Rajshahi district as a hierarchical organization is presented below in Figure 2.14.

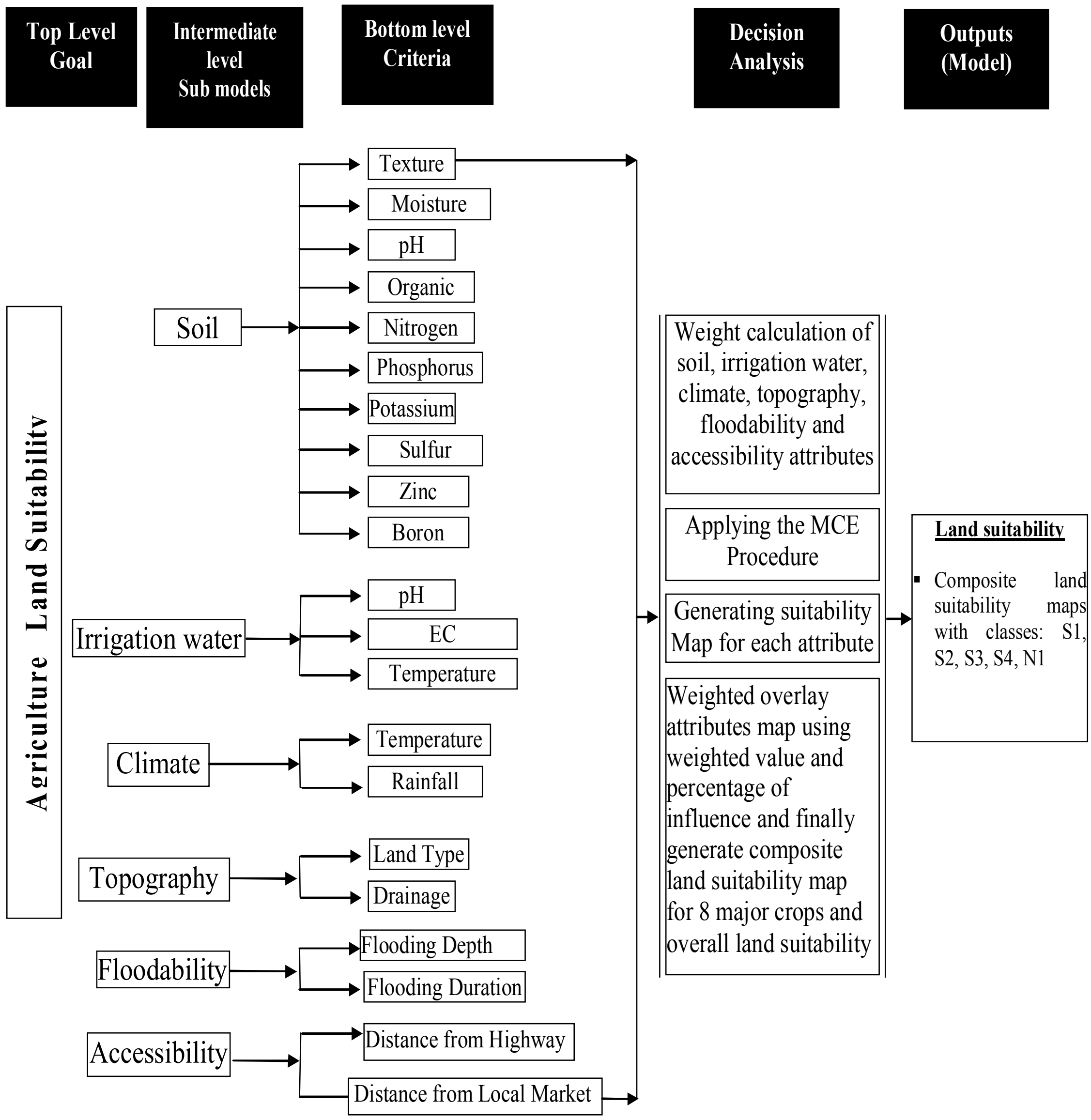

Figure 2.14. **Multi-Criteria Evaluation to Land Suitability Analysis for Sustainable Agriculture Development of Rajshahi District**

A scoring classification of 1 to 10 is chosen for developing agriculture; 9-10 for highly suitable in the study area. The decision makers' preferences with respect to the evaluation criteria are incorporated into the decision model. Last of all, the criteria layers and their weights are integrated to make an overall assessment to generate composite land suitability map for overall land suitability and rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation which are shown above in figure 2.14.

2.11 Analysis of Economic Viability of Major Crops and Cropping Patterns

One of the main means to assess the profitability of the proposed changes of crops cultivation in land is a comparison between the benefits obtained and the costs incurred to obtain them.[15] In this study, economic viability of presently cultivated major crops and cropping patterns in the study area and proposed cropping patterns taking into account the land suitability have been measured by using Net Return Analysis and Benefit-Cost Ratio (BCR) techniques. Positive net returns indicate that the cropping patterns according to land suitability are economically viable. BCR also indicates the same result where BCR is greater than 1.

Benefit-cost analysis (BCA) is a technique for evaluation through comparing the economic benefits with economic costs of an activity. It is used to evaluate the economic merit of proposed changes of cultivation of crops. Decision-making may be defined as the process of choosing between alternative courses of action.[16] BCA works by measuring and valuing the benefits and costs of each. The net returns are benefits minus costs of presently cultivated crops and cropping patterns and land suitability based cropping patterns be calculated and compared. Net return (NR) is defined as the sum of all benefits minus the sum of all costs, which provide an absolute measure of benefits. Cost-benefit analyses of the study area have been carried out only for the major crops and cropping patterns. Computation procedures of economic viability analysis are described below.

2.12 Net Return Analysis

Differences in degrees of suitability of farm are determined mainly by the relationship between benefits and costs.[17] In a quantitative classification, both benefits and costs are to be expressed in monetary forms. It is based on how costs respond to changes in output levels.[18] In this study, the following profit determining model has been employed

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[15] Food and Agricultural Organization, "A Framework for Land Evaluation," *FAO Soils Bulletin* 32 (Rome: FAO of United Nations, 1976), 38.

[16] Ralph S. Polimeni et al., *Cost Accounting: Concepts and Applications for Managerial Decision Making* (New Delhi: Tata McGraw-Hill Publishing Company Limited, 1991), 600.

[17] Food and Agricultural Organization, "A Framework for Land Evaluation," *FAO Soils Bulletin* 32 (1976), 16.

[18] B. M. Lal Nigam and I. C. Jain, *Cost Accounting: Principles and Practice* (New Delhi: Prentice-Hall of India Private Limited, 2000), 967.

to analyze farmers' profitability in producing presently cultivated crops and cropping patterns and land suitability based proposed cropping patterns. Gross revenue and net return techniques have been used to measure the economic viability of agricultural crops production in many studies, such as Rahman and Hossain,[19] and Islam.[20] This model is selected because it is simple and a widely used procedure to determine profitability. The proposed model is given below.

NR= (GR-TC)

GM= (GR-TVC)

Where,

$$GR = \sum_{i=1}^{n} P_{q_i} Q_i$$

$$TC = TVC+TFC$$

$$TVC = \sum_{i=1}^{n} P_{xi} X_i$$

GM = gross margin from i^{th} crop of per 33 decimal land

NR = Net return (profit) from i^{th} crop

GR = Gross return from i^{th} crop

TC = Total cost of i^{th} crop

TVC = Total variable cost

TFC = Total fixed cost (land rent)

P_{qi} = Unit price of the i^{th} main crop and related by-product

Q_i= Quantity of the i^{th} main crop and related by-product

P_{xi}= Unit cost of the i^{th} input

X_i = Quantity of the i^{th} input

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19 Zubaidur Rahman and Md. Elias Hossain, "Economic Viability and Resource Use Efficiency of Rice Production in Naogaon District," *Society and Progress* 1 (2015), 159.

20 Mohammad Monirul Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2015), 88.

Land cost is included in total cost in this study whether it is farmers own land or rented land to see the actual net returns coming from crops cultivation in the study area. Total cost and net returns were analyzed for presently cultivated crops and cropping patterns and land suitability based proposed cropping patterns. Gross return is computed on the basis of actual prices at which farmers sold their crops and by-products. The segments used for calculating total costs and total revenues are itemized in the questionnaire and are annexed in appendices (appendix-8).

2.13 Benefit-Cost Ratios (BCR)

Benefit-cost ratio is also a good technique to assess the economic viability. Undiscounted BCR (Benefit-Cost Ratio) technique is used in this study to assess and compare the economic viability of presently cultivated crops and cropping patterns and economic viability of land suitability based proposed cropping patterns suggested for cultivation. The formula is mentioned below.

$$BCR=\frac{TR}{TC}$$

Where,

BCR= Benefit cost ratio over total cost

TR = Total revenues

TC = Total costs

If the value of BCR of a firm is greater than one (BCR>1), the cultivated crops and cropping patterns are considered as profitable cultivation.

2.14 Citation and English

The researcher has followed The Chicago Citation Style for citation of notes and bibliography (NB) in this study. Chicago citation style is the only accepted style at the Institute of Bangladesh Studies, University of Rajshahi due to footnote system. American English is mainly followed in writing.

2.15 Conclusion

Methods include process and techniques in which various steps of data collection and the analytical techniques are explained. An endeavor is made in this chapter to portray the various aspects of the research methods adopted for the present study. The data collection and analysis tools and techniques were set as deemed appropriate for this research to fulfill the objectives. But in some cases because of social, educational and cultural settings and lack of awareness of the study population, and lack of technical sophistication for land suitability analysis, image classification, and other analyses, validity and reliability of data may have some lackings to perfection, which were out of control of the researcher. However, utmost efforts have been taken to minimize the abovementioned effects on the final result of the study.

Chapter Three
Land Characteristics and Land Suitability Variables

3.1 Introduction

The present agricultural patterns and future development plans for sustainable agriculture must be understood and formulated in the light of the prevailing physical and socio-economic conditions. Many agricultural geographers hold similar views such as Sing and Dhillon.[1] To make agriculture investigation scientifically viable it needs to integrate basic sets of relationships viz., the soil and water resources, climate, topography, inundation, market accessibility, demands in market and the types and number of crops that can be grown etc. Land characteristics and land suitability variables are analyzed in this study integrating six vital components which are soil, irrigation water, climate, topography, floodability, and accessibility of the study area.

3.2 Hypotheses

Soil, irrigation water, climate, and accessibility attributes regarding land characteristics and land suitability variables are quantitative data and topography and floodability attributes are qualitative data. In case of quantitative data, hypotheses formulation and testing are considered important in 'Statistics' to see the nature and dispersion of data. In view of above, to compare population mean with required value for the analysis of data for land suitability analysis is deemed necessary for this study. Hence, the following hypotheses are formulated to test soil, irrigation water, climate, and accessibility attributes for the study area with a view to make comparison with optimum value in the light of the literature review, problem statement and objectives. It may be mentioned here that topography and floodability data are qualitative, that is why hypotheses formulation and testing were not considered appropriate.

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[1] Jasbir Singh and S. S. Dhillon, *Agricultural Geography* (New Delhi: Tata-McGraw-Hill Publishing Company Limited, 1984), 44.

Hypotheses for Soil Attributes

Hypothesis 3: H_0 : Population mean of pH of soil = 6.95

H_1 : Population mean of pH of soil ≠ 6.95

Hypothesis 4: H_0 : Population mean of organic matter (%) of soil = 4.50

H_1 : Population mean of organic matter (%) of soil ≠ 4.50

Hypothesis 5: H_0 : Population mean of nitrogen (%) of soil = 0.315

H_1 : Population mean of nitrogen (%) of soil ≠ 0.315

Hypothesis 6: H_0 : Population mean of phosphorus (μg/g) of soil = 26.255

H_1 : Population mean of phosphorus (μg/g) of soil ≠ 26.255

Hypothesis 7: H_0 : Population mean of potassium (meq/100g) of soil = 0.315

H_1 : Population mean of potassium (meq/100g) of soil ≠ 0.315

Hypothesis 8: H_0 : Population mean of sulfur (μg/g) of soil = 26.255

H_1 : Population mean of sulfur (μg/g) of soil ≠ 26.255

Hypothesis 9: H_0 : Population mean of zinc (μg/g) of soil = 1.575

H_1 : Population mean of zinc (μg/g) of soil ≠ 1.575

Hypothesis 10: H_0 : Population mean of boron (μg/g) of soil = 0.525

H_1 : Population mean of boron (μg/g) of soil ≠ 0.525

Hypotheses for Irrigation Water Attributes

Hypothesis 1: H_0 : Population mean of pH of irrigation water = 7.25

H_1 : Population mean of pH of irrigation water ≠ 7.25

Hypothesis 2: H_0 : Population mean of EC (mmhos/cm) of irrigation water = 350

H_1 : Population mean of EC (mmhos/cm) of irrigation water ≠ 350

Hypothesis 3: H_0 : Population mean of temperature (^{0}c) of irrigation water = 25

H_1 : Population mean of temperature (^{0}c) of irrigation water ≠ 25

Hypotheses for Climate Attributes

Hypothesis 1: H_0: Population mean of temperature = 25.4 ^{0}c

H_1: Population mean of temperature ≠ 25.4 ^{0}c

Hypothesis 2: H_0: Population mean of rainfall = 2401 mm

H_1: Population mean of rainfall ≠ 2401mm

Hypotheses for Accessibility Attributes

Hypothesis 1: H_0: Population mean of distance from highway = ≤ 0.5 km

H_1: Population mean of distance from highway ≠ ≤ 0.5 km

Hypothesis 2: H_0: Population mean of distance from local market = ≤ 2 km

H_1: Population mean of distance from local market ≠ ≤ 2 km

3.3 Soil

Soil is a mixture of mineral and organic matter which in presence of air, moisture and suitable temperatures can support plant growth. It is a thin layer of the earth's crust that serves as a natural medium for the growth of plants.[2] The study area lies in the Barind Tract which is a distinct physiographic unit of Bangladesh having poorly drained grey soil predominance.[3] The essential 16 elements of soils are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, copper, boron, molybdenum, and chlorine are known to be essential for plants normal growth and development. Among 16 essential elements, plants take up all the 13 elements from soil except carbon, hydrogen, and oxygen.[4]

Texture is the relative proportion of different particle sizes (sand, silt, clay) within soil material. Silt loam and loam soils have the good moisture holding capacity which is good for crops. Moisture properties together with climate and topography are important in determining which crops can be grown and how well they grow. Soil pH is the most important factor controlling nutrient availability in soils.[5] Generally, availability of macronutrients increases as soil pH increases and reverse is true for micronutrients. In most cases, pH 6-7 is optimum for adequate availability of nutrients in soil.

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[2] Gopal Chandra De, *Fundamentals of Agronomy* (New Delhi: Oxford and IBH Publishing Company Private Limited, 2002), 87.

[3] Hugh Brammer, *Agro ecological Aspects of Agricultural Research in Bangladesh* (Dhaka: The University Press Limited, 2000), 45.

[4] Bangladesh Agricultural Research Council, *Fertilizer Recommendation Guide-2012* (Dhaka: Bangladesh Agriculture Research Council, 2012), 3.

[5] Ibid., 6.

For optimum plant growth, nutrients must be available as solutes in the soil water, in adequate and balanced amounts, and in a form, which is accessible to the plant root system. Thus, a portion of the total content becomes available for plant uptake depending on some soil conditions, viz. soil pH, soil texture, organic matter content, nutrient interaction etc. [6]

The present study is to analyze the land suitability for sustainable agricultural development in Rajshahi district based on 10 attributes of soil along with irrigation water, climate, topography, floodability, and accessibility. To do this, 78 soil samples have been analyzed from 78 *mauza*s of the study area. But, the nature of soil attributes is that values of attributes of one sample are different from another sample. For example, organic matter (percentage) in Char Ashariadaha union, value of one sample is 0.9, another sample value is 2.06, but midpoint of optimum value is 4.50. Due to this nature of data, it needs to test attribute values of all samples with optimum values. Parametric tests are more powerful because their data are derived from interval and ratio level measurements.[7]

In the light of tests of normality and sample size (>30), z/t- test is employed to compare the population mean with optimum value of soil attributes for crops production. *z*- test is commonly used to test the hypothesis that population mean μ is equal to some pre-assigned value μ_0 or hypothesized mean for the population in case of large sample.[8] Results of z/t tests are shown below with analysis of 8 attributes (except qualitative attribute: texture and moisture) of 78 soil samples of the study area followed by tests of normality.

Table 3.1. Tests of Normality for pH

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
pH	.052	78	.200(*)

* This is a lower bound of the true significance.
a Lilliefors Significance Correction

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[6] Ibid., 5.

[7] M. Nurul Islam, *An Introduction to Research Methods: A Handbook for Business & Health Research* (Dhaka: Mullick & Brothers, 2008), 315.

[8] Islam, *An Introduction to Research Methods: A Handbook for Business & Health Research,* 316 and C. R. Kothari, *Research Methodology: Methods and Techniques,* 2nd ed. (New Delhi: New Age International Private Limited, 1999), 196.

It is seen from the above table of tests of normality that the significance level in the test of Kolmogorov-Smirnov is greater than 0.05. So, the null hypothesis is accepted which means that distribution of data fulfils normality condition. Hence, the data fall in the category of z- test.

Table 3.2. Calculation Table for pH

pH	N	Mean ($\vec{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	7.0615	.56963	6.95

Hypothesis 1: H_0: $\mu = 6.95$

H_1: $\mu \neq 6.95$

Under null hypothesis: The test statistic is,

$$z = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

z = 1.729

Comment: The calculated value of z is less than 1.96. So, we may accept our null hypothesis at 5 % level of significance and conclude that there is no significant difference of pH value from optimum value. Therefore, pH value of soil is suitable for sustainable agriculture in the study area.

Table 3.3. Tests of Normality for Organic Matter

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Org. Matter	.125	78	.004

a Lilliefors Significance Correction

The above table of tests of normality shows that the significance level in the test (Kolmogorov-Smirnov) is less than 0.05. Hence, the null hypothesis is rejected which indicates that distribution of data does not fulfill normality condition. Therefore, the data lie in the category of t- test.

Table 3.4. Calculation Table for Organic Matter (%)

Organic Matter %	N	Mean($\vec{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	1.5251	.41267	4.50

Hypothesis 2: H_0: $\mu = 4.50$

H_1: $\mu \neq 4.50$

Under null hypothesis: The test statistic is,

$$t = -63.668 \quad |t| = |-63.668| \Rightarrow |t| = 63.668$$

Comment: The computed value of $|t|$ is greater than 1.96. So, we may reject our null hypothesis at 5 % level of significance and conclude that there is significant difference of organic matter (%) value from the test value. Consequently, we may opine that organic matter of soil is not suitable for sustainable agriculture in the study area.

Table 3.5. Tests of Normality for Nitrogen

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Nitrogen	.173	78	.000

a Lilliefors Significance Correction

From the above table of tests of normality, we get the results that the significance level of the test (Kolmogorov-Smirnov) is less than 0.05. So, we cannot accept the null hypothesis following the non-fulfillment of normality condition of distribution of data. For this, the data require t- test.

Table 3.6. Calculation Table for Nitrogen

Nitrogen	N	Mean ($\bar{x}$)	Std. Deviation(s)	Test Values (μ_0)
	78	.0776	.02001	0.315

Hypothesis 3: H_0: $\mu = 0.315$

H_1: $\mu \neq 0.315$

Under null hypothesis: The test statistic is,

$$t = -104.786 \quad |t| = |-104.786| \Rightarrow |t| = 104.786$$

Comment: The calculated value of $|t|$ is greater than 1.96. We thus reject our null hypothesis at 5 % level of significance and conclude that there is significant difference of nitrogen value from optimum value. Therefore, study areas nitrogen status of soil is not suitable for sustainable agriculture.

Table 3.7. Tests of Normality for Phosphorus

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Phosphorus	.146	78	.000

a Lilliefors Significance Correction

It is seen in the table of tests of normality that the significance level in the test of Kolmogorov-Smirnov is less than 0.05. Hence, the null hypothesis is rejected which implies that distribution of data does not fulfill normality condition. Therefore, the data require t- test.

Table 3.8. Calculation Table for Phosphorus

Phosphorus	N	Mean ($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	15.0962	10.52542	26.255

Hypothesis 4: $H_0: \mu = 26.255$

$H_1: \mu \neq 26.255$

Under null hypothesis: The test statistic is,

$$t = -9.363 \quad |t| = |-9.363| \Rightarrow |t| = 9.363$$

Comment: Since the calculated value of $|t|$ is greater than 1.96, we may reject our null hypothesis at 5 % level of significance. So, there is significant difference of phosphorus value from test value. Therefore, study areas phosphorus value of soil is not suitable for sustainable agriculture.

Table 3.9. Tests of Normality for Potassium

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Potassium	.088	78	.200(*)

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

From the above table of tests of normality, it is evident that the significance level in the above test is greater than 0.05. So, the null hypothesis is accepted which means that distribution of data fulfills normality condition. Hence, the data fall in the category of z- test.

Table 3.10. Calculation Table for Potassium

Potassium	N	Mean ($\bar{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	.2464	.09539	0.315

Hypothesis 5: $H_0: \mu = 0.315$

$H_1: \mu \neq 0.315$

Under null hypothesis: The test statistic is,

$$z = -6.351 \quad |z| = |-6.351| \Rightarrow |z| = 6.351$$

Comment: Since the calculated value of $|z|$ is greater than 1.96, we can reject the null hypothesis at 5 % level of significance. There are thus sufficient reasons to support that there is significant difference of potassium value from optimum value. Therefore, study areas potassium value of soil is not suitable for sustainable agriculture.

Table 3.11. Tests of Normality for Sulfur

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Sulfur	.194	78	.000

a Lilliefors Significance Correction

It is observed in the above table of tests of normality that the significance level in Kolmogorov-Smirnov test is not greater than 0.05. So, the null hypothesis is rejected which implies that distribution of data does not fulfill normality condition. For this, the data require t- test.

Table 3.12. Calculation Table for Sulfur

Sulfur	N	Mean($\bar{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	12.5867	8.50171	26.25

Hypothesis 6: $H_0: \mu = 26.25$

$H_1: \mu \neq 26.25$

Under null hypothesis: The test statistic is,

$$t = -14.194 \quad |t| = |-14.194| \Rightarrow |t| = 14.194$$

Comment: The computed value of $|t|$ is greater than 1.96. We thus reject our null hypothesis at 5 % level of significance and conclude that the difference between tested value of sulfur and optimum value is significant. So, sulfur value of soil is not suitable for sustainable agriculture.

Table 3.13. Tests of Normality for Zinc

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Zinc	.111	78	.019

a Lilliefors Significance Correction

It is evident in the above table of tests of normality that the significance level in the above test is greater than 0.05. So, we can accept the null hypothesis. It means that distribution of data fulfils normality condition. Hence, the data require z- test.

Table 3.14. Calculation Table for Zinc

Zinc	N	Mean($\vec{x}$)	Std. Deviation(s)	Test Values (μ_0)
	78	76.1872	38.76795	1.575

Hypothesis 12: $H_{0:}\ \mu = 1.575$

$H_{1:}\ \mu \neq 1.575$

Under null hypothesis: The test statistic is,

$$z = 16.997$$

Comment: Since the calculated value of z is greater than 1.96, we may reject our null hypothesis at 5 % level of significance. So, there is significant difference between tested zinc value and optimum value. So, study areas zinc status of soil is not suitable for sustainable agriculture.

Table 3.15. Tests of Normality for Boron

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Boron	.160	78	.000

a Lilliefors Significance Correction

The above table of tests of normality shows that the significance level in the test (Kolmogorov-Smirnov) is less than 0.05. So, the null hypothesis is not accepted which means that distribution of data does not fulfill normality condition. Therefore, the data fall in the category of t- test.

Table 3.16. Calculation Table for Boron

Boron	N	Mean($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	9.9874	6.38538	0.525

Hypothesis 13: $H_0: \mu = 0.525$

$H_1: \mu \neq 0.525$

Under null hypothesis: The test statistic is,

$t = 13.088$

Comment: The calculated value of t is greater than 1.96. We thus reject the null hypothesis at 5 % level of significance. So, the difference between boron value and optimum value is significant. So, boron of soil in the study area is not optimum for sustainable agriculture.

Soil is the most important factor for sustainable agriculture, and crop needs different elements of soil for potential yield. Soil test values would be of no value unless they are positively correlated with crops response.[9] Crops suffer due to deficiency or excess accumulation of elements in the soil. In this backdrop and considering tests of normality and results of z/t tests, soil test results of 78 samples of the study area are presented below with mean value of the study area (upazila) to depict the soil state of the study area.

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[9] Bangladesh Agriculture Research Council, *Fertilizer Recommendation Guide-2012*, 38.

Table 3.17. Soil Test Results of the Study Area

Sl	Union	Y	DD Y	X	DD X	Texture	Moisture	pH	Org. Mat.	Nitr.	Phosp	Potass	Sulfur	Zinc	Boron
1	Basudebpur	24°31′54.6″	24.53183333	88°19′19.7″	88.32213889	Clay	Low	7.4	2.13	0.11	22.28	0.37	41.82	0.92	0.95
2	Basudebpur	24°31′23.5″	24.52319444	88°19′40.5″	88.32791667	Clay	Low	7.15	2.48	0.12	24.67	0.27	28.25	1.25	1.39
3	Basudebpur	24°32′22.6″	24.53961111	88°18′52.4″	88.31455556	Clay	Low	7.45	1.99	0.1	14.7	0.45	17.2	0.98	0.84
4	C. Ashariadaha	24°24′15.6″	24.40433333	88°19′13.0″	88.32027778	Loam	High	7.55	0.9	0.05	6.42	0.23	6.17	0.88	0.11
5	C. Ashariadaha	24°24′02.3″	24.40063889	88°18′57.2″	88.31588889	Loam	Medium	7.6	1.1	0.06	16.06	0.23	6.59	0.68	0.23
6	C. Ashariadaha	24°23′26.3″	24.39063889	88°20′45.1″	88.34586111	Loam	Medium	8.3	1.85	0.09	17.43	0.35	5.42	0.91	0.9
7	C. Ashariadaha	24°23′10.8″	24.38633333	88°24′22.1″	88.40613889	Loam	Medium	8.2	2.34	0.12	4.59	0.4	38.05	0.88	0.48
8	C. Ashariadaha	24°24′32.3″	24.40897222	88°19′30.6″	88.32516667	Loam	Medium	7.9	1.92	0.1	24.34	0.47	7.17	0.35	0.29
9	C. Ashariadaha	24°23′03.1″	24.38419444	88°20′15.1″	88.33752778	Loam	Medium	8.3	2.06	0.1	15.22	0.43	5.77	0.82	0.9
10	Deopara	24°25′52.7″	24.43130556	88°31′16.3″	88.52119444	Clay	Low	8.1	2.06	0.1	8.49	0.38	5.12	1.86	0.26
11	Deopara	24°25′18.3″	24.42175	88°30′59.0″	88.51638889	Loam	Medium	6.85	1.72	0.09	12.07	0.21	3.03	3.17	0.13
12	Deopara	24°26′55.0″	24.44861111	88°31′19.2″	88.522	Clay	Low	7.6	2.26	0.11	21.2	0.26	20.91	0.75	1.21
13	Deopara	24°23′10.0″	24.38611111	88°28′37.0″	88.47694444	Loam	Low	7.35	1.3	0.07	6.31	0.25	13.66	0.99	0.89
14	Deopara	24°23′24.0″	24.39	88°26′47.0″	88.44638889	Loam	High	7.2	2.06	0.1	14.16	0.4	36.94	1.23	0.34
15	Deopara	24°26′02.9″	24.43413889	88°31′20.6″	88.52238889	Clay	Low	8	1.92	0.1	5.33	0.47	9.86	0.95	0.6
16	Deopara	24°25′47.0″	24.42972222	88°27′26.0″	88.45722222	Loam	Low	7.75	1.38	0.07	16.78	0.11	13.19	1.05	0.49
17	Deopara	24°25′58.0″	24.43277778	88°28′14.0″	88.47055556	Loam	Low	7.7	1.17	0.06	13.8	0.15	10.71	1.6	0.9
18	Deopara	24°25′34.9″	24.42636111	88°27′47.5″	88.46319444	Clay	Low	7.6	2.34	0.12	3.98	0.29	33.87	0.53	0.72
19	Gogram	24°26′54.1″	24.44836111	88°26′04.3″	88.43452778	Loam	Low	6.6	1.58	0.08	13.19	0.15	9.25	1.76	0.27
20	Gogram	24°27′10.2″	24.45283333	88°26′18.8″	88.43855556	Clay Loam	Low	6.3	1.17	0.06	4.35	0.28	10.09	1.28	0.68
21	Gogram	24°28′42.0″	24.47833333	88°25′35.7″	88.42658333	Clay Loam	Low	6.4	1.51	0.08	6.77	0.23	9.32	0.93	0.25
22	Gogram	24°26′22.3″	24.43952778	88°27′11.2″	88.45311111	Clay Loam	Low	6.8	1.24	0.06	8.34	0.24	6.28	1.5	0.13
23	Gogram	24°26′08.5″	24.43569444	88°25′52.4″	88.43122222	Clay Loam	Low	6.7	1.92	0.1	23.67	0.19	12.34	1.36	0.12
24	Gogram	24°26′29.0″	24.44138889	88°26′07.9″	88.43552778	Clay Loam	Low	6.6	1.24	0.06	12.28	0.12	6.36	0.85	0.15
25	Gogram	24°27′52.2″	24.4645	88°25′53.3″	88.43147222	Loam	Low	7	1.92	0.1	8.15	0.18	4.36	0.87	0.5

26	Gogram	24°25′45.7″	24.42936111	88°24′41.2″	88.41144444	Clay Loam	Low	6.55	1.85	0.09	8.12	0.12	13.59	0.96	0.5
27	Gogram	24°24′57.7″	24.41602778	88°25′35.3″	88.42647222	Clay Loam	Low	6.45	1.79	0.09	18.98	0.3	30.75	0.98	1.5
28	Gogram	24°25′36.0″	24.42666667	88°27′35.0″	88.45972222	Loam	Low	6.5	1.38	0.07	3.24	0.22	6.32	1.82	0.72
29	Gogram	24°27′28.3″	24.45786111	88°26′19.5″	88.43875	Clay Loam	Low	6.3	2.2	0.11	6.68	0.21	18	0.99	0.14
30	Matikata	24°26′57.2″	24.44922222	88°20′59.6″	88.34988889	Clay Loam	Low	7.9	1.58	0.08	11.86	0.3	13.04	1.77	0.48
31	Matikata	24°26′10.9″	24.43636111	88°22′49.3″	88.38036111	Clay Loam	Low	7.2	1.58	0.08	29.75	0.42	4.53	0.74	0.51
32	Matikata	24°25′40.2″	24.42783333	88°24′00.1″	88.40002778	Clay Loam	Low	7.5	1.1	0.06	51.22	0.35	5.3	0.55	0.49
33	Matikata	24°27′06.4″	24.45177778	88°22′41.9″	88.37830556	Loam	Low	7.05	1.38	0.07	16.13	0.24	16.44	1.01	0.44
34	Matikata	24°24′13.0″	24.40361111	88°24′02.3″	88.40063889	Clay	Low	7.4	2.13	0.11	5.16	0.32	16.71	1.35	0.9
35	Matikata	24°25′55.1″	24.43197222	88°22′46.3″	88.37952778	Loam	Low	7	1.23	0.06	14.46	0.16	17.05	1.36	0.18
36	Rishikul	24°28′35.8″	24.47661111	88°30′42.6″	88.51183333	Clay Loam	Low	7.5	1.65	0.08	37.81	0.17	36.62	1.38	1.89
37	Rishikul	24°30′33.7″	24.50936111	88°29′16.4″	88.48788889	Clay Loam	Low	7.2	1.1	0.06	6.73	0.1	11.93	1.19	0.33
38	Rishikul	24°28′29.9″	24.47497222	88°30′12.4″	88.50344444	Clay Loam	Low	7.4	1.3	0.07	23.5	0.28	16.93	0.92	1.02
39	Rishikul	24°28′12.4″	24.47011111	88°29′44.9″	88.49580556	Loam	Low	7.1	0.93	0.05	5.72	0.16	6.94	0.62	0.93
40	Rishikul	24°29′12.7″	24.48686111	88°27′13.6″	88.45377778	Clay Loam	Low	7.2	1.78	0.09	19.08	0.32	13.86	1.56	0.31
41	Rishikul	24°28′19.7″	24.47213889	88°28′00.9″	88.46691667	Loam	Low	7.15	1.78	0.09	15.06	0.12	15.09	1.17	1.05
42	Rishikul	24°29′04.8″	24.48466667	88°30′17.0″	88.50472222	Clay Loam	Low	7.8	1.17	0.06	11.13	0.25	2.17	2.73	0.56
43	Rishikul	24°31′26.0″	24.52388889	88°30′22.0″	88.50611111	Clay Loam	Low	7	2.06	0.1	18.05	0.15	15.56	0.94	0.8
44	Rishikul	24°28′51.6″	24.481	88°30′30.7″	88.50852778	Clay Loam	Low	7.6	0.92	0.05	7.52	0.27	22.8	0.83	1.01
45	Rishikul	24°28′30.7″	24.47519444	88°30′35.3″	88.50980556	Loam	Low	7.5	0.96	0.05	17.24	0.18	19.33	1.25	1.14
46	Godagari	24°29′30.0″	24.49166667	88°19′18.0″	88.32166667	Loam	Low	6.35	1.38	0.07	17.84	0.17	2.14	1.44	1.03
47	Godagari	24°30′13.0″	24.50361111	88°19′42.0″	88.32833333	Loam	Low	6.6	1.03	0.05	32.05	0.25	5.74	1.09	0.52
48	Godagari	24°29′00.0″	24.48333333	88°20′21.4″	88.33927778	Clay Loam	Low	7.3	1.03	0.05	5.83	0.35	13.43	1.15	0.7
49	Godagari	24°30′00.2″	24.50005556	88°20′26.5″	88.34069444	Loam	Low	7.2	1.1	0.06	16.61	0.33	10.59	1.88	0.69
50	Godagari	24°29′25.3″	24.49036111	88°21′59.5″	88.36652778	Loam	Low	6.4	1.17	0.06	7.48	0.26	13.2	0.96	0.53
51	Godagari	24°27′32.9″	24.45913889	88°21′30.7″	88.35852778	Loam	Low	6.8	1.38	0.07	30.24	0.32	6.98	0.88	0.31
52	Mohanpur	24°30′53.3″	24.51480556	88°21′51.1″	88.36419444	Loam	Low	6.6	1.78	0.09	14.73	0.25	9.89	1.56	0.2
53	Mohanpur	24°31′06.6″	24.5185	88°22′13.1″	88.37030556	Loam	Low	7.05	1.24	0.06	55.2	0.29	6.36	0.91	1.14

54	Mohanpur	24°32′29.2″	24.54144444	88°23′17.2″	88.38811111	Loam	Low	5.6	0.93	0.05	5.93	0.22	4.81	1.04	0.73
55	Mohanpur	24°33′21.1″	24.55586111	88°19′53.1″	88.33141667	Clay Loam	Low	7.4	1.17	0.06	15.21	0.18	10.44	1.13	0.31
56	Mohanpur	24°33′42.0″	24.56166667	88°21′03.3″	88.35091667	Loam	Low	6.7	1.44	0.07	15.88	0.37	5.36	1.75	0.37
57	Mohanpur	24°33′40.9″	24.56136111	88°21′25.5″	88.35708333	Loam	Low	7	1.44	0.07	16.18	0.25	12.68	1.12	0.49
58	Mohanpur	24°33′09.5″	24.55263889	88°22′50.7″	88.38075	Clay Loam	Low	6.7	1.78	0.09	5.33	0.24	9.08	1.88	0.17
59	Mohanpur	24°32′53.6″	24.54822222	88°22′13.3″	88.37036111	Loam	Low	5.7	1.44	0.07	3.34	0.15	6.75	1.23	0.58
60	Mohanpur	24°32′54.1″	24.54836111	88°23′24.6″	88.39016667	Clay Loam	Low	6.6	1.78	0.09	7.82	0.21	9.21	2.12	0.71
61	Mohanpur	24°34′31.2″	24.57533333	88°25′21.2″	88.42255556	Clay Loam	Low	6.8	1.58	0.08	6.6	0.12	4.74	1.2	0.21
62	Mohanpur	24°35′11.8″	24.58661111	88°25′13.2″	88.42033333	Loam	Low	6.85	1.72	0.09	21.61	0.15	13.59	0.89	1.04
63	Mohanpur	24°35′59.6″	24.59988889	88°25′37.4″	88.42705556	Clay Loam	Low	7.3	1.3	0.07	20.27	0.37	6.12	0.91	0.73
64	Mohanpur	24°34′32.2″	24.57561111	88°25′08.4″	88.419	Clay Loam	Low	6.5	1.38	0.07	5.55	0.12	11.39	0.89	0.1
65	Mohanpur	24°33′45.2″	24.56255556	88°24′19.8″	88.4055	Clay Loam	Low	6.8	1.58	0.08	12.49	0.29	8.57	0.87	0.24
66	Mohanpur	24°33′16.7″	24.55463889	88°24′15.6″	88.40433333	Clay Loam	Low	5.65	0.9	0.05	9.41	0.21	5.97	0.87	0.62
67	Mohanpur	24°35′57.9″	24.59941667	88°23′02.0″	88.38388889	Loam	Low	6.4	1.3	0.07	6.42	0.18	12.88	0.55	0.28
68	Pakri	24°32′30.1″	24.54169444	88°27′06.5″	88.45180556	Clay Loam	Low	6.9	1.65	0.08	7.18	0.14	12.09	0.98	0.51
69	Pakri	24°32′55.0″	24.54861111	88°27′56.8″	88.46577778	Clay Loam	Low	7.1	0.96	0.05	49.18	0.3	11.63	0.9	0.13
70	Pakri	24°33′23.7″	24.55658333	88°28′16.5″	88.47125	Clay Loam	Low	7.45	1.03	0.05	7.19	0.38	13.92	0.36	1.29
71	Pakri	24°33′29.4″	24.55816667	88°27′31.5″	88.45875	Clay Loam	Low	7.4	1.38	0.07	16.21	0.17	15.22	1.53	0.45
72	Pakri	24°34′14.9″	24.57080556	88°27′46.2″	88.46283333	Clay Loam	Low	6.75	1.3	0.07	5.57	0.1	9.75	1.28	0.27
73	Pakri	24°34′32.4″	24.57566667	88°27′10.2″	88.45283333	Loam	Low	7.1	0.92	0.05	23.81	0.12	11.56	0.97	0.75
74	Pakri	24°35′22.0″	24.58944444	88°26′27.3″	88.44091667	Loam	Low	7.1	1.3	0.07	26.52	0.14	12	0.89	0.33
75	Pakri	24°31′36.2″	24.52672222	88°26′49.2″	88.447	Loam	Low	6.7	1.92	0.1	11.1	0.22	4.38	0.67	0.95
76	Pakri	24°32′28.6″	24.54127778	88°26′08.4″	88.43566667	Clay Loam	Low	6.6	2.06	0.1	15.19	0.2	12.2	1.1	0.59
77	Pakri	24°33′51.4″	24.56427778	88°26′08.7″	88.43575	Clay Loam	Low	7	1.24	0.06	14.88	0.22	11.08	0.92	0.32
78	Pakri	24°34′00.3″	24.56675	88°25′41.7″	88.42825	Clay Loam	Low	6.7	1.92	0.1	16.63	0.2	13.32	1.38	0.17
Upazila/Study Area Average Value								7.06	1.53	0.08	15.09	0.25	12.59	1.15	0.59

Source: Soil Resource Development Institute (SRDI), 2015

Notes: Unit= pH=1-14 Organic Matter =% Nitrogen (N) =% Phosphorus (P)= µg/g Potassium (K)= meq/100gm Sulfur (S)= µg/g Zinc (Zn)= µg/g Boron (B) = µg/g

Y = latitude X = longitude DDY = decimal degree of latitude DDX = decimal degree of longitude

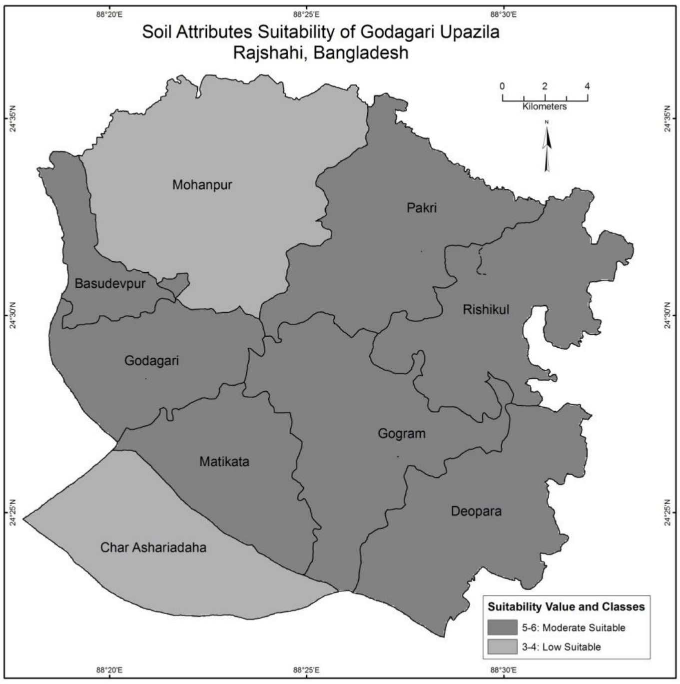

Figure 3.1. Soil Attributes Suitability Class

Source: Produced as of ArcGIS 10.1 Model

It is evident from the above table that values of most attributes of the soil in the study area are not in optimum condition. Soil quality differs from place to place, which are directly related to agricultural sustainability. Hence, union wise average values comparing with optimum values for crops are presented below to depict scenarios of sustainable agriculture spatially.

Table 3.18. Union Wise Average Value of Soil Attributes and Comparison with Optimum Value

Sl.	Union	Texture	Moisture	pH	Org Ma	Nitr	Phosp	Potas	Sulfur	Zinc	Bor
1	Basudebpur	Clay	Low	7.33	2.20	0.11	20.55	0.36	29.09	1.05	1.06
2	C.Ashariadaha	Loam	Medium	7.97	1.69	0.08	14.01	0.35	11.53	0.75	0.48
3	Deopara	Clay-Loam	Low	7.68	1.63	0.08	11.52	0.18	19.26	1.06	0.70
4	Gogram	Clay Loam	Low	6.42	1.79	0.09	9.63	0.24	18.36	1.26	0.79
5	Matikata	Clay Loam	Low	7.15	1.58	0.08	11.92	0.24	16.73	1.24	0.51
6	Rishikul	Clay Loam	Low	7.37	1.31	0.07	14.27	0.20	19.23	1.01	0.98
7	Godagari	Loam	Low	6.80	1.22	0.06	18.11	0.30	10.26	1.24	0.51
8	Mohanpur	Loam and Clay Loam	Low	6.28	1.26	0.07	9.44	0.23	9.14	0.76	0.38
9	Pakri	Clay Loam	Low	6.77	1.74	0.09	15.57	0.21	12.20	1.13	0.36
10	Upazila	Clai Loam and Loam	Low	7.06	1.53	0.08	15.09	0.25	12.59	1.15	0.59
-	Optimum Value	Loam	High	6.95	4.50	0.315	26.25	0.315	26.25	1.58	0.53

Source: 78 Soil Samples of the Study Area of SRDI, 2015

Notes: Unit = pH=1-14, Organic Matter =%, Nitrogen =%, Phosphorus = μg/g, Potassium= meq/100gm, Sulfur= μg/g, Zinc= μg/g, Boron = μg/g

Interpretations of texture, moisture, pH, organic matter, and 6 nutrient elements of soil values in very low, low, medium, optimum, high, and very high category for different crops are presented below.

Table 3.19. Interpretation of Soil Values Based on Texture, Moisture, pH, Organic Matter, and Nutrient Elements in Critical Limits in Loamy to Clayey Soils

Sl.	Attributes of Soil	Very Low	Low	Medium	Optimum	High	Very High	Midpoint of optimum value*
1	Texture**	-	-	-	Loam	-	-	-
2	Moisture**	-	-	-	Good	-	-	-
3	pH (1-14)	< 4.5	4.6-5.5 & 5.6-6.5	6.6-7.3 (neutral)	6.6-7.3	7.4-8.4	8.5-9.0 & > 9.6	6.95
4	Organic Matter (%)	< 1.0	1.0-1.7	1.8-3.4	3.5-5.5	3.5-5.5	> 5.5	4.5
5	Nitrogen (N)(%)(Olsen method)	≤ 0.09	0.091-0.18	0.181-0.27	0.271-0.36	0.361-0.45	>0.45	0.315
6	Phosphorus (P) (µg/g)	≤ 7.5	7.51-15.0	15.1-22.5	22.51-30	30.1-37.5	>37.5	26.255
7	Potassium (K)(meq/100g)	≤ 0.09	0.091-0.18	0.181-0.27	0.271-0.36	0.361-0.45	> 0.45	0.315
8	Sulfur (S) (µg/g)	≤ 7.5	7.51-15.0	15.1-22.5	22.51-30	30.1-37.5	> 37.5	26.255
9	Zinc (Zn)(µg/g)	≤ 0.45	0.451-0.9	0.91-1.35	1.351-1.8	1.81-2.25	> 2.25	1.575
10	Boron (B) (µg/g)	≤ 0.15	0.151-0.3	0.31-0.45	0.451-0.6	0.61-0.75	> 0.75	0.525

Source: Bangladesh Agriculture Research Council, 2012

*Notes: * = Midpoint calculated from optimum range of nutrients, org. matter and neutral values of p^H for z test*
** P^H values are presented in present structure keeping all the values intact **=Qualitative data*

Table 3.20. Texture and Moisture Data

Texture Class	No of Sample	Percentage	Moisture Class	No of Samples	Percentage
Loam	35	45	High	2	2.56
Clay	8	10	Medium	6	7.70
Clay Loam	35	45	Low	70	89.74
Sandy	-	-	-	-	-
Sandy Loam	-	-	-	-	-

Source: 78 Samples of the Study Area of SRDI,2015

Excess nutrient accumulation may lead to soil and water pollution.[10] Consequently, crop production and yield rate are affected. On the other hand, nutrient deficiency may eventually

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[10] Bangladesh Agriculture Research Council, *Fertilizer Recommendation Guide - 2012*, 8.

cause soil degradation and affect crop production. To achieve sustainability, the quantity of nutrient inputs and outputs should be equal and nutrient uptake by a crop is the resultant product of crop nutrient concentration and crop yield. Functions of abovementioned10 elements in plants are described below in relation with present soil quality of the study area.

Table 3.21. Functions of Soil Properties and Present State in the Study Area

Sl.	Attribute	Functions	Present State in the Study Area
1	Texture	Texture determines the ability of the soil to hold and conduct the water and air necessary for sustainable life of plants	Clay loam which is not good
2	Moisture	Moisture holding capacity is the ability of soil to hold moisture for use by plants during dry periods	Low
3	pH	pH controls nutrient availability in soils	Good
4	Org Matter	Organic matters improve soil structure, water holding capacity, aeration etc. It is a storehouse of plant nutrients, chiefly N, P, and S. It also serves as a food and energy for plants.	very low
5	Nitrogen	Constituent of proteins and nucleic acids helps in vigorous vegetative growth	very low
6	Phosphorus	Role in energy storage and transfer, constituent of nucleic acids, stimulates root growth, promotes fruit and seed formation, enhances nodulation in legumes	very low
7	Potassium	Activate enzyme related starch synthesis, N metabolism and respiration, translocation of sugars, produces stiff straw in cereals and imparts disease resistance to plants	3 unions ok,6 unions low
8	Sulfur	Constituent of amino acids, biotin, vitamin and coenzyme. Helps in nodulation of legumes, aids in fats and oil formation and chlorophyll synthesis	low except 1 union
9	Zinc	Production of auxins, activation of enzymes, chlorophyll synthesis and cell membrane integrity	Low
10	Boron	Involved in metabolism, protein synthesis, photosynthesis, pollen viability, seed formation, increases Ca and mobility in plants	high &low

Source: BARC, 2012 and Present State is Data

It is found that soil properties vary from union to union. Hence, union wise standard deviations of soil attributes of the study area are presented below.

Table 3.22. Union Wise Standard Deviation of Soil Attributes and Comparison with Upazila

Sl.	Union	Texture*	Moisture*	pH	Org.Ma	Nitr	Phosp	Potas	Sulfur	Zinc	Boron
1	Basudebpur	-	-	0.16	0.25	0.01	5.21	0.09	12.33	0.18	0.29
2	C.Ashariadaha	-	-	0.34	0.57	0.03	7.35	0.10	13.00	0.21	0.34
3	Deopara	-	-	0.08	0.62	0.03	6.70	0.09	12.72	0.54	0.21
4	Gogram	-	-	0.10	0.41	0.02	8.28	0.05	12.22	0.48	0.68
5	Matikata	-	-	0.22	0.48	0.03	5.91	0.08	0.31	0.20	0.36
6	Rishikul	-	-	0.32	0.65	0.03	5.86	0.06	3.62	0.22	0.17
7	Godagari	-	-	0.40	0.15	0.01	11.45	0.04	3.12	0.56	0.19
8	Mohanpur	-	-	0.58	0.34	0.02	3.04	0.06	3.49	0.18	0.21
9	Pakri	-	-	0.21	0.44	0.02	0.93	0.01	1.12	0.23	0.21
10	Upazila	-	-	0.56	0.41	0.02	10.36	0.09	8.95	0.46	0.37

*Notes: *= Qualitative data Unit= pH=1-14 Organic Matter =% Nitrogen =% Phosphorus = µg/g Potassium= meq/100gm Sulfur= µg/g Zinc= µg/g Boron = µg/g*

3.4 Irrigation Water

Crops build up their biomass and nutrients using water from soils.[11] Good quality water has the potential to allow maximum yield and plants transpire easily only pure water. On the other hand, with poor water quality, soil and cropping problems can be occurred to develop which reduce yields.[12]

The suitability of irrigation water is determined by its potential to cause problems for yield reduction. pH and Alkalinity are two important factors in determining the suitability of water for irrigating plants. Water temperature affects plant growth and yield has been held for a long time.[13] Yield declines as temperature increases. Acceptable range or no restriction on use for irrigation is 20-30°c, but at the border line temperature creates a few problems for plants optimum growth. Acidic water has detrimental effect on plant growth, particularly causing nutritional problems, while strongly acidic water (below 4) can contribute to soil acidification that also affects growth and yield. The generally accepted pH for irrigation water is between 5.5 and 7.5, but a few problems can occur within this range. The relationship between pH and Hardness is described below.

[11] Bangladesh Agriculture Research Council, *Fertilizer Recommendation Guide-2012*, 5.

[12] R. S. Ayers and D. W. Westcot, "Water Quality for Agriculture," *FAO Irrigation and Drainage Paper* 29 (1976), 4.

[13] M. Robert Hagan, R. Haise Howard and W. Edminster Talcott, eds., *Irrigation of Agricultural Land* (Madison: American Society of Agronomy, 1967), 1029.

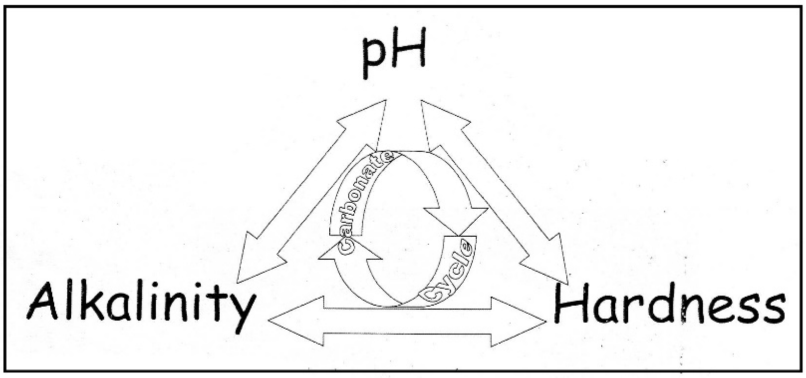

Figure 3.2. **Relationship Between pH, Alkalinity and Hardness**

For sustainable agriculture, the optimum values of water are very important. Below is given the acceptable limit or no restriction on use of water for irrigation to produce crop.

Table 3.23. **Interpretation of Irrigation Water Values**

Sl.	Attributes of Water	Unit	Acceptable Limit or No Restriction on Use for Irrigation	Reference	Midpoint of Acceptable Range/ No Restriction on Use *
1	pH	1-14	6.0-8.5	DoE and Bangladesh Gazette – 1997	7.25
2	EC	mmhos/cm	0-700	Ayers and Westcot, 1994	350
3	Temperature	°c	20-30	DoE and Bangladesh Gazette -1997	25

*Note:*Midpoint calculated from acceptable range or no restriction on use for irrigation for z –test/t-test.*

The nature of data of irrigation water is that values of attributes of one sample are different from another sample. For example, electrical conductivity (mmhos/cm) in Deopara union, one sample value is 528, another sample value is 787, but midpoint of optimum value is 350. Due to this nature of data, it needs to test attribute values of all samples with optimum value. As per tests of normality and sample size (78), z/t- test is employed to compare the population mean with optimum value of irrigation water attributes for crop production. Results of z/t tests are shown below with analysis of three attributes of 78 irrigation water samples of the study area followed by tests of normality.

Table 3.24. Tests of Normality

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
pH	.113	78	.015

a Lilliefors Significance Correctio

It is seen from the above table of tests of normality that the significance level in both the test (Kolmogorov-Smirnov) is greater than 0.05. So, there are adequate reasons to accept the null hypothesis. It indicates that distribution of data fulfils normality condition. Hence, the data fall in the category of z- test.

Table 3.25. Calculation Table for pH

pH	N	Mean($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	7.0910	.42737	7.25

Hypothesis 1: $H_0: \mu = 7.25$

$H_1: \mu \neq 7.25$

Under null hypothesis: The test statistic is,

$$z = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$z = -3.285 \qquad |z| = |-3.285| \Rightarrow |z| = 3.285$

Comment: The calculated value of $|z|$ is greater than 1.96. We may reject the null hypothesis at 5 % level of significance and conclude that there is difference between tested pH value and optimum value. So, pH of water in the study area is not in optimum point for sustainable agriculture, but it is close to the optimum position.

Table 3.26. Tests of Normality

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
EC	.142	78	.000

a Lilliefors Significance Correctio

The above table of tests of normality shows that the significance level in Kolmogorov-Smirnov test is less than 0.05. So, the null hypothesis is rejected which implies that distribution of data does not fulfill normality condition. Hence, the data require t- test.

Table 3.27. Calculation Table for EC

EC	N	Mean ($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	602.2949	87.28787	350

Hypothesis 2: $H_0: \mu = 350$

$H_1: \mu \neq 350$

Under null hypothesis: The test statistic is,

$t = 25.527$

Comment: Since the calculated value of t is greater than 1.96, we may reject our null hypothesis at 5 % level of significance. So, difference between tested EC value and optimum value is significant. So, study areas EC of water is not suitable for sustainable agriculture.

Table 3.28. Tests of Normality

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Temper.	.208	78	.000

a Lilliefors Significance Correction

It is evident from the above table of tests of normality that the significance level in the test of Kolmogorov-Smirnov is not greater than 0.05. So, the null hypothesis is not accepted which means that distribution of data do not fulfill normality condition. Hence, it require t- test.

Table 3.29. Calculation Table for Temperature (^{0}c)

Temperature	N	Mean($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	78	25.4615	3.24214	25

Hypothesis 5: $H_0: \mu = 25$

$H_1: \mu \neq 25$

Under null hypothesis: The test statistic is,

t = 1.257

Comment: As the calculated value of t is less than 1.96, we fail to reject our null hypothesis at 5 % level of significance. There is thus insufficient evidence to support the significant difference between tested temperature and optimum value. Therefore, water temperature in the study area is not unsuitable for sustainable agriculture.

Good quality irrigation water is crucial for optimum crop productivity. On the other hand, poor quality irrigation water creates soil and cropping problems that reduce yields. Against this backdrop and taking tests of normality and z/t tests into account, irrigation water test results of 78 samples of the study area are presented below with mean values of the study area to portray the study areas irrigation water quality.

Table 3.30. Irrigation Water Test Results of the Study Area

Sl	Union	*Mauza* Name	*Mauza* No.	*Mauza* Geo-Code No.	pH	EC(xs/cm)	Temp(°c)
1	Basudebpur	Basudebpur	5	80-34-09-109	7.6	563	24
2	Basudebpur	Abhaya	9	80-34-09-005	7	597	24
3	Basudebpur	Mohanpur	17	80-34-09-704	6.9	506	24
4	C.Ashariadaha	N. Khasmahal	233	80-34-19-765	7	803	24
5	C.Ashariadaha	D. Manikchar	235	80-34-19-290	7.1	729	24
6	C.Ashariadaha	Ashariad. K.mahal	234	80-34-19-048	7.1	754	24
7	C.Ashariadaha	Elahinagar	231	80-34-19-334	7.2	763	24
8	C.Ashariadaha	Char Barnish	232	80-34-19-262	7.7	555	24
9	C.Ashariadaha	Ashariadah	236	80-34-19-045	7.5	731	24
10	Deopara	Gulai	361	80-34-28-395	6.8	787	22
11	Deopara	Deopara	356	80-34-28-293	6.8	711	22
12	Deopara	Chak Chapal	385	80-34-28-237	7.4	726	28
13	Deopara	Sarail	384	80-34-28-936	7.2	596	28
14	Deopara	Bil Khalaspur	382	80-34-28-176	7.3	596	28
15	Deopara	Bijaynagar	371	80-34-28-163	7.4	706	28
16	Deopara	Khanjagati	388	80-34-28-581	7.2	531	28
17	Deopara	B. Pushkarni	362	80-34-28-198	7.3	528	28
18	Deopara	Pathargata	376	80-34-28-808	7.4	681	32
19	Gogram	Sekhalipara	301	80-34-47-915	6.5	582	20
20	Gogram	Kanaitkunda	313	80-34-47-538	6.6	420	20
21	Gogram	Hazipur	348	80-34-47-418	6.5	570	20
22	Gogram	Gogram	315	80-34-47-380	6.3	525	20
23	Gogram	Kursana Eusafpur	316	80-34-47-622	6.4	621	20

24	Gogram	Itahari	308	80-34-47-441	6.4	597	20
25	Gogram	Terapara	307	80-34-47-977	6.5	543	20
26	Gogram	Bhabanipur	296	80-34-47-145	6.3	534	20
27	Gogram	Muraripur	306	80-34-47-716	6.4	602	20
28	Gogram	Tikail	312	80-34-47-979	6.5	618	20
29	Gogram	Raninagar	351	80-34-47-852	6.1	753	31
30	Matikata	Sonadighi	277	80-34-57-933	7.2	559	24
31	Matikata	Shaharagachi	241	80-34-57-885	7.3	488	24
32	Matikata	Ujanpara	245	80-34-57-992	6.8	636	24
33	Matikata	Sahabdipur	253	80-34-57-877	7.2	557	24
34	Matikata	Jot Joyrampur	246	80-34-57-489	7.1	532	24
35	Matikata	Gopalpur	270	80-34-57-390	8.2	665	24
36	Rishikul	Chabbisnagar Araz	176	80-34-85-229	6.7	602	22
37	Rishikul	Bamlahal	169	80-34-85-079	6.8	519	22
38	Rishikul	Talai	166	80-34-85-966	6.7	519	22
39	Rishikul	Tilahari	168	80-34-85-982	6.9	476	22
40	Rishikul	Bainpur	175	80-34-85-073	6.7	513	22
41	Rishikul	Kakun	152	80-34-85-515	6.5	617	31
42	Rishikul	Kasia	158	80-34-85-551	6.8	578	27
43	Rishikul	Palasi	142	80-34-85-780	6.9	608	28
44	Rishikul	Kunorpur	162	80-34-85-617	6.9	597	27
45	Rishikul	Bhanpur	163	80-34-85-158	6.8	579	27
46	Godagari	Mahisalbari	221	80-34-38-660	7.1	520	24
47	Godagari	Ramnagar	210	80-34-38-844	7.5	593	24
48	Godagari	Kismat Rasandighi	187	80-34-38-591	7.2	519	24
49	Godagari	Madhopur	183	80-34-38-637	7.3	503	24
50	Godagari	Fazilpur	212	80-34-38-349	7.1	550	24
51	Godagari	Paramanandapur	185	80-34-38-798	6.4	460	31
52	Mohanpur	Chholong	81	80-34-66-219	7.4	557	27
53	Mohanpur	Murhatta	32	80-34-66-719	7.7	752	27
54	Mohanpur	Mirzapur	53	80-34-66-693	7.6	577	28
55	Mohanpur	Kalipur	20	80-34-66-522	7.5	594	27
56	Mohanpur	Khandita	30	80-34-66-576	7.4	532	27
57	Mohanpur	Madhaipur	100	80-34-66-635	7.1	508	27
58	Mohanpur	Mirpur	96	80-34-66-691	7.3	568	27
59	Mohanpur	Kapasiapara	70	80-34-66-548	7.4	725	27
60	Mohanpur	Sidna	51	80-34-66-928	7.7	588	28
61	Mohanpur	Tentulia	22	80-34-66-924	7.5	751	27
62	Mohanpur	Jaban	54	80-34-66-443	7.7	567	28
63	Mohanpur	Kanaipur	65	80-34-66-535	7.5	624	27
64	Mohanpur	Haripur	89	80-34-66-408	7.4	554	27
65	Mohanpur	Baze Gobindapur	67	80-34-66-122	7.2	556	27

66	Mohanpur	Paharpur	102	80-34-66-778	6.7	584	31
67	Mohanpur	Jot Sangram	60	80-34-66-497	7	484	31
68	Pakri	Makranda	107	80-34-76-668	7.6	673	27
69	Pakri	Sundarpur	130	80-34-76-956	7.2	440	27
70	Pakri	Pakri	109	88-34-76-778	6.7	595	27
71	Pakri	Gopalpur	112	80-34-76-385	6.8	723	31
72	Pakri	Narayanpur	110	80-34-76-742	7.6	599	27
73	Pakri	Hapania	121	80-34-76-403	7.4	674	27
74	Pakri	Jauban Basail	126	80-34-76-459	7.6	657	30
75	Pakri	Khatandar	119	80-34-76-563	7.3	598	30
76	Pakri	Abdulpur	139	80-34-76-002	7.2	710	27
77	Pakri	Kadipur	124	80-34-76-505	7.5	698	27
78	Pakri	Jayrampur	133	80-34-76-466	7.6	673	27
-	Upazila	Average	-	-	7.09	602.29	25.46

Sources: BADC (Irrigation), BMDA, DPHE, and Laboratory Tests (2014-2015)

From the above table it is evident that values of most attributes of the irrigation water in the study area are not in optimum condition for potential production. Not only that, water quality differs from place to place which is related to potential yields. Hence, union wise average values comparing with optimum values for crops and union wise standard deviation are presented below to depict scenarios of sustainable agriculture spatially.

Table 3.31. Union Wise Average Value of Irrigation Water Attributes and Comparison with Optimum Value

Sl.	Union	pH(1-14)	EC(mmhos/ds)	Temperature(°c)
1	Basudevpur	7.17	555.33	24
2	Char Ashariadaha	7.27	722.50	24
3	Deopara	7.30	606.33	28.67
4	Gogram	6.37	607.83	21.83
5	Matikata	7.30	572.83	24
6	Rishikul	6.77	582.00	27
7	Godagari	7.10	524.17	25.17
8	Mohanpur	7.25	561.50	28.50
9	Pakri	7.43	668.33	28
-	Upazila	7.09	602.29	25.46
-	Optimum Value	7.25	350	25

Source: Calculated from table 3.30

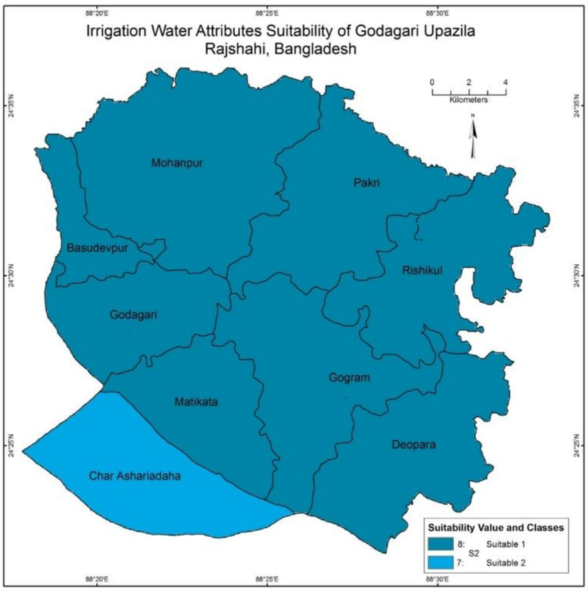

Figure 3.3. Irrigation Water Attributes Suitability

Source: Produced as of ArcGIS 10.1 Model

It is seen from the above table that pH value of irrigation water of the study area is close to optimum level and congenial for crops production. Average EC and temperature are shown below comparing with optimum value.

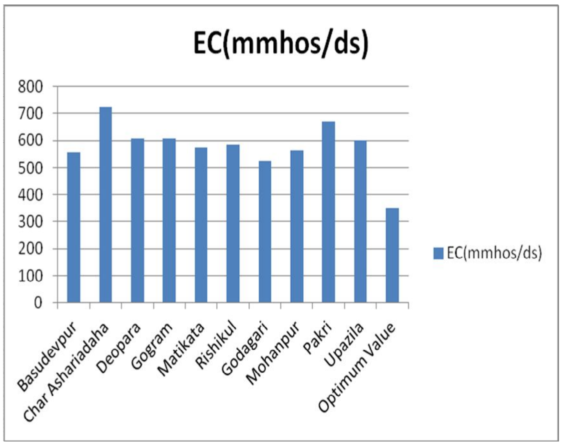

Figure 3.4. Union Wise EC Status

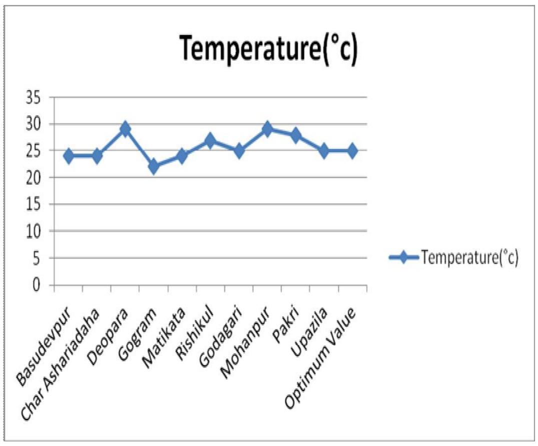

Figure 3.5. Union Wise Temperature Status

It may be mentioned here that all these values are not significantly harmful to crops production i.e., irrigation water quality is no problem in the study area though they are not in optimum state but within normal range. It may be mentioned here that all these values at border area of normal range can create problems for optimum production of crops. Union wise standard deviation of irrigation water is presented below.

Table 3.32. Union Wise Standard Deviation of Irrigation Water Attributes and Comparison with Upazila

Sl.	Union	pH(1-14)	EC(mmhos/ds)	Temperature(°c)
1	Basudevpur	0.38	45.98	0.00
2	Char Ashariadaha	0.27	86.35	0.00
3	Deopara	0.09	74.21	1.63
4	Gogram	0.15	78.72	4.49
5	Matikata	0.47	66.02	0.00
6	Rishikul	0.13	49.43	3.37
7	Godagari	0.37	44.75	2.86
8	Mohanpur	0.27	80.51	1.35
9	Pakri	0.32	80.15	1.58
-	Upazila	0.43	87.29	3.24

3.5 Climate

The potential crop-producing capability of an area is dependent largely on the existing climatic conditions.[14] Many other scholars are also of the similar views. Weather is the key source of uncertainty affecting crop yield. Rainfall and temperature are important climatic inputs for agricultural production and crop loss is directly related to unfavorable climate.[15] But the prevailing climatic conditions in the study area are not favorable for sustainable agriculture especially high temperature and scanty rainfall.

Since there is no meteorological station in Godagari upazila of Rajshahi district, data of about 15 km away district headquarter meteorological station are used for analysis of climate state of the study area. The two most important climate related elements taken into consideration in assessing land suitability for sustainable agriculture are temperature and rainfall which are discussed below.

3.5.1 Temperature

Air temperature is the most important weather element which affects plant life. Germination of seeds and growth of plants are retarded in unsuitable temperature conditions. Apart from yield reductions many visible injuries on the plants are seen due to very low or very high temperatures. Each crop needs some certain effective heat units

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[14] Singh and Dhillon, *Agricultural Geography,* 61.

[15] Rong-Gang Cong and Mark Brady, "The Interdependence between Rainfall and Temperature: Copula Analysis," *The Scientific World Journal* 2012 (2012), 1. https://lup.lub.lu.se/search/ws/files/1651853/3327867.pdf·PDF file (accessed September 23, 2016).

for germination, growth, stalking, maturing, flowering, and ripening. The maximum production of dry matter occurs when the temperature ranges from 20 to 30°c and high and low temperatures affect plants growth and even get killed.[16] Every plant has its own optimum, maximum, and minimum temperature limits for its normal growth and reproduction which are known as cardinal temperature points. Cardinal temperatures for germination of seeds of three major crops of the study area and optimum temperature requirements for different stages of rice are presented below in tables 3.33 and 3.34.

Table 3.33. Cardinal Temperatures for Germinations of Seeds

Crops	Optimum(°c)	Maximum(°c)	Minimum(°c)
Rice	30-32	36-38	10-12
Wheat	25	30-32	3-4.5
Maize	32-35	40-44	8-10

Source: N. Gopalaswamy, Agricultural Meteorology (P. 20)

Table 3.34. Optimum Temperature Requirements for the Different Stages of Rice Crop

Growth Stage	Optimum Temperature
Germination	20-35
Seedling Establishment	25-30
Rooting	25-28
Leaf Elongation	31
Tillering	25-31
Panicle Initiation	33
Anthesis	30-32
Ripening	20-25

Source: Agricultural Meteorology (P. 71)

Due to nature of data, test of normality and z/t-test are employed for climate data which are described below.

Table 3.35. Tests of Normality for Temperature

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Temperature	1	13	..000

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

[16] N. Gopalaswamy, *Agricultural Meteorology* (Jaipur: Rawat Publications, 1994), 19.

It is seen from the above table of tests of normality that the significance level in the above test is less than 0.05. So, the null hypothesis is not accepted which means that distribution of data does not fulfill normality condition. Hence, the data fall in the category of t- test.

Table 3.36. Calculation Table for Temperature

Temperature	N	Mean ($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	13	25.241	4.477	25.4

Hypothesis 1: $H_0: \mu = 25.4$

$H_1: \mu \neq 25.4$

Under null hypothesis: The test statistic is,

$$t = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

t= - 0.127 $|t| = |-0.127| \Rightarrow |t| = 0.127$ Tabulated value= 2.179

Comment: The calculated value of $|t|$ is less than tabulated value (2.179). So, we may accept our null hypothesis at 5 % level of significance and conclude that there is insignificant difference between temperature values from optimum value. Therefore, temperature value of climate is suitable for sustainable agriculture in the study area.

Table 3.37. Monthly Average Temperature in the Study Area (°c)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1975	18.2	21.5	26.7	31.1	30.3	30.3	28	28.9	28.2	28	22.4	18.5
1976	18.6	22.1	27.5	29.7	28.5	29	28.7	28.1	28.5	27.6	24.6	18.4
1977	17.2	20.7	28.1	27.8	27.5	27.2	28.6	29	29.3	26.5	24.2	19.5
1978	17.4	20.3	23.9	28.1	28	27.9	28.3	28.3	27.9	27.4	23.3	18.5
1979	18.4	19	25.3	29.4	32.4	30.2	28.4	28.9	28.8	27.3	24.8	19
1980	17.1	19.8	24.8	31.7	28.2	28.6	28.5	28.8	28.8	26.3	23	19.2
1981	17.3	20.3	24.1	26.1	27.4	29.1	28.2	28.9	28.3	27.2	22.5	17.5
1982	17.8	19.4	23.4	27.9	30.5	28.7	29.4	28.1	29.2	26.5	21.6	17.6
1983	16.3	19	25.3	27.6	28.1	30.1	29.3	28.4	28.5	26.6	22.4	17.1
1984	16.4	18.8	25.5	30.2	29	28.2	28	28.4	28	27.2	21.9	17.8

1985	17.7	19.3	26.7	30.3	28	28.9	27.6	28.7	28.1	26.3	21.9	18.6
1986	17.5	19.9	25.7	27.8	28.1	29.5	28.4	29.2	27.3	25.5	22.8	18.8
1987	17.3	20.9	25.5	28.5	30.2	29.9	28	28.3	28.7	27.1	22.8	18.9
1988	17.7	20.7	24.6	28.9	28.8	28.4	28.5	28.8	29.3	26.8	23	19.6
1989	15.6	19.4	24.6	30.3	30	28.9	28.2	28.8	28.1	27.1	21.8	17.3
1990	17	20.2	23.1	27.9	28.1	29.2	28.3	29.1	28.3	25.1	23.4	17.9
1991	16.2	20.9	25.6	29.1	29	28.8	28.7	29	28	26.2	21.1	17.3
1992	16.4	18.4	25.8	30.5	29	29.9	28.2	28.8	28.5	26.4	21.8	17.1
1993	15.8	21	23.8	27.7	28.3	28.8	28.8	28.6	27.9	27	23	19.1
1994	17.5	18.7	25.3	28.5	29.9	28.7	28.8	28.9	28	26.3	22.4	17.7
1995	15.7	19.3	24.5	30.2	31.2	29.4	28.4	28.5	28.2	27.2	22.5	18.1
1996	16.8	20.1	26.4	29.1	30.4	28.5	28.9	28.4	29	26.1	21.9	17.9
1997	16	18.8	25.1	26	29.5	29.2	28.4	28.8	27.8	25.9	22.8	17.4
1998	15.1	19.9	22.8	27.6	29.5	30.9	28.9	29	28.6	27.8	24.2	19.1
1999	17	21.3	26	30.9	29.1	29.4	28.5	28.4	27.8	27.1	22.9	19.3
2000	16.4	18.5	24.2	28.3	28.1	29.1	29.1	29.3	27.7	27.1	23.2	18.2
2001	15.9	20	24.8	29.3	27.8	28.6	28.8	29.5	28.7	27.1	23.4	17.7
2002	17.8	20.3	25.3	27.6	27.9	28.9	29.2	28.8	28.4	26.4	22.6	18.1
2003	14.3	20.1	23.7	29.1	29.7	29.2	29.3	29.5	28.6	26.7	22.4	18.6
2004	15.7	20	26.6	28.4	30.6	28.9	28.6	29.1	27.8	25.9	22	19.3
2005	16.9	21.6	25.7	29.1	29.3	30.4	28.7	29.2	29	26	21.5	18.6
2006	16.7	23	25.4	28.7	29	29.5	29.2	28.9	28.3	27.2	22.3	18.4
2007	16	19.8	23.5	28.7	29.6	29	28.5	29.3	28.7	26.9	23	17.4
2008	16.7	18.4	26	29	29.1	28.4	28.4	29	28.6	26.3	22	19.3
2009	17.5	20.3	25	30	28.9	31	29.3	28.9	28.9	26.3	22.8	17.4
2010	15.1	20.3	27.2	31.3	30.1	29.8	29.7	29.6	28.6	27	23.2	17.4
2011	14.7	19.6	25.6	27.6	28.7	29.3	29.3	28.5	28.7	27.2	22.2	17.4
2012	16.7	19.8	25.2	28.6	31.4	30.6	29	29.5	28.9	26.4	21.3	16.6
2013	15.5	20.2	25.5	28.9	28.7	29.9	29.8	29	29.2	26.5	21.8	18.1
2014	16.2	18.6	24.4	29.8	30.6	29.9	29.7	29.2	29	26.7	21.7	17.2
Av.	16.7	20.0	25.2	28.9	29.2	29.3	28.7	28.9	28.5	26.7	22.6	18.2

Source: Bangladesh Meteorological Department (BMD), 2015

Table 3.38. Rajshahi and Country Average Normal Temperature (°c) of 1975 - 2014

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Ag. Av
Rajshahi	16.7	20.0	25.2	28.9	29.2	29.3	28.7	28.9	28.5	26.7	22.6	18.2	25.24
Bangladesh	18.1	21.3	25.5	28.0	28.6	28.5	28.2	28.3	28.2	27.1	23.6	19.5	25.40

Source: Bangladesh Meteorological Department (BMD), 2015

Though the aggregate average temperature of Bangladesh (25.40°c) and Rajshahi (25.24°c) are almost same but monthly average temperature varies which is shown below in figure 3.6.

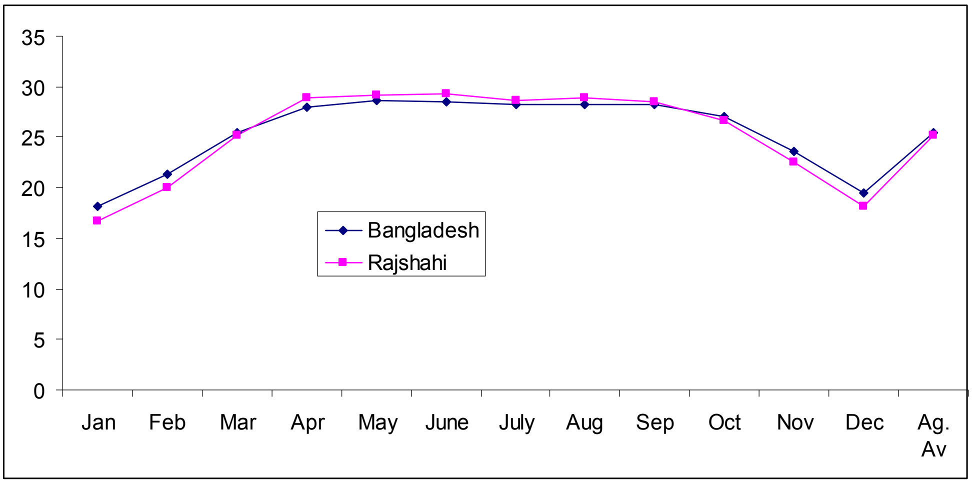

Figure 3.6. Monthly Average Temperature of Rajshahi and Bangladesh

3.5.2 Rainfall

Rainfall is the dominant single weather element influencing farming systems and crops.[17] Rainfall is generally confined to a particular season in the study area as well as in Bangladesh. Rain spells and dry-spells are important as they have important bearing on the agriculture of an area. Crops depend on rainfall for their moisture need. Deficient rain limits crop growth and heavy rains are even more harmful for crops. Occurrence of drought and famines are mainly due to inadequate rainfall over a continuous period. Test of normality and z/t-test are also employed for rainfall data to compare population mean with optimum value.

Table 3.39. Tests of Normality for Rainfall

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Rainfall	1	13	..000	.561	13	.000

* This is a lower bound of the true significance.
a Lilliefors Significance Correction

17 Singh and Dhillon, *Agricultural Geography,* 71.

It is seen from the above table of tests of normality that the significance level in the test of Kolmogorov-Smirnov is less than 0.05. So, the null hypothesis is rejected which means that distribution of data does not fulfill normality condition. Hence, the data fall in the category of t- test.

Table 3.40. Calculation Table for Rainfall

Rainfall	N	Mean($\bar{x}$)	Std. Deviation(s)	Test Values (μ_0)
	13	224.005	386.578	2401

Hypothesis 1: $H_0: \mu = 2401$

$H_1: \mu \neq 2401$

Under null hypothesis: The test statistic is,

$$t = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$t = -20.304 \quad |t| = |-20.304| \Rightarrow |t| = 20.304$

Comment: The calculated value of $|t|$ is greater than tabulated value (2.179). So, we may reject our null hypothesis at 5 % level of significance and conclude that there is significant difference of rainfall value from optimum value. Therefore, rainfall value of climate is not suitable for sustainable agriculture in the study area.

Table 3.41. Monthly Total Rainfall in the Study Area

Monthly Total Rainfall of Rajshahi (in millimeter)													
Year	Months												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
1975	9	5	12	55	109	71	381	179	197	125	1	0	1144
1976	0	10	4	10	235	234	242	389	257	45	1	0	1427
1977	4	19	0	229	241	543	399	157	121	162	10	33	1918
1978	1	46	62	93	104	492	126	149	545	92	24	0	1734
1979	45	17	2	35	13	46	492	275	379	188	28	28	1548
1980	29	12	69	0	156	349	281	316	215	149	0	0	1576
1981	71	49	26	240	290	159	574	340	398	0	3	91	2241
1982	0	10	80	139	43	260	189	217	66	38	60	1	1103
1983	1	2	4	34	121	65	366	505	149	358	0	24	1629

1984	31	1	0	10	94	325	294	321	297	202	0	0	1575
1985	4	7	3	71	190	232	274	146	233	77	3	12	1252
1986	3	12	19	93	81	175	262	238	406	190	27	4	1510
1987	0	4	12	76	102	160	488	400	193	43	5	4	1487
1988	1	30	36	107	139	404	301	356	89	94	27	0	1584
1989	4	8	5	2	224	190	357	117	332	78	0	8	1325
1990	0	34	46	97	301	263	464	238	180	127	17	0	1767
1991	6	0	19	25	157	211	286	96	484	122	0	92	1498
1992	1	33	0	16	121	85	244	185	124	29	5	0	843
1993	0	5	55	70	65	477	247	177	316	157	54	0	1623
1994	18	36	5	31	115	237	171	206	171	130	22	0	1142
1995	17	31	9	8	91	291	287	270	370	13	44	1	1432
1996	0	21	4	73	95	284	106	270	298	118	0	0	1269
1997	8	35	19	56	53	242	763	468	348	4	44	22	2062
1998	16	5	52	33	129	92	404	268	310	198	33	0	1540
1999	0	0	0	9	144	348	349	354	502	155	1	0	1862
2000	4	47	27	136	198	244	115	190	644	85	0	0	1690
2001	0	0	9	13	209	324	338	209	95	184	1	0	1382
2002	10	1	20	96	196	222	316	238	281	48	17	0	1445
2003	3	18	64	45	84	280	230	128	262	292	0	6	1412
2004	10	0	0	61	92	507	339	275	349	153	0	0	1786
2005	14	1	104	27	108	92	492	161	131	275	0	0	1405
2006	0	0	7	36	189	188	130	247	302	36	10	0	1145
2007	0	27	59	13	260	313	364	236	309	76	1	0	1658
2008	26	0	0	30	144	247	373	245	129	121	0	0	1315
2009	1	7	28	0	131	126	183	240	282	45	0	0	1043
2010	0	2	2	37	75	211	94	101	101	127	3	39	792
2011	6	0	10	94	187	341	144	454	203	35	1	0	1475
2012	6	0	6	123	17	137	314	179	178	102	101	1	1164
2013	0	22	12	51	188	178	101	254	238	204	0	0	1248
2014	0	27	12	51	151	188	242	359	153	5	0	0	1188
Av.	8.72	14.6	22.58	60.63	141.1	245.83	303.05	253.8	265.93	117.1	13.6	9.15	1456

Source: Bangladesh Meteorological Department (BMD), 2015

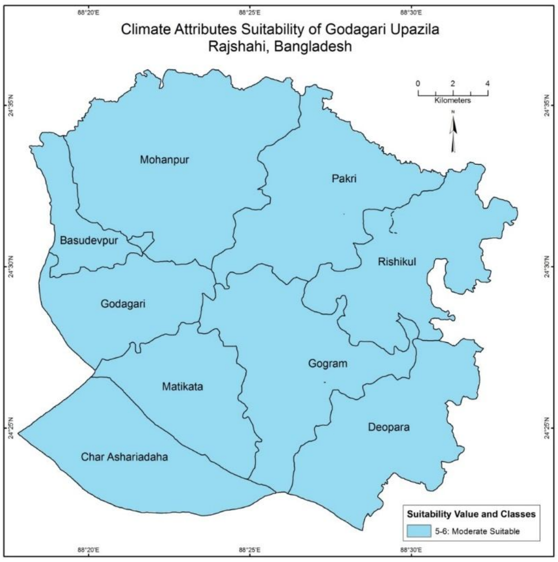

Figure 3.7. Climate Attributes Suitability

Source: Produced as of ArcGIS 10.1 Model

Table 3.42. Monthly Total Rainfall of Rajshahi and Bangladesh

Monthly Total Rainfall (in millimeter)													
1975-2014	Months												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
Rajshahi	8.72	14.6	22.58	60.63	141.1	245.83	303.05	253.8	265.93	117.1	13.6	9.15	1456
Bangladesh	7	20	42	111	275	464	515	411	325	182	35	8	2401

Source: Bangladesh Meteorological Department, 2015

Total rainfall in Rajshahi is only about 61 per cent of Bangladesh and it is very low in *rabi* (October-March) and *kharif* 1 (March-July) season which is shown below in figure 3.8.

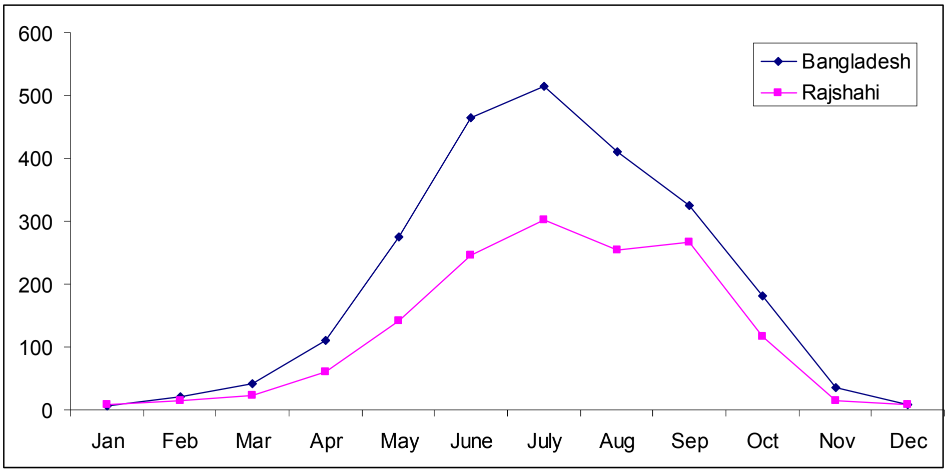

Figure 3.8. Monthly Total Rainfall of Bangladesh and Rajshahi

3.6 Topography

Topography produces changes in the climate and it involves the altitude of the place, steepness of the slope and exposure of the slope to light and wind.[18] Topography includes land type and drainage condition in this study. Soils of Barind Tract are fine in texture as a result pore spaces are comparatively smaller. Hence, drainage condition in this area is poor. Land type is of 5 classes, high land, medium high land, medium low land, low land, and very low land. Different land types cover 83 per cent and miscellaneous land cover rest 17 per cent of Rajshahi district and high land accounts 52 per cent areas out of 83 per cent of different land types. On the other hand, drainage condition is of 5 types namely, well, moderately, somewhat poor, poor, and very poor. Somewhat poor accounts much inter alia. Land type classes are presented below in figure 3.9.

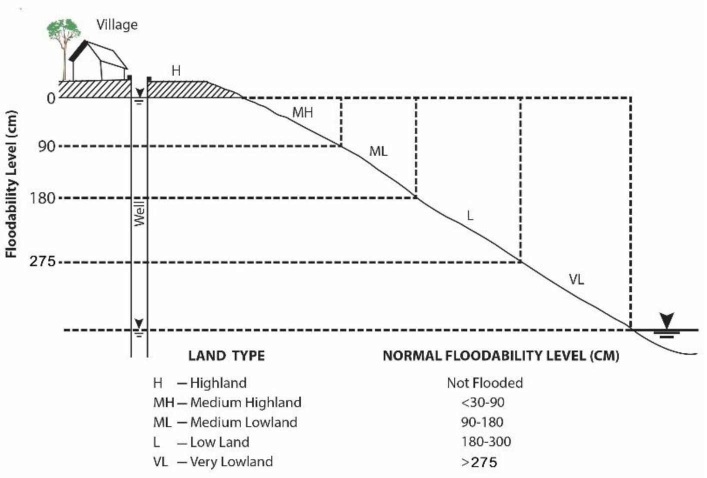

Figure 3.9. Land Type and Floodability Level

The study area is mainly high land. Topography of the study area is presented below in table 3.43.

Table 3.43. Land Type and Drainage Condition of Topography Data of the Study Area

1	Union	Y	DD Y	X	DD X	Land Type	Drainage
1	Basudebpur	24°31′54.6″	24.53183333	88°19′19.7″	88.32213889	Low Land	Poor
2	Basudebpur	24°31′23.5″	24.52319444	88°19′40.5″	88.32791667	Medium Low Land	Poor
3	Basudebpur	24°32′22.6″	24.53961111	88°18′52.4″	88.31455556	Low Land	Poor
4	C. Ashariadaha	24°24′15.6″	24.40433333	88°19′13.0″	88.32027778	Medium High Land	Somewhat Poor
5	C. Ashariadaha	24°24′02.3″	24.40063889	88°18′57.2″	88.31588889	Medium High Land	Poor
6	C. Ashariadaha	24°23′26.3″	24.39063889	88°20′45.1″	88.34586111	Medium High Land	Somewhat Poor
7	C. Ashariadaha	24°23′10.8″	24.38633333	88°24′22.1″	88.40613889	Medium Low Land	Poor

[18] Gopalaswamy, *Agricultural Meteorology,* 6.

8	C. Ashariadaha	24°24′32.3″	24.40897222	88°19′30.6″	88.32516667	Medium High Land	Somewhat Poor
9	C. Ashariadaha	24°23′03.1″	24.38419444	88°20′15.1″	88.33752778	Medium High Land	Poor
10	Deopara	24°25′52.7″	24.43130556	88°31′16.3″	88.52119444	Medium High Land	Poor
11	Deopara	24°25′18.3″	24.42175	88°30′59.0″	88.51638889	High Land	Somewhat Poor
12	Deopara	24°26′55.0″	24.44861111	88°31′19.2″	88.522	Medium High Land	Poor
13	Deopara	24°23′10.0″	24.38611111	88°28′37.0″	88.47694444	High Land	Somewhat Poor
14	Deopara	24°23′24.0″	24.39	88°26′47.0″	88.44638889	Medium High Land	Poor
15	Deopara	24°26′02.9″	24.43413889	88°31′20.6″	88.52238889	Medium Low Land	Poor
16	Deopara	24°25′47.0″	24.42972222	88°27′26.0″	88.45722222	High Land	Somewhat Poor
17	Deopara	24°25′58.0″	24.43277778	88°28′14.0″	88.47055556	High Land	Somewhat Poor
18	Deopara	24°25′34.9″	24.42636111	88°27′47.5″	88.46319444	High Land	Poor
19	Gogram	24°26′54.1″	24.44836111	88°26′04.3″	88.43452778	High Land	Somewhat Poor
20	Gogram	24°27′10.2″	24.45283333	88°26′18.8″	88.43855556	High Land	Somewhat Poor
21	Gogram	24°28′42.0″	24.47833333	88°25′35.7″	88.42658333	High Land	Somewhat Poor
22	Gogram	24°26′22.3″	24.43952778	88°27′11.2″	88.45311111	High Land	Somewhat Poor
23	Gogram	24°26′08.5″	24.43569444	88°25′52.4″	88.43122222	High Land	Poor
24	Gogram	24°26′29.0″	24.44138889	88°26′07.9″	88.43552778	High Land	Somewhat Poor
25	Gogram	24°27′52.2″	24.4645	88°25′53.3″	88.43147222	High Land	Somewhat Poor
26	Gogram	24°25′45.7″	24.42936111	88°24′41.2″	88.41144444	High Land	Poor
27	Gogram	24°24′57.7″	24.41602778	88°25′35.3″	88.42647222	High Land	Somewhat Poor
28	Gogram	24°25′36.0″	24.42666667	88°27′35.0″	88.45972222	High Land	Somewhat Poor
29	Gogram	24°27′28.3″	24.45786111	88°26′19.5″	88.43875	High Land	Somewhat Poor
30	Matikata	24°26′57.2″	24.44922222	88°20′59.6″	88.34988889	Medium High Land	Poor
31	Matikata	24°26′10.9″	24.43636111	88°22′49.3″	88.38036111	High Land	Somewhat Poor
32	Matikata	24°25′40.2″	24.42783333	88°24′00.1″	88.40002778	High Land	Somewhat Poor
33	Matikata	24°27′06.4″	24.45177778	88°22′41.9″	88.37830556	High Land	Somewhat Poor
34	Matikata	24°24′13.0″	24.40361111	88°24′02.3″	88.40063889	Medium Low Land	Poor
35	Matikata	24°25′55.1″	24.43197222	88°22′46.3″	88.37952778	High Land	Somewhat Poor
36	Rishikul	24°28′35.8″	24.47661111	88°30′42.6″	88.51183333	High Land	Somewhat Poor
37	Rishikul	24°30′33.7″	24.50936111	88°29′16.4″	88.48788889	Low Land	Poor
38	Rishikul	24°28′29.9″	24.47497222	88°30′12.4″	88.50344444	Medium High Land	Somewhat Poor
39	Rishikul	24°28′12.4″	24.47011111	88°29′44.9″	88.49580556	High Land	Somewhat Poor
40	Rishikul	24°29′12.7″	24.48686111	88°27′13.6″	88.45377778	High Land	Somewhat Poor
41	Rishikul	24°28′19.7″	24.47213889	88°28′00.9″	88.46691667	High Land	Poor
42	Rishikul	24°29′04.8″	24.48466667	88°30′17.0″	88.50472222	High Land	Somewhat Poor
43	Rishikul	24°31′26.0″	24.52388889	88°30′22.0″	88.50611111	Medium High Land	Poor
44	Rishikul	24°28′51.6″	24.481	88°30′30.7″	88.50852778	High Land	Somewhat Poor
45	Rishikul	24°28′30.7″	24.47519444	88°30′35.3″	88.50980556	High Land	Somewhat Poor
46	Godagari	24°29′30.0″	24.49166667	88°19′18.0″	88.32166667	High Land	Somewhat Poor
47	Godagari	24°30′13.0″	24.50361111	88°19′42.0″	88.32833333	High Land	Somewhat Poor
48	Godagari	24°29′00.0″	24.48333333	88°20′21.4″	88.33927778	High Land	Somewhat Poor
49	Godagari	24°30′00.2″	24.50005556	88°20′26.5″	88.34069444	High Land	Somewhat Poor
50	Godagari	24°29′25.3″	24.49036111	88°21′59.5″	88.36652778	High Land	Somewhat Poor

51	Godagari	24°27′32.9″	24.45913889	88°21′30.7″	88.35852778	High Land	Somewhat Poor
52	Mohanpur	24°30′53.3″	24.51480556	88°21′51.1″	88.36419444	High Land	Somewhat Poor
53	Mohanpur	24°31′06.6″	24.5185	88°22′13.1″	88.37030556	High Land	Somewhat Poor
54	Mohanpur	24°32′29.2″	24.54144444	88°23′17.2″	88.38811111	High Land	Somewhat Poor
55	Mohanpur	24°33′21.1″	24.55586111	88°19′53.1″	88.33141667	High Land	Poor
56	Mohanpur	24°33′42.0″	24.56166667	88°21′03.3″	88.35091667	High Land	Somewhat Poor
57	Mohanpur	24°33′40.9″	24.56136111	88°21′25.5″	88.35708333	High Land	Somewhat Poor
58	Mohanpur	24°33′09.5″	24.55263889	88°22′50.7″	88.38075	High Land	Poor
59	Mohanpur	24°32′53.6″	24.54822222	88°22′13.3″	88.37036111	High Land	Somewhat Poor
60	Mohanpur	24°32′54.1″	24.54836111	88°23′24.6″	88.39016667	High Land	Somewhat Poor
61	Mohanpur	24°34′31.2″	24.57533333	88°25′21.2″	88.42255556	High Land	Somewhat Poor
62	Mohanpur	24°35′11.8″	24.58661111	88°25′13.2″	88.42033333	High Land	Somewhat Poor
63	Mohanpur	24°35′59.6″	24.59988889	88°25′37.4″	88.42705556	High Land	Somewhat Poor
64	Mohanpur	24°34′32.2″	24.57561111	88°25′08.4″	88.419	High Land	Somewhat Poor
65	Mohanpur	24°33′45.2″	24.56255556	88°24′19.8″	88.4055	High Land	Poor
66	Mohanpur	24°33′16.7″	24.55463889	88°24′15.6″	88.40433333	High Land	Somewhat Poor
67	Mohanpur	24°35′57.9″	24.59941667	88°23′02.0″	88.38388889	High Land	Somewhat Poor
68	Pakri	24°32′30.1″	24.54169444	88°27′06.5″	88.45180556	Medium High Land	Poor
69	Pakri	24°32′55.0″	24.54861111	88°27′56.8″	88.46577778	High Land	Somewhat Poor
70	Pakri	24°33′23.7″	24.55658333	88°28′16.5″	88.47125	Medium High Land	Somewhat Poor
71	Pakri	24°33′29.4″	24.55816667	88°27′31.5″	88.45875	High Land	Poor
72	Pakri	24°34′14.9″	24.57080556	88°27′46.2″	88.46283333	High Land	Somewhat Poor
73	Pakri	24°34′32.4″	24.57566667	88°27′10.2″	88.45283333	High Land	Somewhat Poor
74	Pakri	24°35′22.0″	24.58944444	88°26′27.3″	88.44091667	High Land	Somewhat Poor
75	Pakri	24°31′36.2″	24.52672222	88°26′49.2″	88.447	High Land	Somewhat Poor
76	Pakri	24°32′28.6″	24.54127778	88°26′08.4″	88.43566667	High Land	Somewhat Poor
77	Pakri	24°33′51.4″	24.56427778	88°26′08.7″	88.43575	High Land	Poor
78	Pakri	24°34′00.3″	24.56675	88°25′41.7″	88.42825	High Land	Poor

Source: Soil Resource Development Institute (SRDI), Rajshahi, 2015

It is found in above table that land type and drainage conditions vary from union to union which are important for type of crops to be cultivated, yield, and profit margin. For this, union wise land type and drainage condition are presented below in table 3.44.

Table 3.44. Union Wise Land Type and Drainage Condition of the Study Area

Union	Land Type					Drainage Condition				
	High	Medium High	Medium Low	Low	Very Low	Well	Moderate Well	Somewhat Poor	Poor	Very Poor
Basudevpur	-	-	1	2	-	-	-	-	3	-
C. Ashariadaha	-	5	1	-	-	-	-	3	3	-
Deopara	5	3	1	-	-	-	-	4	5	-
Gogram	11	-	-	-	-	-	-	9	2	-
Matikata	4	1	1	-	-	-	-	4	2	-
Rishikul	7	2	-	1	-	-	-	7	3	-
Godagari	6	-	-	-	-	-	-	6	-	-
Mohanpur	16	-	-	-	-	-	-	13	3	-
Pakri	9	2	-	-	-	-	-	7	4	-
Upazila	58	13	4	3	-	-	-	53	25	-

Source: Calculated from 78 Samples of SRDI, 2015

It is seen that high land and poor drainage condition dominate the study area which are presented below in figures 3.10 and 3.11.

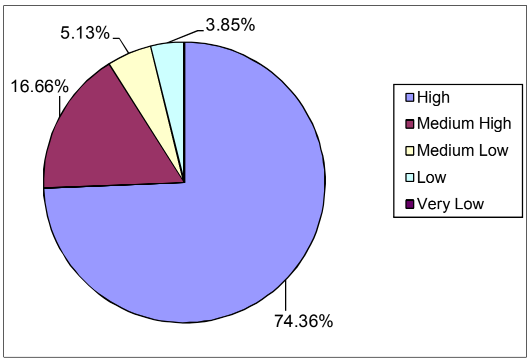

Figure 3.10. Land Type

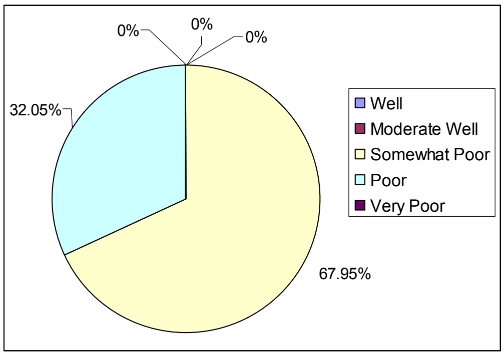

Figure 3.11. Drainage Condition

It is also found that in the study area drainage condition is not well or moderately well. This certainly tells that the study area is poorly drained area which is not good for agriculture. Poor drainage condition affects agriculture in the rainy season means *kharif* 2 as well as delays sowing in the *rabi* season. Topography attributes suitability of the study area is presented below.

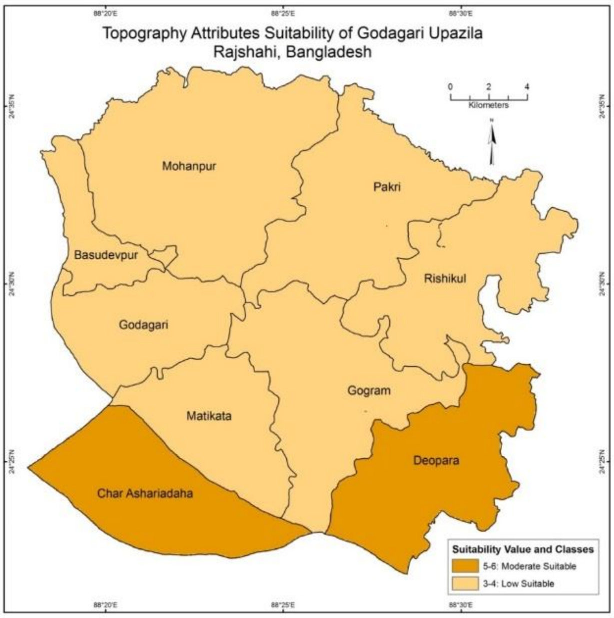

Figure 3.12. Topography Attributes Suitability

Source: Produced as of ArcGIS 10.1 Model

The above figure reveals that topographically Char Ashariadaha and Deopara union are low suitable which cover 18.66 per cent area and rest 7 unions are moderate suitable which account 81.34 per cent area. This picture tells that most of the land area are topographically moderately suitable for agriculture in the study area and it should be taken into consideration for agriculture development planning.

3.7 Floodability

The floodplains of Bangladesh are not flat and geographical investigation of the floodability of agricultural relevance is important in identifying the areal differences in agricultural type and formation. Many parts of the study area are subject to seasonal flooding with different extent of duration and the extent of flooding varies from year to year. A spatial variation of agricultural complexes is common in an area since land type and flooding depth have its own distinctive characterization.[19] The land of Bangladesh itself varies from place to place in terms of its suitability for agriculture because of the noticeable variations in flooding depth and duration. A pronounced contrast in respect of this alignment is noticed in different areas of Rajshahi district. The depth and duration of seasonal flooding and the perceived risks of flood damage

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[19] Singh and Dhillon, *Agricultural Geography,* 44.

determine the kinds of crops which farmers in different regions can grow on their different kinds of land.[20] The cultivation of crops is restricted by floodability level such as cotton or sugarcane or banana etc. Selection of crops, yield potentials, profitability, and sustainability are directly related with it. Floodability is analyzed below by flooding depth and flooding duration.

3.7.1 Flooding Depth

Farmers cropping practices on a particular field are mainly determined by the depth of seasonal flooding.[21] Depth of flooding mainly influences the kinds of crops that can be grown. According to SRDI classification, flooding depths in the study area are of five categories which are as follows:

1. Land above normal flooding = High Land
2. Land normally flooded up to 90 cm depth = Medium High Land
3. Land normally flooded up to 90 - 180 cm depth = Medium Low Land
4. Land normally flooded up to 180 - 275 cm depth = Low Land
5. Land normally flooded >275 cm depth = Very Low Land

Flooding depth is related to agriculture. Flooding depth is presented below in figure 3.13.

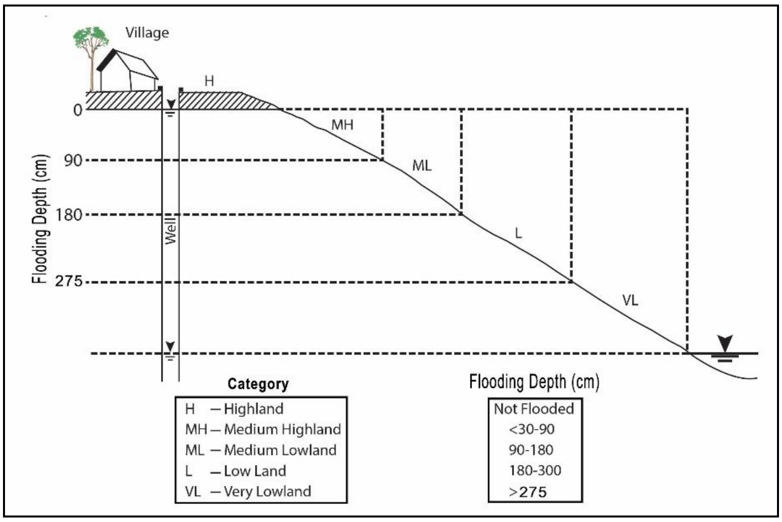

Figure 3.13. Flooding Depth

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[20] Hugh Brammer, *Can Bangladesh be Protected from Flood?* (Dhaka: The University Press Limited, 2004), 26.

[21] Ibid.,139.

The classification mentioned above has been standardized from Bangladeshi farmers' own classification of land types in relation to seasonal flooding. The rationale for such a detailed land classification system is the sensitivity of different kinds of rice, the country's main cereal crop, to specific depths of flooding at particular growth stages.

Table 3.45. Flooding Depth Data of the Study Area

Sl	Union	Y	DD Y	X	DD X	Flooding Depth
1	Basudebpur	24°31′23.5″	24.53183333	88°19′40.5″	88.32213889	Flooded: 90-180 cm depth
2	Basudebpur	24°31′54.6″	24.52319444	88°19′19.7″	88.32791667	Flooded: 180-275 cm depth
3	Basudebpur	24°33′54.1″	24.53961111	88°18′56.8″	88.31455556	Flooded: 180-275 cm depth
4	C. Ashariadaha	24°23′32″	24.40433333	88°20′5.8″	88.32027778	Flooded: up to 90 cm depth
5	C. Ashariadaha	24°24′36″	24.40063889	88°20′28″	88.31588889	Flooded: 90-180 cm depth
6	C. Ashariadaha	24°22′53.4″	24.39063889	88°24′11.1″	88.34586111	Flooded: 90-180 cm depth
7	C. Ashariadaha	24°23′10.8″	24.38633333	88°24′22.1″	88.40613889	Flooded:90-180 cm depth
8	C. Ashariadaha	24°23′21.4″	24.40897222	88°24′27.0″	88.32516667	Flooded: 90-180 cm depth
9	C. Ashariadaha	24°26′15.6″	24.38419444	88°19′13″	88.33752778	Flooded: up to 90 cm depth
10	Deopara	24°26′2.9″	24.43130556	88°31′20.6″	88.52119444	Flooded: 90-180 cm depth
11	Deopara	24°26′45.7″	24.42175	88°32′5.7″	88.51638889	Flooded: up to 90 cm depth
12	Deopara	24°27′14.8″	24.44861111	88°30′3.6″	88.522	Flooded:180-275 cm depth
13	Deopara	24°25′29.8″	24.38611111	88°30′48.01″	88.47694444	Flooded: up to 90 cm depth
14	Deopara	24°26′55″	24.39	88°31′19.2″	88.44638889	Flooded: up to 90 cm depth
15	Deopara	24°23′55″	24.43413889	88°29′24″	88.52238889	Flooded: up to 90 cm depth
16	Deopara	24°23′.06″	24.42972222	88°30′31″	88.45722222	Flooded: 90-180 cm depth
17	Deopara	24°27′1.1″	24.43277778	88°30′13.4″	88.47055556	Normally flood free
18	Deopara	24°26′23.5″	24.42636111	88°30′14.0″	88.46319444	Flooded: 90-180 cm depth
19	Gogram	24°25′36″	24.44836111	88°27′35″	88.43452778	Normally flood free
20	Gogram	24°27′39.2″	24.45283333	88°26′21.5″	88.43855556	Flooded:90-180 cm depth
21	Gogram	24°28′28.5″	24.47833333	88°27′32.5″	88.42658333	Normally flood free
22	Gogram	24°25′45.7″	24.43952778	88°24′41.2″	88.45311111	Normally flood free
23	Gogram	24°26′21.6″	24.43569444	88°25′0.2″	88.43122222	Flooded: up to 90 cm depth
24	Gogram	24°26′20.3″	24.44138889	88°26′6.8″	88.43552778	Normally flood free
25	Gogram	24°27′52.2″	24.4645	88°25′53.3″	88.43147222	Normally flood free
26	Gogram	24°24′57.7″	24.42936111	88°25′35.3″	88.41144444	Normally flood free
27	Gogram	24°26′8.5″	24.41602778	88°25′52.4″	88.42647222	Normally flood free
28	Gogram	24°26′29.0″	24.42666667	88°26′7.9″	88.45972222	Normally flood free
29	Gogram	24°26′54.1″	24.45786111	88°26′4.3″	88.43875	Normally flood free
30	Matikata	24°27′36″	24.44922222	88°22′9.2″	88.34988889	Normally flood free
31	Matikata	24°27′6.5″	24.43636111	88°23′49.4″	88.38036111	Flooded: up to 90 cm depth
32	Matikata	24°25′8″	24.42783333	88°22′51″	88.40002778	Flooded:90-180 cm depth
33	Matikata	24°26′16″	24.45177778	88°21′45″	88.37830556	Flooded: up to 90 cm depth
34	Matikata	24°26′15.8″	24.40361111	88°21′54.9″	88.40063889	Flooded: up to 90 cm depth
35	Matikata	24°24′13.0″	24.43197222	88°24′2.3″	88.37952778	Flooded: 90-180 cm depth
36	Rishikul	24°28′35.8″	24.47661111	88°30′42.6″	88.51183333	Normally flood free

37	Rishikul	24°30′33.7″	24.50936111	88°29′16.4″	88.48788889	Flooded:180-275 cm depth
38	Rishikul	24°29′39.7 ″	24.47497222	88°29′16.0″	88.50344444	Normally flood free
39	Rishikul	24°28′29.9″	24.47011111	88°30′12.4″	88.49580556	Flooded: up to 90 cm depth
40	Rishikul	24°29′12.7″	24.48686111	88°27′13.6″	88.45377778	Normally flood free
41	Rishikul	24°29′4.8″	24.47213889	88°30′17″	88.46691667	Normally flood free
42	Rishikul	24°31′26″	24.48466667	88°30′22″	88.50472222	Flooded: up to 90 cm depth
43	Rishikul	24°30′53.6″	24.52388889	88°31′39.3″	88.50611111	Flooded: up to 90 cm depth
44	Rishikul	24°32′28.9″	24.481	88°30′49.1″	88.50852778	Flooded: up to 90 cm depth
45	Rishikul	24°31′45″	24.47519444	88°29′17.2″	88.50980556	Normally flood free
46	Godagari	24°29′15″	24.49166667	88°20′20.5″	88.32166667	Normally flood free
47	Godagari	24°29′25.3″	24.50361111	88°21′59.5″	88.32833333	Normally flood free
48	Godagari	24°30′05″	24.48333333	88°22′36.3″	88.33927778	Flooded: up to 90 cm depth
49	Godagari	24°27′17.1″	24.50005556	88°20′23.5″	88.34069444	Flooded: up to 90 cm depth
50	Godagari	24°29′00″	24.49036111	88°19′12″	88.36652778	Normally flood free
51	Godagari	24°29′44.9″	24.45913889	88°18′41.6″	88.35852778	Flooded: up to 90 cm depth
52	Mohanpur	24°30′12.5″	24.51480556	88°23′47″	88.36419444	Flooded: up to 90 cm depth
53	Mohanpur	24°30′16.9″	24.5185	88°21′34.9″	88.37030556	Normally flood free
54	Mohanpur	24°31′6.6″	24.54144444	88°22′13.1″	88.38811111	Normally flood free
55	Mohanpur	24°33′42″	24.55586111	88°21′3.3″	88.33141667	Normally flood free
56	Mohanpur	24°32′29.2″	24.56166667	88°23′17.2″	88.35091667	Normally flood free
57	Mohanpur	24°33′40.9″	24.56136111	88°21′25.5″	88.35708333	Normally flood free
58	Mohanpur	24°32′53.6″	24.55263889	88°22′13.3″	88.38075	Normally flood free
59	Mohanpur	24°35′11.8″	24.54822222	88°26′13.2″	88.37036111	Normally flood free
60	Mohanpur	24°35′59.6″	24.54836111	88°25′37.4″	88.39016667	Normally flood free
61	Mohanpur	24°32′37″	24.57533333	88°20′50″	88.42255556	Normally flood free
62	Mohanpur	24°32′55.9″	24.58661111	88°23′6.9″	88.42033333	Flooded: up to 90 cm depth
63	Mohanpur	24°35′25.7″	24.59988889	88°24′23.9″	88.42705556	Flooded: up to 90 cm depth
64	Mohanpur	24°35′48.9″	24.57561111	88°22′12.8″	88.419	Flooded: up to 90 cm depth
65	Mohanpur	24°35′40.9″	24.56255556	88°21′17.3″	88.4055	Normally flood free
66	Mohanpur	24°31′42.2″	24.55463889	88°22′41.9″	88.40433333	Normally flood free
67	Mohanpur	24°30′12.5″	24.59941667	88°23′47″	88.38388889	Flooded: up to 90 cm depth
68	Pakri	24°32′30.1″	24.54169444	88°27′6.5″	88.45180556	Flooded: up to 90 cm depth
69	Pakri	24°33′23.7″	24.54861111	88°28′16.5″	88.46577778	Flooded: up to 90 cm depth
70	Pakri	24°34′14.9″	24.55658333	88°27′46.2″	88.47125	Normally flood free
71	Pakri	24°34′4.4″	24.55816667	88°27′16.5″	88.45875	Normally flood free
72	Pakri	24°35′22″	24.57080556	88°26′27.3″	88.46283333	Normally flood free
73	Pakri	24°30′0.9″	24.57566667	88°24′33.2″	88.45283333	Normally flood free
74	Pakri	24°31′36.2″	24.58944444	88°26′49.2″	88.44091667	Normally flood free
75	Pakri	24°32′9.8″	24.52672222	88°26′49.2″	88.447	Normally flood free
76	Pakri	24°32′28.6″	24.54127778	88°26′8.4″	88.43566667	Normally flood free
77	Pakri	24°33′51.4″	24.56427778	88°26′8.7″	88.43575	Normally flood free
78	Pakri	24°34′0.3″	24.56675	88°25′41.7″	88.42825	Normally flood free

Source: Soil Resource Development Institute (SRDI), Rajshahi, 2015

It is seen that different union have different type of depth of flooding. Agriculture is dependent with depth of flooding. Hence, union wise statistics of depth of flooding is summarized and presented below in table 3.46.

Table 3.46. Union Wise Depth of Flooding

Union	Above Normal Flooding	Flooded up to 90 cm Depth	Flooded up to 90-180 cm Depth	Flooded up to 180-275 cm Depth	Flooded >275 cm Depth
Basudevpur	0	0	1	2	0
C.Ashariadaha	0	2	4	0	0
Deopara	1	4	3	1	0
Gogram	9	1	1	0	0
Matikata	1	3	2	0	0
Rishikul	5	4	0	1	0
Godagari	3	3	0	0	0
Mohanpur	11	5	0	0	0
Pakri	9	2	0	0	0
Upazila	39	24	11	4	0

Source: Calculated from 78 Floodability Samples from Data of SRDI, 2015

It is found from above table that flood is no problem in the study area as the region is high land area. In case of depth of flooding, about 50 per cent areas are above normal flooding, 31 per cent areas may be flooded up to 90 cm depth, 14 per cent areas may be flooded up to 90-180 cm depth and only 5 per cent areas may be flooded up to 180-275 cm depth. The kinds of crops that can be grown depend on depth of flooding mainly in the *kharif* 2 season. It also affects crops production, timing of sowing of crops etc. The study area is virtually free from flooding problem except about 5 per cent areas and hence agriculture is not significantly affected by flood.

3.7.2 Flooding Duration

Flooding duration is very important for agriculture and crops damage is linked with it. It influences farmers' choice of crops and crop rotation in several ways. For example, the time of flood recession determines whether early, middle, or late dry land *rabi* crops are grown, or whether such crops can be grown at all. Early *rabi* crops are those such as *maskhalai* and mustard which can be sown in September to mid-November. Flooding duration is classified for the study area in the following way:

1. Flooding Duration: Normally not flooded or 1 or 2 days flooding;
2. Flooding Duration: Flooded for 2-15 days duration;
3. Flooding Duration: Flooded for 16-60 days' duration;
4. Flooding Duration: Flooded for 61-120 days (3-4 months); and
5. Flooding Duration: Flooded for 121-210 days (5-7 months) duration.

The study area is dominated by highland. Flooding duration of the study area is presented below.

Table 3.47. Union Wise Flooding Duration of the Study Area

Union	Flooding Duration							
	2-16 days		16-60 days		61-120 days		121-210 days	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Basudevpur	761	2.24	39	1.35	103	5.11	616	16.83
C.Ashariadaha	-	-	-	-	1126	55.97	75	2.04
Deopara	3635	10.73	114	3.95	275	13.66	799	21.84
Gogram	5214	15.40	801	27.81	149	7.40	575	15.71
Matikata	2630	7.77	164	5.70	100	4.98	595	16.27
Rishikul	4296	12.70	403	14.00	-	-	913	24.96
Godagari	2723	8.04	442	15.34	259	12.88	10	0.28
Mohanpur	8933	26.40	489	16.98	-	-	76	2.07
Pakri	5657	16.72	428	14.87	-	-	-	-
Upazila	33849	100	2880	100	2012	100	3659	100

Source: Calculated from Land and Soil Resources Utilization Guide: Godagari Thana, 2015

The above table shows that most areas in the study area are virtually flood free means 2-16 days flooding in the rainy season. A few areas may be flooded by 121-210 days of Basudevpur, Deopara, Gogram, Matikata, and Rishikul union. The flooding areas are mainly low lands, char lands and valley like areas between highlands. Crop cultivations are not possible in these areas in the rainy season means *kharif* 2 season.

Table 3.48. Flooding Duration of Godagari Upazila

Upazila	Flooding Duration									
	2-16 days		16-60 days		61-120 days		121-210 days		Total	
	Area (ha)	%	Area(ha)	%	Area (ha)	%	Area(ha)	%	Area(ha)	%
Godagari	33849	79.84	2880	6.80	2012	4.74	3659	8.62	42400	100

Source: Calculated from Land and Soil Resources Utilization Guide: Godagari Thana

It is found in above table that duration of flooding occurs only 2-15 days in 79.84 per cent areas which are considered virtually flood free.

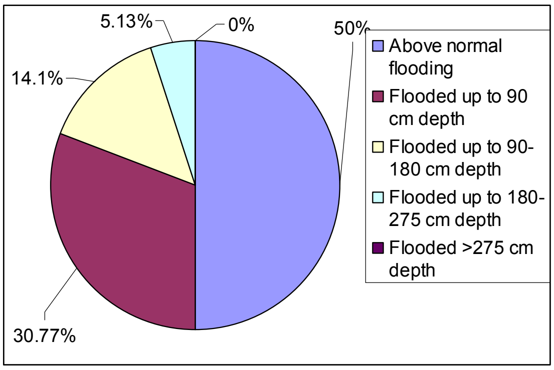

Figure 3.14. Depth of Flooding

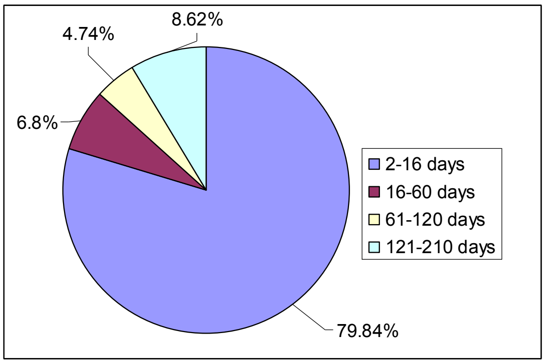

Figure 3.15. Duration of Flooding

Flooding duration may be 16-60 days only in about 6.80 per cent areas, 61-120-day duration may occur in 4.74 per cent areas and 121-210 days' duration are found in only 8.62 per cent areas. These statistics tell that 4/5 areas in the study area are flood free and above normal flooding. Only 8.62 per cent areas may go under flood for long time. Only 5 per cent areas are low land in the study area out of 47563 ha. These areas are valley (locally known as *baid*) in between highlands and *char* land areas which are generally submerged during the rainy season. Farmers can not cultivate this 5 per cent area in the rainy season.

Considering flooding depth and duration, it is thought that flood is no problem in the study area. Floodability attributes of the study area are presented below in figure 3.16.

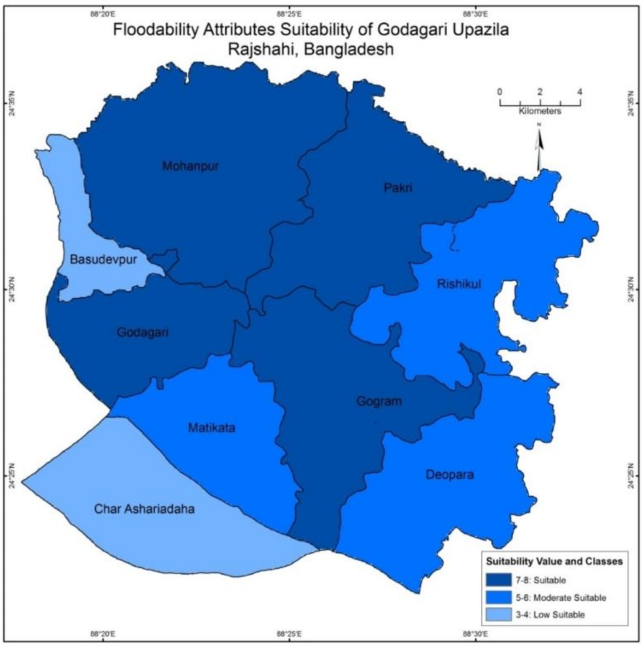

Figure 3.16. Floodability Attributes Suitability

Source: Produced as of ArcGIS 10.1 Model

The above figure 3.16 reveals that most of the areas are suitable for agriculture which accounts about 57 per cent areas. Matikata, Deopara and Rishikul union are moderately suitable which covers about 32 per cent areas. Only Basudevpur and Char Ashariadaha union are low suitable which covers about12 per cent area. The study area is 47563 ha area and suitable class covers more than half of the area which is good for agriculture. Insignificant area is low suitable which are natural in Bangladesh.

3.8 Accessibility

Distance from highway and distance from local markets are essential considering factors in modern farm operations for optimum production and highest economic return. Distance from highway and distance from local markets play an important role in farming being the determinants of inputs and outputs mobility for agricultural production and marketing and margin of profit. Developed rural infrastructure significantly promotes adoption of diversified cropping system and open up opportunities for management, marketing, storage, and resource supplies.[22] Diversified cropping system is considered one of the best ways to develop agriculture. The framework for economically viable agriculture consists of marketing facilities, accessibility to main roads, transport costs, and market prices, etc. These attributes individually or collectively influence agricultural patterns, productivity, and economic profit.[23]

3.8.1 Distance from Highway

Highways are the lifeline-the arteries of an economic activity. For the development of inherent agricultural potentials of an area, road accessibility is a terrible need as road transportation plays an important role in selling their productions.[24] Highways represent important linkages in the process of bettering agriculture of any area. A network of highways provides proper access to market for all types of farmers for their inputs and selling of outputs. Four km is the maximum distance that an individual may be willing to travel from home to the main road as opined by many experts. This distance should vary in accordance with the type of transportation, the total distance and the prices farmers may get from selling their farm produce. Transport costs depend on distances

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[22] Mohammad Monirul Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshai, 2015), 146.

[23] Singh and Dhillon, *Agricultural Geography,* 155.

[24] Ibid., 159.

that affect profits. Perishable produce needs good communication network for efficient and quick selling.

Buffer distance from highway is created and calculated using Euclidian distance method of ArcGIS 10.1, which is presented below in figure 3.17.

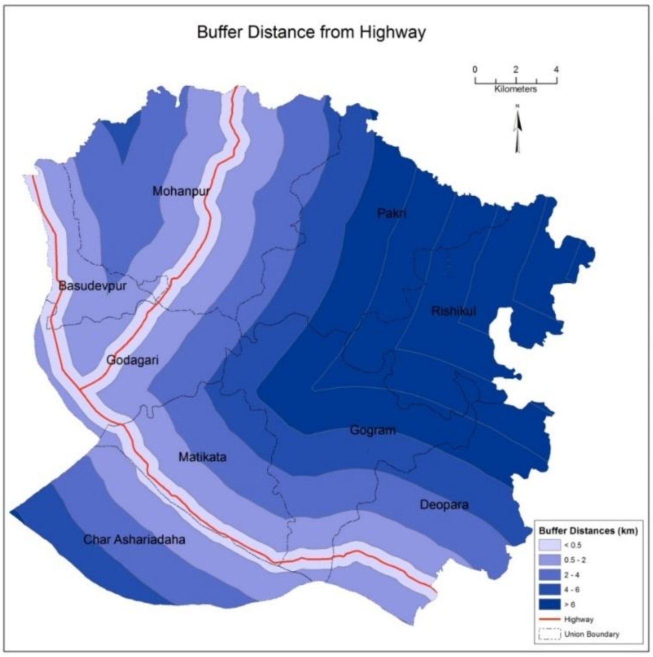

Figure 3.17. Buffer Distance from Highway

Source: Multiple Ring Buffers Created in ArcGIS 10.1 Model

The above figure shows that a significant portion agriculture area is away from short distance from highway which are mainly in Rishikul, Pakri, and Gogram union. Char Ashariadaha union is not far away from highway but separated by the Padma river which is a major barrier to use the highway for transporting agriculture commodities to the markets. These four union constitute about 48 per cent area. These areas need development of communication and easy access to highway.

Table 3.49. Tests of Normality for Distance from Highway

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Distance from Highway	.943	9	.000

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

It is seen from the above table of tests of normality that the significance level in the test (Kolmogorov-Smirnov) is less than 0.05. So, the null hypothesis is rejected which means that distribution of data does not fulfill normality condition. Hence, the data fall in the category of t- test.

Table 3.50. Calculation Table for Distance from Highway

Distance from Highway	N	Mean ($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	9	4.937	3.515	≤ 0.5

Hypothesis 1: H_0: $\mu = \leq 0.5$

H_1: $\mu \neq \leq 0.5$

Under null hypothesis: The test statistic is,

$$t = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

t = 3.787

Comment: The calculated value of t is greater than tabulated value (2.306). So, we may reject our null hypothesis at 5 % level of significance and conclude that there is significant difference of distance from highway value from optimum value. Therefore, distance from highway value of accessibility is not suitable for sustainable agriculture in the study area.

3.8.2 Distance from Local Market

Market is one of the most potent factors significantly stimulating agricultural production of an area, and farmers always need an easily accessible local market where farmers can sell their surplus agricultural produce. Distance to market is one of the most important considering factors in this respect when sold to that affect maximum returns after the deduction of marketing charges and production costs.[25] Agricultural production varies according to the demand of each products and distance from the concerned selling market.

Table 3.51. Tests of Normality for Distance from Local Market

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
Distance from Local Market	.998	9	.000

* This is a lower bound of the true significance.

a Lilliefors Significance Correction

25 Sing and Dhillon, Agricultural Geography, 155.

It is seen from the above table of tests of normality that the significance level in the above test (Kolmogorov-Smirnov) is less than 0.05. So, the null hypothesis is rejected which means that distribution of data does not fulfill normality condition. Hence, the data fall in the category of t- test.

Table 3.52. Calculation Table for Distance from Local Market

Distance from Local Market	N	Mean($\overline{X}$)	Std. Deviation(s)	Test Values (μ_0)
	9	5.106	1.484	≤ 2

Hypothesis 1: H_0: $\mu = \leq 2$

H_1: $\mu \neq \leq 2$

Under null hypothesis: The test statistic is,

$$t = \frac{\sqrt{n}(\bar{x} - \mu_0)}{s} \quad \text{Where, } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

t = 6.276

Comment: The calculated value of t is greater than tabulated value (2.306). So, we may reject our null hypothesis at 5 % level of significance and conclude that there is significant difference between distances from highway value to optimum value. Therefore, distances from highway value of accessibility is not suitable for sustainable agriculture in the study area.

Buffer distance from local markets are created and presented below.

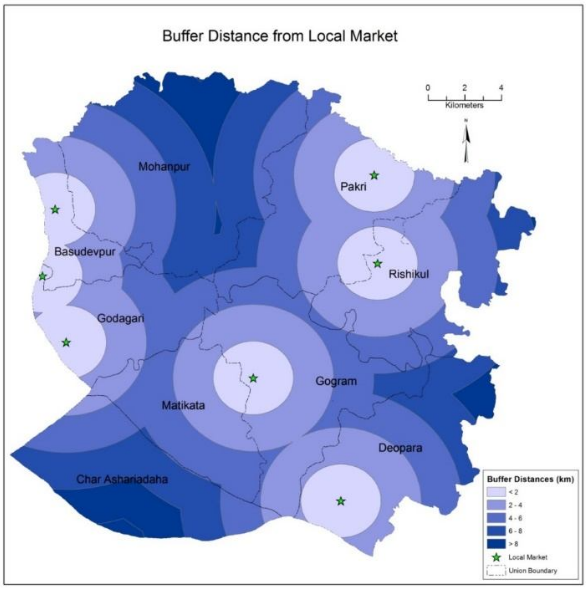

Figure 3.18. Buffer Distance from Local Markets

Source: Multiple Ring Buffers Created in ArcGIS 10.1 Model

The above figure shows that there are good numbers of agriculture areas particularly Char Ashariadaha, Mohanpur, Pakri, and Deopara union which are far away from local markets. Farmers of these areas are suffering problems with marketing their agricultural products and have to bear extra expenses for selling their products which minimize their margin of profit.

The study area has 9 unions and some of them have good communication facilities and near to highway and a few unions are away from highway and local markets which have implications on easy marketing and profitability. Union wise distance from highway and local markets are presented below in table 3.53 and figure 3.19.

Table 3.53. Union Wise Distance from Highway and Distance from Local Market

Name of Union	Distance from Highway	Distance from Local Market
Basudevpur	1.5824 km	3.0290 km
Char Ashariadaha	3.4986 km	7.8935 km
Deopara	4.7150 km	5.3228 km
Godagari	2.1085 km	4.2052 km
Gogram	6.2970 km	4.5061 km
Matikata	2.9418 km	4.9010 km
Mohanpur	2.8816 km	6.9933 km
Pakri	7.7731 km	4.3049 km
Rishikul	12.6423 km	4.8041 km
Mean	4.937 km	5.106 km

Source: Multiple Ring Buffers Created in ArcGIS 10.1Model

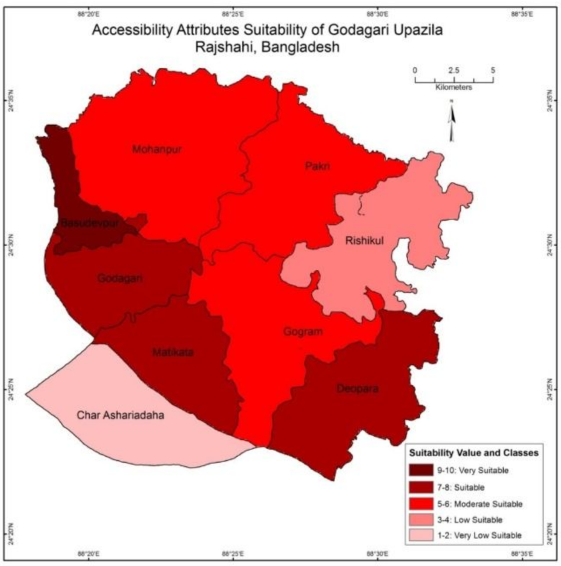

Figure 3.19. Accessibility Attributes Suitability

Source: Produced as of ArcGIS 10.1 Model

It is found in above table and figure that Rishikul, Pakri, Gogram, and Deopara union are situated more than 4 km away from highway. Though Char Ashariadaha union is about 3.5 km away but due to 4-8 km wide mighty the Padma river which requires 80-100 BDT for transporting 40 kg goods is a major barrier for transportation, profitability and agriculture development. On the other hand, except Basudevpur, all unions have more than 4 km distance from local markets that are much, require extra money to reach to the markets, and minimize the margin of profit.

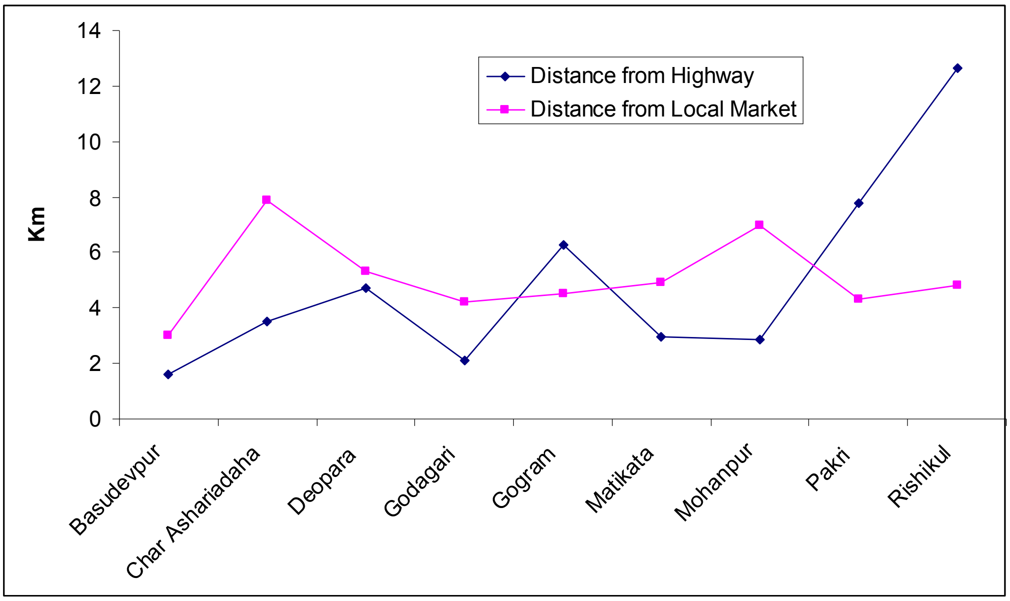

Figure 3.20. Union Distance from Highway and Local Market

The mean distance from highway and local market is about 5 km which is high and need to minimize for agriculture development. Hence, road networks and local market facilities should be developed.

3.9 Conclusion

The land characteristics and land suitability variables have been portrayed above based on present soil, irrigation water, climate, topography, floodability, and accessibility characteristics taking into account the optimum requirements for agriculture. Irrigation water quality is good but soil, rainfall, and topographical conditions are not favorable for sustainable agriculture. Floodability is no problem but accessibility is a major problem for Char Ashariadaha union. Road networks need to be developed and agriculture markets should be established depending on distance.

Chapter Four
Land Suitability Analysis Model

4.1 Introduction

The study of the relationships between physical and agro-economic phenomena and land suitability for sustainable agricultural development in an area is quite challenging. For undertaking such a study relating to clear comprehension of land suitability for leading agricultural crops, the use of models offers the most effective means of comprehending reality in all its diversity and complexity. Land suitability is a function of land characteristics and agricultural crops requirements for the maximum benefits. The objective of a firm is the choice of the optimal way of rising output as well as maximizing profits.[1]

A model for land suitability analysis for sustainable agricultural development has been developed after perusing a few related models to see the congruence of the proposed model for land suitability analysis of the study area. A description of suitability value and classes, model builder work flows, reclassified value calculation, percentage of influence calculation, and validation of the proposed model are described below.

4.2 Selection of Suitability Value and Classes of Data and Justifications

Different crops have different physiological and agronomical requirements. In this situation, all classes and their values of attributes were set as per experts' opinion and used in the model. According to the given weights, five suitability classes namely, highly suitable, suitable, moderately suitable, marginally suitable, and not suitable were selected and assigned weights to mentioned 5 suitability classes are 9-10, 7-8, 5-6, 3-4 and 1-2 respectively according to experts' opinions which are similar to many studies, such as Hugh Brammer.[2]

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[1] A. Koutsoyannis, *Modern Microeconomics,* 2nd ed. (London: Macmillan Education Ltd, 1979), 92.

[2] Hugh Brammer, *Agricultural Development Possibilities in Bangladesh* (Dhaka: The University Press Limited, 1997), 340.

4.2.1 Soil

Soil is important for agriculture and production considerably depends on soil quality. Good quality soil is conducive for high yield and poor quality soil is responsible for poor yield and accordingly high weighted values are assigned to good soil quality and low weighted values are given to poor soil quality. Depending on degrees of goodness to agriculture, weights were distributed from 10 to 1. In case of texture of soil, loams soil is good and sandy soil is bad for most crops in the study area. According to goodness of soil texture to agriculture, loam, sandy loam, clay loam, clay, and sandy soil have been given 9-10, 7-8, 5-6, 3-4, and 1-2 weights respectively. These 5 classes are widely used and accepted classes for classification of texture of soil. On the other hand, high moisture holding capacity of soil is good and low moisture holding capacity is bad for agriculture. Depending on their degrees of goodness to crops, classes were selected for moisture as high moisture holding capacity, medium moisture holding capacity, and low moisture holding capacity and weights were assigned 8-10, 5-7, and 2-4 for high, medium, and low moisture holding capacity respectively.

Similarly, for pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc and boron of soils, five classes namely, optimum, medium, high, low, and very low classes are set which are widely used classes for agriculture and scientific according to degrees of possibility for potential yields and for Bangladesh perspective. Weights were given accordingly from high to low production potentiality which are 9-10, 7-8, 5-6, 3-4, and 1-2 for optimum, medium, high, low, and very low classes respectively. According to the mean values of 10 attributes of 78 soil samples of the study area weights were given by 14 experts and mean values of those weights are given input into the model. In view of above it is projected that classes and weighted values of soil are rational and scientific.

4.2.2 Irrigation Water

Irrigation water is very important for potential yield and yield depends on water quality. Yield increases as irrigation water quality increases and yield decreases when water quality decreases. Therefore, higher weighted values were assigned to good quality and low weights to poor quality which are rational and widely used. Weighted value decreases as the degrees of restrictions on use for irrigation increase. pH, EC, and temperature are three important components of irrigation water and agriculture.

Temperature is particularly important for this study due to hottest temperature condition in the study area. For pH, EC, and temperature five suitability classes were followed. For pH, 9-10, 7-8, 5-6, 3-4, and 1-2 values were denoted as optimum (pH value 5.5-7.5), medium (pH value 4.5-5.5), high (pH value >7.5), low (pH value 4-5.5) and very low(pH value <4) respectively. For EC, 9-10, 7-8, 5-6, 3-4, and 1-2 values are symbolized for no restriction (0-700 mmhos/cm), slight restriction (701-1300 mmhos/cm), moderate restriction (1301-1900 mmhos/cm), severe restriction (1901-2500 mmhos/cm) and very severe restriction(>2500 mmhos/cm) respectively. In case of temperature, 9-10, 7-8, 5-6, 3-4, and 1-2 weights are assigned for no limitation(20-30°c), slight limitation(30-35 & 15-20°c), moderate limitation(35-38 & 10-15°c), severe limitation(8-10 &38-40°c) and very severe limitation(< 8 & > 40°c) respectively.

4.2.3 Climate

Climate condition and its uncertainties are important for agriculture. Production increases or decreases depending on suitability of climate condition. Therefore, suitable climate deserve higher weights and less suitable climate gets low weights. Five classes have been selected for classification of temperature and rainfall with a view to analyze data and use in the proposed model as input. 9-10, 7-8, 5-6, 3-4, and 1-2 values are designated as no limitation(20-30°c), slight limitation(30-35 and 15-20°c), moderate limitation(35-38 and 10-15°c), severe limitation(38 - 40 and 8-10°c) and very severe limitation (< 8 and > 40°c) for temperature. These five classes are selected as per experts' opinion considering the potential effects of temperature on yields which are very much useful for analysis of temperature in relation to crops yield, growth rate, potential damage to crops etc. For rainfall classification, 5 classes are chosen as no limitation, slight limitation, moderate limitation, severe limitation, and very severe limitation class considering the effects of rainfall on crops production. Rainfall classes used are no limitation for >1500 mm rainfall, slight limitation for 1200-1500 mm, moderate limitation for 1000-1200 mm, severe limitation for 750-1000 mm and very severe limitation for <750 mm rainfall respectively.

4.2.4 Topography

Land suitability hinges upon topographical condition. Better topographical condition is suitable to good agricultural production and suitability decreases as the topographical condition decreases and weighted values were allocated accordingly. Five classes were chosen for classification of topographical attributes in the model. In case of land type, 9-10, 7-8, 5-6, 3-4, and 1-2 were symbolized as medium low, medium high, low, very low, and high land type. Well, moderate well, somewhat poor, poor, and very poor classes for drainage condition were selected and values were assigned 9-10, 7-8, 5-6, 3-4, 1-2 respectively in lieu of mentioned drainage type. The above classes are standardized classification from farmers own classification of Bangladesh for land types in relation to normal seasonal flooding.

4.2.5 Floodability

Land suitability depends on flooding depth and flooding duration. If flooding depth and duration increases land suitability and yield potential decrease. Hence, weighted value increases as the depth of flooding and duration of flooding decrease and it is rational as the depth of flooding and duration of flooding become high they become more harmful for agriculture. For the purpose of giving input into model for land suitability analysis of depth of flooding 1-2, 3-4, 5-6, 7-8, 9-10 values were designated as very high(>275 cm depth), high(180-275 cm depth), medium(90-180 cm depth), low(up to 90 cm depth) and very low (not flooded)classes respectively. On the other hand, 1-2, 3-4, 5-6, 7-8 and 9-10 weighted values were nominated as 121-210 days, 61-120 days, 16-60 days, and 2-15 days flooding duration and normally not flooded for duration of flooding respectively.

4.2.6 Accessibility

Accessibility of agricultural land includes distance from highway and distance from local market. If farm distance becomes less from highway and local market it is more accessible and assigns higher weights. The distances from highway and local market increases, the land suitability decreases and hence weighted value decreases and it is widely used and accepted in these cases. Similar examples of weighted values are seen as to distance to road and distance to local market in the study of Hossain.[3] For distance from highway, ≤ 0.5km distance is very suitable which is denoted here as 9-10 weighted value, 7-8 denoted as suitable (0.5-2 km), 5-6 denoted as moderate suitable (2-4 km), 3-4 as low suitable (4-6 km) and 1-2 as very low suitable (> 6 km). On the other hand, ≤ 2

[3] M. Shahadat Hossain, "Land Suitability Analysis for Sustainable Aquaculture Development in Noakhali Coast" (PhD dissertation, University of Chittagong, 2008), 63.

km distance from local market is very suitable which are denoted as 9-10 weighted value, 7-8 as suitable (2-4 km), 5-6 as moderate suitable (4-6 km), 3-4 as low suitable (6-8 km) and 1-2 weighted values as very low suitable (>8 km). If an agricultural village is located more than 8 km from a main road it is considered very much interior and inaccessible,[4] which create problems to buy inputs with a view to use in farms and sells agricultural produces in the markets.

4.3 Work Flows (Analysis Procedures) of Model Builder for Land Suitability Analysis

Soil, irrigation water, climate, topography, floodability, and accessibility parameters are used to create model. The techniques that employed in this study are the spatial model creation and flow and the weighted overlay. The weighted overlay tool has the advantage to reclassify values in the input raster into a common evaluation scale of suitability by multiplying of each input raster, their cell values by the recognition of the raster's weight of importance and then create an integrated analysis by adding the cell values to produce the final suitability output raster as a result of weighted average of the values. The workflows (analysis procedures) of model builder were conducted in 3 steps.

1. Feature to Raster;
2. Reclassify Raster; and
3. Weighted Overlay.

Step 1: Feature to Raster

A model is created using Model Builder of Arc Toolbox from ArcGIS 10.1 software application to conduct all flow processes inside the model builder for analyzing data to make the land suitability analysis. Model is workflows that string together sequences of geo processing tools, feeding the output of one tool into another tool as input. The sequences are:

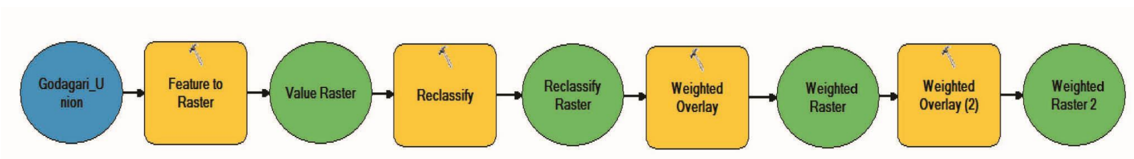

Figure 4.1. The Model Builder Graphical Representation of the Analysis Process

[4] Jasbir Singh and S. S. Dhillon, Agricultural *Geography* (New Delhi: Tata McGraw-Hill Publishing Company Limited, 1984), 158.

Union wise data of soil (texture, moisture, pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron) were converted from vector shape to raster. Similarly, irrigation water (pH, EC, and temperature), climate (temperature and rainfall), topography (land type and drainage), floodability (depth of flooding and duration of flooding) and accessibility (distance from highway and distance from local market) data were converted from vector shapes to raster.

Step 2: Reclassify Raster

In this step, the values in all the raster are reclassified to a common measure (1 to 10 scale and values) following the weighted values and percentage of influence using feature to raster tool. The reclassify is a tool that changes of the values in a raster. In the reclassify tool process, the following inputs (soil, irrigation water, climate, topography, floodability, and accessibility) in a total of 6 reclassifications were used. All data were converted into raster according to attribute value. Raster value was then reclassified to weighted value as 1 to 10 for classes of suitability. The point scale and reclassified values are described below.

2.1. Soil Attributes Reclassify to Raster: According to experts' opinion, the texture data were gathered as 1 to 10-point scale for the soil texture quality. Texture value 9-10 are denoted as loam soil, 7-8 as sandy loam soil, 5-6 as clay loam soil, 3-4 as clay soil and 1-2 as sandy soil (table 4.1; column 1). Moisture data were grouped as 1 to 10 point scale for moisture holding capacity level. Moisture value 8-10 are symbolized as high moisture holding capacity, 5-7 as medium moisture holding capacity and 2-4 as low moisture holding capacity (table 1; column 2). For pH, organic matter, nitrogen, phosphorus, potassium, sulfur, zinc, and boron attributes data were gathered as 1 to 10 point scale for aforementioned soil attributes. For these soil attributes, values 9-10 are embodied as optimum, 7-8 as medium, 5-6 as high, 3-4 as low, and 1-2 as very low (table 4.1; columns 3-10).

2.2. Irrigation Water Attributes Reclassify to Raster: According to experts' opinion, the irrigation water data were grouped as 1 to 10 point scale for the irrigation water quality. pH value 9-10 are represented as optimum (5.5-7.5), 7-8 as medium (4.5-5.5), 5-6 as high (>7.5), 3-4 as low (4-5.5) and 1-2 as very low (<4)(table 4.2;column 1). EC value 9-10 are represented as no restriction (0-700 mmhos/cm), 7-8 as slight restriction (701-1300 mmhos/cm), 5-6 as moderate restriction (1301-1900 mmhos/cm), 3-4 as severe restriction (1901-2500 mmhos/cm) and 1-2 as very severe restriction (>2500 mmhos/cm) (table 4.2;column 2). Temperature value 9-10 are indicated as no limitation (20-30°c), 7-8 as slight limitation (30-35 & 15-20°c), 5-6 as moderate limitation (35-38 & 10-15°c), 3-4 as severe limitation (8-10 &38-40°c), and 1-2 as very severe limitation (< 8 & > 40°c) (table 4.2;column 3).

2.3. Climate Attributes Reclassify to Raster: Based on experts' opinion the climate data were grouped as 1 to 10 point scale. Temperature value 9-10 are replaced as no limitation (20-30°c), 7-8 as slight limitation (30-35 and 15-20°c), 5-6 as moderate limitation (35-38 and 10-15°c), 3-4 as severe limitation (38 - 40 and 8-10°c) and 1-2 as very severe limitation (< 8 and > 40°c)(table 4.3;column1). Rainfall value 9-10 are changed as no limitation (>1500 mm), 7-8 as slight limitation (1200-1500 mm), 5-6 as moderate limitation (1000-1200 mm), 3-4 as severe limitation (750-1000 mm), 1-2 as and very severe limitation (<750 mm) (table 4.3;column1).

2.4. Topography Attributes Reclassify to Raster: According to experts' opinion, the land type data were grouped as 1 to 10 point scale for land type class. Land type weighted values 9-10 are symbolized as medium low, 7-8 as medium high, 5-6 as low, 3-4 as very low and 1-2 as high(table 4.4;column 1). Drainage data were gathered as 1 to 10 point scale for drainage condition. Drainage condition weighted values 9-10 are shown as well, 7-8 as moderate well, 5-6 as somewhat poor, 3-4 as poor, and 1-2 as very poor (table 4.4; column 2).

2. 5. Floodability Attributes Reclassify to Raster: The floodability data were grouped as 1 to 10 point scale for depth of flooding and duration of flooding. Depth of flooding weighted value 1-2 are signified as very high(>275 cm depth), 3-4 as high (180-275 cm depth), 5-6 as medium (90-180 cm depth), 7-8 as low (up to 90 cm depth) and 9-10 as very low (not flooded)(table 4.5;column1). Duration of flooding weighted values 1-2 are denoted as 121-210 days, 3-4 as 61-120 days, 5-6 as 16-60 days,7-8 as 2-15 days and 9-10 as normally not flooded(Table 4.5;column 2).

2.6. Accessibility Attributes Reclassify to Raster: Accessibility data were generated as 1 to 10 point scale for the distance from highway and distance from local market. Tabular distance to highway value 9-10 are labeled as very suitable (< 0.5km), 7-8 as suitable (0.5-2 km), 5-6 as moderate suitable (2-4 km), 3-4 as low suitable (4-6 km) and

1-2 as very low suitable (> 6 km). Tabular distance to local market weighted values 9-10 are symbolized as very suitable (< 2 km)(table 4.6;column 1), 7-8 as suitable (2-4 km), 5-6 as moderate suitable (4-6 km), 3-4 as low suitable (6-8 km) and 1-2 as very low suitable (>8 km) (Table 4.6;column 2).

Step 3: Weighted Overlay

From step 2 the researcher generated 21 reclassified raster images on study theme; these themes were weighted overlay in this session on the basis of 100 per cent influence of each theme. Twenty one reclassified raster images were weighted overlay to generate 6 themes using expert given percentage of influences (table 4.7; column 3). Six themes were further weighted overlay to produce final overall land suitability map raster image on the basis of percentage of influence (table 4.7; column 12). To generate crop wise 8 suitability maps, same 21 reclassified raster images were used and model were run separately for each crop. Twenty one reclassified raster images were weighted overlay on the basis of percentage of influences (table 4.7; columns 4-11) to produce crop wise 6 themes. Crop wise 6 themes were second time weighted overlay following percentage of influences (table 4.7; columns 13-20) as given by experts. Thus, overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops suitability maps were generated.

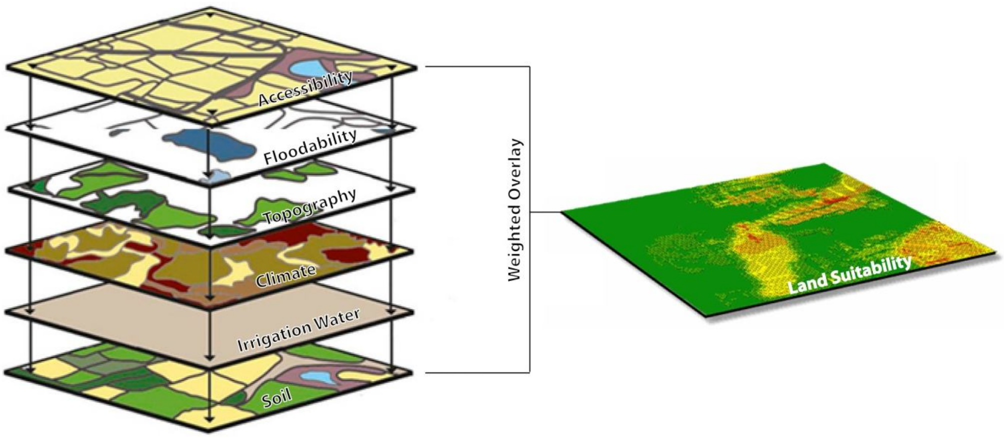

Figure 4.2. Weighted Overlay

Source: Developed by the Researcher

The final process is illustrated in figure 4.3(final process of model builder) to generate the final output raster that represents the land suitability value and classes. In the above mentioned way the final suitability map of overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion and chili crops cultivation suitability maps were generated which show the 5 land suitability classes and values; 9-10 = Highly Suitable, 7-8= Suitable, 5-6= Moderately Suitable, 3-4= Marginally Suitable, and 1-2= Not Suitable.

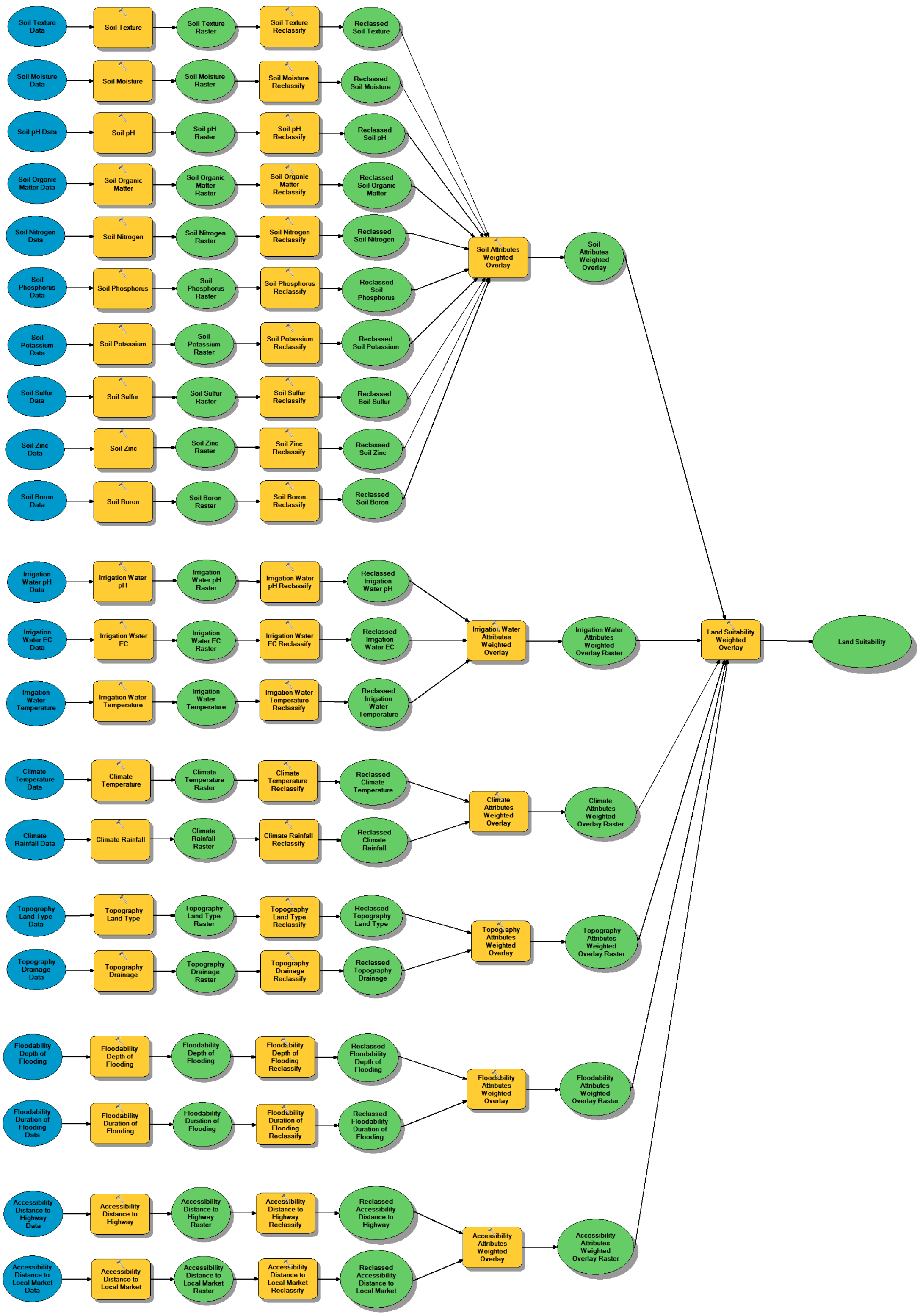

Figure 4.3. Work Flows of Model Builder

Source: Developed by the Researcher

4.4 Reclassified Value Calculation of Data

Reclassified values of data used in the model are presented below in tabulating form. On the other hand, the main data are presented in chapter three named "Land Characteristics and Land Suitability Variables".

4.4.1 Soil Attributes

The main properties of soils for plant growth are texture, moisture holding capacity, pH, organic matter, nitrogen, phosphorus, and potassium. In addition to main properties of soils mentioned above sulfur, zinc and boron are taken into consideration for land suitability analysis considering the study areas soil characteristics and suggestions of agriculture officials. For the purpose of use of soil data into the land suitability model 78 soil samples data were processed and constructed into spatial database using ArcGIS 10.1. According to position of mean values of data in relation to optimum values of that attribute weighted value were given and used in the model as input. The estimated union wise reclassified values for selected 10 attributes of soil of the study area that used in the model are presented in table 4.1. Using the union wise reclassified values of soil attributes through model, generated soil attributes suitability map is given in figure 4.4.

Table 4.1. Union Wise Reclassified Values of Soil Attributes Based on Weights

Union	Texture	Moisture	pH	Org Ma	Nitr	Phosp	Potas	Sulfur	Zinc	Boron
Basudebpur	4	3	8	7	4	8	8	8	7	5
C.Ashariadaha	8	7	6	4	2	4	8	4	4	9
Deopara	5	4	6	4	2	4	7	8	7	6
Gogram	6	3	4	4	3	3	8	8	8	6
Matikata	5	3	8	4	2	4	8	7	8	9
Rishikul	4	3	8	3	2	4	7	8	7	5
Godagari	6	3	8	3	2	7	7	3	7	8
Mohanpur	6	3	4	3	2	3	8	3	4	7
Pakri	5	3	8	4	3	7	7	4	7	7

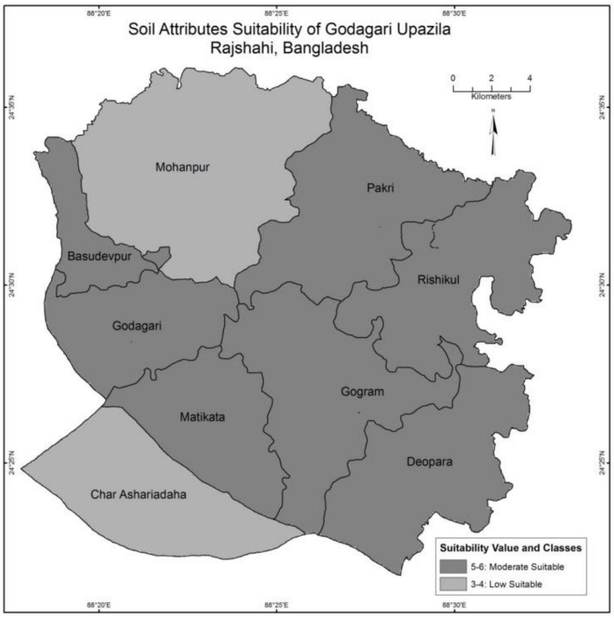

Figure 4.4. Soil Attributes Suitability Map

Source: Expert Opinion (Table).Generated as of ArcGIS 10.1 Model Based on Expert Opinion (Figure)

4.4.2 Irrigation Water Attributes

Irrigation water quality affects plants growth and is a critical factor for production of crops. Ground waters are only used in the study area for irrigation, no surface water is found to use. Farming in dry land like the study area without irrigation is uneconomic and good quality irrigation water allows maximum yields. Experts given union wise reclassified values for selected 3 attributes of irrigation water namely, pH, EC and temperature used in the land suitability model and suitability map produced based on reclassify values are as follows.

Table 4.2. Union Reclassified Values of Irrigation Water

Union	pH	EC	Temperature
Basudevpur	8	9	7
Char Ashariadaha	8	7	7
Deopara	8	9	6
Gogram	9	9	6
Matikata	8	9	7
Rishikul	8	9	6
Godagari	8	9	7
Mohanpur	8	9	6
Pakri	8	8	6

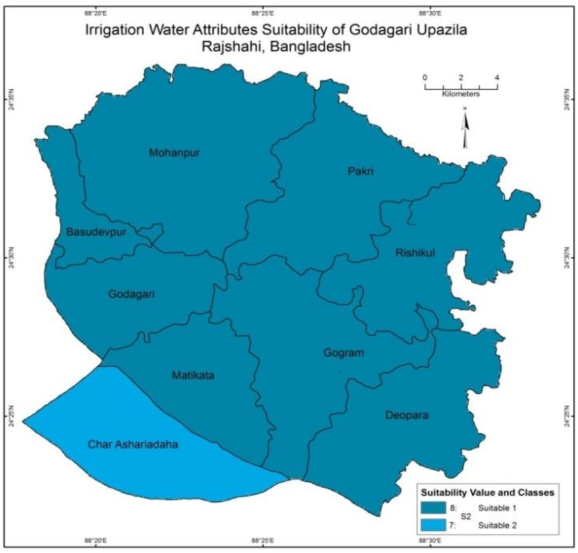

Figure 4.5. Irrigation Water Attribute Suitability

Source: Expert Opinion (Table). Generated as of ArcGIS 10.1Model Based on Expert Opinion (Figure)

4.4.3 Climate Attributes

The most powerful determinant of an ecosystem is climate, which determines what plants grow where. There is no variation of climate data in the study area as there is only one meteorological station. Since climate data have no variations spatially, it matters nothing in changing pattern of land suitability and has little significance on land suitability analysis. But, potential crop- producing capability of any area is dependent mainly on the existing climatic conditions. Temperature and rainfall are the most important factors characterizing an area's climate.[5] It is essential to take into account variability of rainfall and temperature which are especially important for agriculture of a given region. As the study area is located in the dry part of Bangladesh and rainfall is scanty and not sufficient for agriculture, temperature and rainfall of climate have taken into consideration and weights were assigned accordingly taking into account the little significance of spatially in varied data of climate. Experts given union wise weighted values for selected 2 attributes of climate namely, temperature and rainfall used in the model and suitability map generated are presented below in table 4.3 and figure 4.6.

Table 4.3. Reclassified Values of Climate

Union	Temperature	Rainfall
Basudevpur	6	6
Char Ashariadaha	6	6
Deopara	6	6
Gogram	6	6
Matikata	6	6
Rishikul	6	6
Godagari	6	6
Mohanpur	6	6
Pakri	6	6

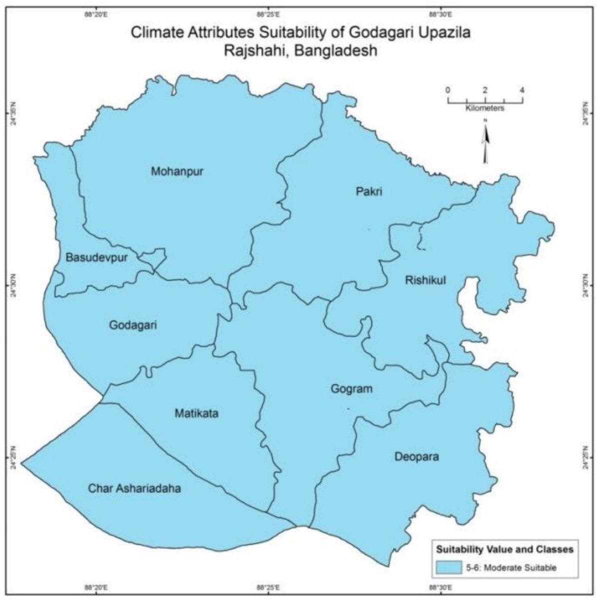

Figure 4.6. Climate Attributes Suitability

Source: Expert Opinion (Table). Generated as of ArcGIS 10.1Model Based on Expert Opinion (Figure)

[5] Watson M Laetsch, *Plants: Basic Concepts in Botany* (Canada: Little, Brown and Company Limited, 1979), 422.

4.4.4 Topography Attributes

Topography analysis is a measurement about an area, its landform, and surface variability. Topographic analysis effectively relates topographic features with agricultural characteristics. Land type and drainage condition are used in this study for land suitability analysis for sustainable agricultural development of the study area. Based on the position of topographic data in comparison to optimum value for agriculture, union wise class and weighted value were calculated and used for land suitability analysis. The estimated reclassified values for selected two attributes of topography namely, land type and drainage condition which are used in the model for land suitability presented in table 4.4 and produced suitability map in figure 4.7.

Table 4.4. Reclassified Values for Topography

Union	Land Type	Drainage Condition
Basudebpur	6	3
C. Ashariadaha	7	4
Deopara	5	4
Gogram	3	5
Matikata	3	5
Rishikul	3	5
Godagari	3	5
Mohanpur	3	5
Pakri	3	5

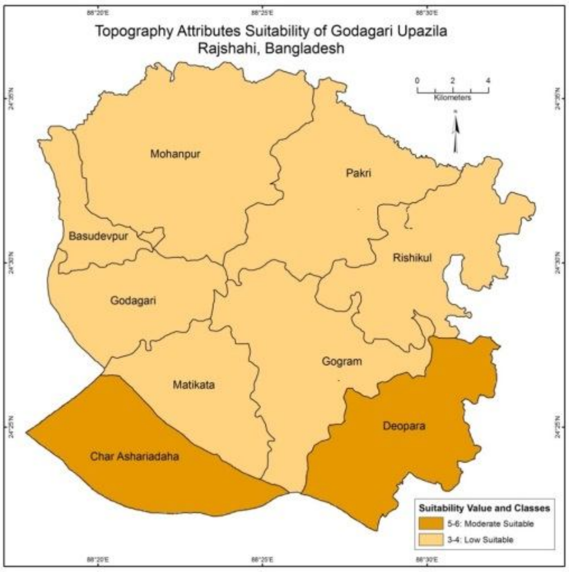

Figure 4.7. Topography Attributes Suitability

Source: Expert Opinion (Table). Generated as of ArcGIS 10.1Model Based on Expert Opinion (Figure)

4.4.5 Floodability Attributes

Flood is a common phenomenon in Bangladesh. The probability of flooding can never be reduced to zero. The study area is situated along the mighty Padma river. Therefore, it is important to take into account the floodability for land suitability analysis and sustainable agricultural development. Experts given union wise reclassified values for selected two attributes of floodability namely, depth of flooding and duration of flooding used in the land suitability model and map produced through the developed model on the basis of mentioned weights are presented below in table 4.5 and figure 4.8.

Table 4.5. Reclassified Values of Floodability

Union	Depth	Duration
Basudebpur	4	4
C. Ashariadaha	3	3
Deopara	6	6
Gogram	7	6
Matikata	6	6
Rishikul	7	5
Godagari	7	6
Mohanpur	8	7
Pakri	7	8

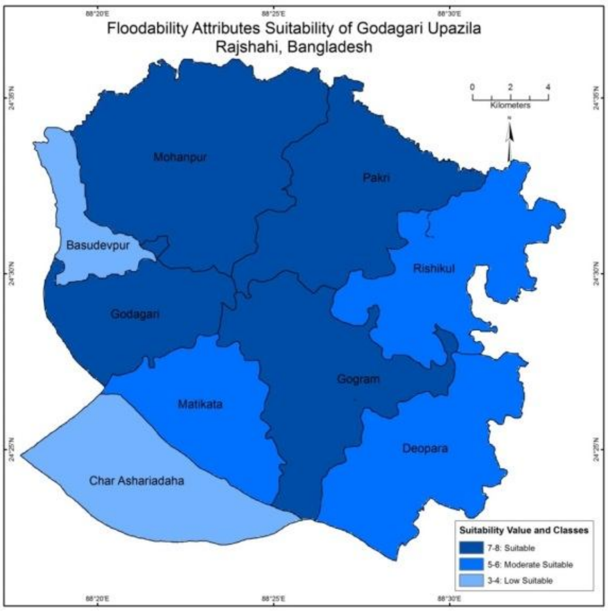

Figure 4.8. Floodability Attributes Suitability

Source: Expert Opinion (Table). Generated as of ArcGIS 10.1Model Based on Expert Opinion (Figure)

4.4.6 Accessibility Attributes

Accessibility is an important factor in modern agriculture being the determinants of inputs and outputs mobility for agricultural production and marketing. Farmers sell their produce to small traders at home or in the nearest markets which are then taken to secondary and urban wholesale markets to retailers to reach it to final consumers. Prices differ by location and distance to markets. There are many researches in this regard, such as Alam.[6] In the present study, distance from highway and distance from local markets have taken into consideration for land suitability analysis. The mighty Padma river flows through the study area and separated union Char Ashariadaha from other unions and made virtually inaccessible for agricultural marketing and per 40 kg costs 80/100 BDT to sell in the mainland markets. There is only one highway and road communications matter. The estimated reclassified values for selected two attributes of accessibility namely, distance from highway and distance from local market by experts which are used in the model for land suitability analysis presented below in table 4.6 and produced map in figure 4.9.

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[6] Jahangir Alam, *Studies on Agriculture and Rural Development* (Dhaka: Palok Publishers, 2008), 127.

Table 4.6. Reclassified Values of Accessibility

Union	Distance from Highway	Distance from Local Market
Basudebpur	9	8
C. Ashariadaha	1	2
Deopara	7	6
Gogram	5	7
Matikata	8	6
Rishikul	1	6
Godagari	9	7
Mohanpur	8	4
Pakri	3	7

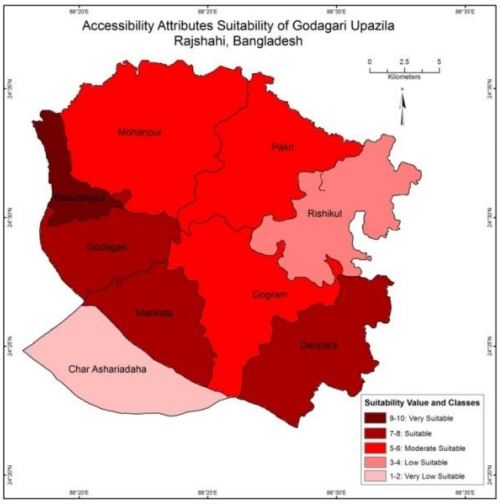

Figure 4.9. Accessibility Attributes Suitability

Source: Expert Opinion (Table). Generated as of ArcGIS 10.1 Model Based on Expert Opinion (Figure)

4.5 Percentage of Influence of Weighted Overlay

Twenty one thematic maps of soil, irrigation water, climate, topography, floodability, and accessibility attributes were combined and weighted overlay to generate six main raster using experts given percentage of influence. Generated six raster were then weighted overlay to produce overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion and chili crops cultivation suitability maps using experts given percentage of influence. Different crops have different physiological and agronomical requirements and hence weighted value and percentage influence are supposed to be different from one crop to another. Experts given percentage of influence for 21 attributes of soil, irrigation water, climate, topography, floodability and accessibility are presented in table 4.7(columns 3-11). Experts given percentage of influences of 6 themes namely, soil, irrigation water, climate, topography, floodability and accessibility to generate overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion and chili crops' cultivation suitability are mentioned in the table 4.7 (columns 12-20).

Table 4.7. Percentage of Influences of Overall Land Suitability, Rice, Wheat, Maize, Potato, Lentil, Mustard, Onion, and Chili Crops Cultivation

Attributes	Sub Attributes	Percentage Influence of 21 Sub Attributes									Percentage Influence of 6 Themes								
		OLS	Rice	Wheat	Maize	Potato	Lentil	Mustard	Onion	Chili	OLS	Rice	Wheat	Maize	Potato	Lentil	Mustard	Onion	Chili
Soil	Texture	10	10	09	10	12	11	14	08	10	35	42	42	44	42	52	51	49	47
	Moisture	10	08	08	08	10	09	09	08	08									
	pH	10	06	05	05	05	08	05	07	05									
	Org Matter	20	20	20	20	20	20	20	18	15									
	Nitrogen	10	12	12	18	14	08	12	12	12									
	Phosphorus	10	12	12	10	11	14	12	12	12									
	Potassium	10	14	14	10	14	14	12	12	15									
	Sulfur	10	08	08	08	07	07	06	13	14									
	Zinc	05	06	06	06	05	04	05	06	05									
	Boron	05	04	06	05	02	05	05	04	04									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**									
Irrigation Water	pH	40	42	46	44	46	42	44	44	42	20	20	18	16	18	04	09	10	14
	EC	40	38	38	34	35	34	28	38	37									
	Temperature	20	20	16	22	19	24	28	18	21									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**									
Climate	Temperature	50	32	64	68	67	55	48	47	46	10	08	07	07	08	07	07	07	05
	Rainfall	50	68	36	32	33	45	52	53	54									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**									
Topography	Land Type	50	56	52	47	54	52	38	48	54	15	14	16	16	16	21	20	18	17
	Drainage	50	44	48	53	46	48	62	52	46									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**									
Floodability	Depth	50	36	48	36	48	36	38	42	42	15	08	08	08	06	06	04	06	07
	Duration	50	64	52	64	52	64	62	58	58									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**									
Accessibility	Distance to Highway	50	38	32	34	34	32	28	34	28	05	08	09	09	10	10	09	10	10
	Distance to Local Market	50	62	68	66	66	68	72	66	72									
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Expert Opinion

Note: OLS= Overall Land Suitability

4.6 Validation of the Proposed Model

The proposed land suitability model is considered representation for some essentials for the study according to the need of the specific objectives. For a clear comprehension and appreciation of land characteristics and suitability of leading agricultural crops, models are nowadays considered the most vital tools in empirical investigation. The proposed land suitability model is validated in this study in respect of:

1. **Empirical Investigation:** As the model prepared considering the real world i.e., study area, it involves the empirical data. The structure of the model presents the evaluation of the variables and integrated essentials for the results of the study.

2. **Component Testing:** The model linked with different attributes that shows the analyzed result of the study and thus it involves component testing and validity of the components. Examination of field situation and sensitivity of inputs could be achieved with reliability through this model as described earlier.

3. **Weight Calculation:** Weights of each attributes could be calculated through the proposed model. The results of the calculation are again linked with land suitability analyses and represents multistage analytical methods regarding land suitability and sustainable agriculture as described above.

4. **Analytical Model Validation Techniques:** The proposed model based on GIS and information technology that include integrated analysis of all variables and shows separate outputs of the variable in details. The combined results of the variables also considered for the final outputs of the study. Thus, the analytical techniques of the model are considered as appropriate techniques.

5. **Spatial Pattern Analysis:** Depending on six important attributes of voluminous data union wise spatial patterns are analyzed for overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion and chili crops cultivation, this is virtually impossible manually.

6. **Congruence of Model:** This type of model is seen to use in many cases for land suitability analysis and proved effective. Therefore, the used model is valid from the point of congruence.

7. **Comprehensiveness:** Key properties of land suitability and sustainable agriculture- soil, irrigation water, climate, topography, floodability, and accessibility attributes were used in the model for land suitability analysis. So, it is comprehensive and useful to a large number of situations regarding land suitability vis-à-vis sustainable agricultural development.

8. **Predictability:** The used model is suitable to predict the characteristics of individual phenomenon of soil, irrigation water, climate, topography, floodability, and accessibility of the study area as well as land suitability of rice, wheat, maize, potato, lentil, mustard, onion and chili crops cultivation and overall land suitability of the study area.

9. **Efficiency:** The model used in this study is concise and to the point that it could make the analyses using huge data and a lot of statements within very short time. Model edited, tabulated, processed and used voluminous data and gave many outputs with many kinds of explanations and analyses in a short time.

10. **Applicability:** The quantitative analysis of land suitability has been simplified by the use of the model and it is applicable to all similar cases.

11. **Appropriateness:** This model has simplified substantiation and explanation of facts in an abridged and concrete form. It is appropriate for manifold functions to analyze land suitability and generation of composite land suitability maps and explanations.

12. **Accuracy:** The proposed model has the quality of accurate predictions which matches model predictions with observations. With respect to verified 56 sites, model provides accurate figure of land suitability outputs in this study in relation to field observations and accuracy rate between land suitability model outputs and field observation data is found between 87.50 percent and 92.85 percent.

13. **Explanation:** The model simplified and concretized the explanations regarding land suitability and sustainable agriculture of the study area demonstrating the properties in a simplified and accurate form. The study of relationship will be great help in clubbing together the phenomena possessing similar characteristics and the areas of homogenous agricultural activities.

14. **Use of ArcGIS 10.1 Model and Weighted Overlay Procedure:** ArcGIS 10.1 model and weighted overlay procedures have been used which are very refined for land suitability analysis.

In view of above it is claimed that the proposed land suitability model of this study has good range of validation.

4.7 Conclusion

Model demonstrates a fundamental understanding of the spatial analysis and includes reasoning about reality in a spatial-temporal perspective. The present study focuses on land suitability analysis for sustainable agricultural development of Rajshahi district throwing light on leading agricultural crops based on soil, irrigation water, climate, topography, floodability, and accessibility attributes of the study area. To achieve the goal of the research work the used model acts as simplified and hypothetical description of the interaction of phenomena of the study area relating to suitability analysis of main crops of the study area as described above.

Chapter Five
Land Suitability Analysis of the Study Area

5.1 Introduction

Land suitability analysis for overall land suitability and leading agricultural crops of Godagari upazila in Rajshahi district of Bangladesh is done based on six important variables viz., soil, irrigation water, climate, topography, floodability, and accessibility attributes of the study area. The outputs generated as suitability maps for overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation following the procedures mentioned in chapter four “Land Suitability Analysis Model”.

Different crops have different physiological and agronomical requirements which were taken into consideration in the process. Organic matter, nitrogen, phosphorus, sulfur, and zinc of soil are important for rice but not potassium though potassium is important for potato. Cereal crops and potato are sensitive to high soil boron. High and low pH, high EC, and very high and very low temperature of irrigation water are not conducive for good yield. Temperatures below 7°c may produce seed prematurely of many crops such as cabbage, carrot, and cauliflower and above 30°c affect pollination and shed flowers of many vegetable crops. Flooding time, duration, and topography determine crop cultivation and yield.

Nevertheless, there are no fixed weighted value and percentage of influence of soil, irrigation water, climate, topography, floodability, and accessibility attributes for different crops. Available sketchy relevant information in different documents such as soil, water and climate requirements for crops by Hussain, Chowdhury and Chowdhury,[1] Land and Soil Resources Utilization Guide of SRDI,[2] zijsvelt’s soil-crop suitability model for Bangladesh by FAO,[3] soil conditions for crops by BARC,[4] water

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[1] Sk. Ghulam Hussain, M. Khalequzzaman A. Chowdhury and M. Abeed Hossain Chowdhury, *Land Suitability Assessment and Crop Zoning of Bangladesh* (Dhaka: Bangladesh Agricultural Research Council, 2012), 91-100.

[2] Soil Resources Development Institute, *Land and Soil Resources Utilization Guide: Godagari Thana, Rajshahi District* (Dhaka: SRDI, Ministry of Agriculture, 1991), 96-101.

[3] Food and Agricultural Organization, “Land Resources Appraisal for Bangladesh for Agricultural Development,” Report 7, Vol. 2 (Rome: FAO of United Nations, 1988), 96.

quality for irrigation by Ayers and Westcot,[5] suitability class by Prakash,[6] suitability rating for crops by Brammer,[7] diagnostic characteristics for vegetables by Baniya,[8] surface water classification by DoE and BEMP,[9] distance to road and distance to local market by Hossain,[10] and other relevant documents were perused and taken into consideration during weighted value and classes calculation.

It is noteworthy to mention here that Analytic Hierarchy Process (AHP) developed by Saaty and pairwise comparison matrix were perused but it was not found apposite in this case because of the uneven distribution of attributes (ten attributes for soil, three attributes for irrigation water, and two attributes each for climate, topography, floodability, and accessibility). Pairwise comparison matrix has only 9 scales which had possibility to be insufficient for soil attributes (soil has 10 attributes in this study). The approximation in pairwise comparison matrix is worked well for small matrix size $n \leq 3$ and there is no guarantee that the rank will not reverse because of the approximation error.[11]

Against this backdrop to assign weighted value and percentage of influence for overall land suitability and major crops (rice, wheat, maize, potato, lentil, mustard, onion and chili cultivation) of the study area total 14 experts' opinion regarding 6 criteria and 21 sub criteria were taken and weighted mean values were calculated and used in this study. The detailed account of weighted value and percentage of influence is mentioned in "Land Suitability Analysis Model" chapter.

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[4] Bangladesh Agriculture Research Council, *Fertilizer Recommendation Guide-2012* (Dhaka: BARC, 2012), 5-7.

[5] R. S. Ayers and D. W. Westcot, "Water Quality for Agriculture," *FAO Irrigation and Drainage Paper* 29, Rev. 1 (Rome: FAO of United Nations, 1985), 7.

[6] Prakash T. N., "Land Suitability Analysis for Agricultural Crops: A Fuzzy Multi-Criteria Decision Making Approach" (M. Sc. thesis, Geo-Informatics, Institute for Geo-Information Science and Earth Observation, 2003), 57.

[7] Hugh Brammer, *Agricultural Development Possibilities in Bangladesh* (Dhaka: The University Press Limited, 1997), 340.

[8] Nabarath Baniya, "Land Suitability Evaluation Using GIS for Vegetable Crops in Kathmandu Valley/Nepal" (PhD dissertation, Humboldt University of Berlin, 2008), 55-56.

[9] Department of Environment and Bangladesh Environmental Management Project, *A Compilation of Environmental Laws Administered by the Department of Environment* (Dhaka: Progati Printers, 2002), 205.

[10] M. Shahadat Hossain, "Land Suitability Analysis for Sustainable Aquaculture Development in Noakhali Coast" (PhD dissertation, University of Chittagong, 2008), 63.

[11] Kardi Technomo, "Analytic Hierarchy Process (AHP) Tutorial" (2006), 1. http:// people. revoledu. com/kardi /tutorial/ AHP/ (accessed January 21, 2016)

5.2 Land Suitability Components

5.2.1 Soil

Soil is the most important attributes for agriculture. The study area lies in the Barind Tract, a distinct physiographic unit of Bangladesh, which is poorly drained grey soil predominance. The soils in this region are low in natural fertility and have a low moisture holding capacity.[12] The main properties of soils for plants growth are texture, moisture, pH, organic matter, nitrogen, phosphorus, and potassium. In addition to those, sulfur, zinc, and boron of soil are included in this study for land suitability analysis considering the study areas soil characteristics and suggestions by agriculture officials. Ten soil attributes suitability maps and attributes based areas of different suitability classes are presented below in figures 5.1-5.10 and table 5.1.

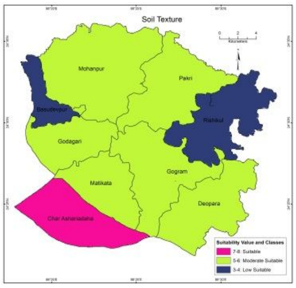

Figure 5.1. Texture Suitability

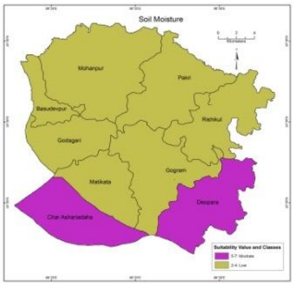

Figure 5.2. Moisture Suitability

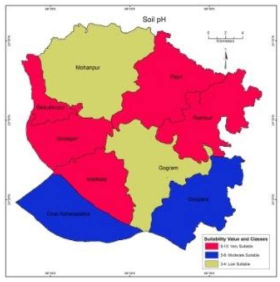

Figure 5.3. pH Suitability

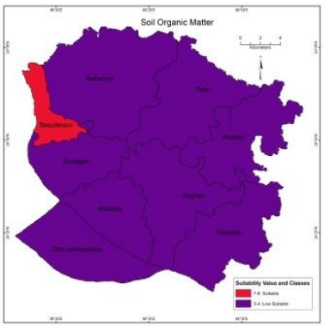

Figure 5.4. Organic Matter Suitability

Figure 5.5.Nitrogen Suitability

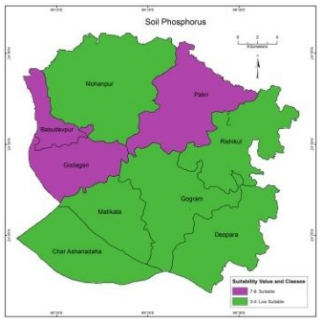

Figure 5.6. Phosphorus Suitability

[12] Hugh Brammer, *Soil-Crop Suitability Classification for Bangladesh,* 2nd revised ed. (Dhaka: Ministry of Agriculture, 2000), 19.

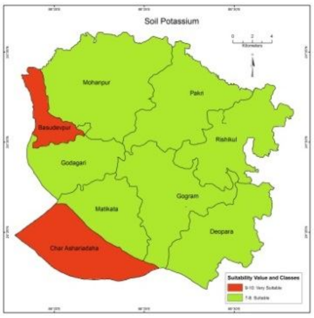

Figure 5.7. Potassium Suitability

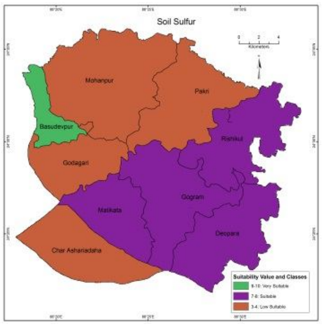

Figure 5.8. Sulfur Suitability

Figure 5.9. Zinc Suitability

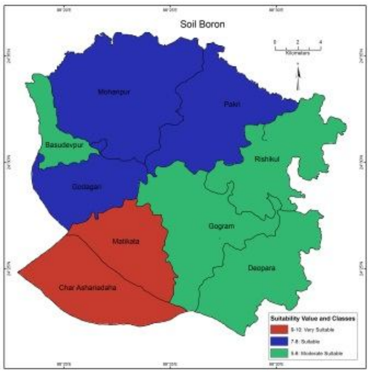

Figure 5.10. Boron Suitability

Table 5.1. Areas Under Different Suitability Class for Soil Attributes

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
Texture	-	-	3646	7.66	36088	75.87	7829	16.47	-	-
Moisture	-	-	-	-	8880	18.66	38683	81.34	-	-
pH	22010	46.27	-	-	8880	18.66	16673	35.07	-	-
Or Matter	-	-	1896	3.99	-	-	45667	96.01	-	-
Nitrogen	-	-	-	-	-	-	15317	32.21	32246	67.79
Phosphor	-	-	12121	25.48	-	-	35442	74.52	-	-
Potassium	5542	11.65	42021	88.35	-	-	-	-	-	-
Sulfur	1896	3.99	22149	46.57	-	-	23518	49.44	-	-
Zinc	-	-	34270	72.05	-	-	13293	27.95	-	-
Boron	7602	15.98	19872	41.79	20089	42.23	-	-	-	-

Source: Soil Attributes Suitability Maps of ArcGIS 10.1 Model

The figures shown above confirm that moderate suitable category of soil texture dominates the study area i.e., about 76 per cent area. Loam soil is good for agriculture but its proportions are only 45 per cent and proportion of clay loam is 45 per cent in the study area as per calculated statistics of 78 soil samples of the study area.

With respect to moisture holding capacity, 81.34 per cent land are low suitable in the study area. The reasons are that the soils in the study area have low moisture holding capacity probably due to inherent soil characteristics and local differences in the thickness of subsurface layers with different textures. Soil texture and organic matter content determine how much moisture a particular soil can hold which plants can use. Generally, loam soils hold much moisture and clay soil low in organic matter does not hold sufficient moisture after the rainy seasons which are not enough for satisfactorily growth for *rabi* crops.

pH status in the study area is good and within optimum range in most unions. Soil pH is the most important factor controlling nutrient availability in soils and in most cases; pH level 6-7 is optimum for adequate availability of nutrients in soil. Soil pH, texture, organic matter content, nutrient interaction, temperature etc. make available a portion of total content for plant uptake.

With respect to organic matter, about 96 per cent area are low suitable. Organic matter is very important for agriculture but its presence in the study area is very low (about 1.53 per cent) against optimum range 3.5-5.5 per cent which is not enough for potential yields. Organic matter is called “the life of the soil” which plays a key role in maintaining soil fertility. It also helps build stable soil aggregates, improves soil structure, tilth and aeration, and increases water holding and cation exchange capacity. The soils in the Barind Tracts are regarded as severely deficient in organic matter contents and show deficiency symptoms of nitrogen, phosphorus, sulfur, and zinc.[13]

In respect of nitrogen, very low suitable class accounts about 68 per cent area. For phosphorus about 75 percent areas are low suitable and 88 per cent area are suitable for potassium. According to the statistics based on 78 soil samples of the study area, NPK (nitrogen, phosphorus, and potassium) statuses are 0.08 per cent, 15.09 μg/g and 0.25 meq/100gm compared to optimum value 0.315 per cent, 26.25 μg/g, and 0.315 meq/100gm respectively which are much lower than required for potential yield and sustainable agriculture.

Mean values of 78 samples of the study area indicate that state of sulfur and zinc level are low but boron status is good. Soil attributes suitability map and union wise areas under different suitability class are depicted below in figure 5.11 and table 5.2.

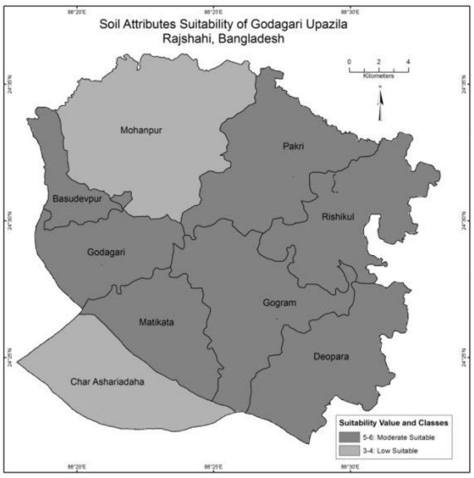

Figure 5.11. Soil Attributes Suitability

Table 5.2. Areas of Different Suitability Class for Soil

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	5	Moderate Suitable
C Ashariada	3646	7.66	4	Low Suitable
Deopara	5234	11.00	5	Moderate Suitable
Gogram	7026	14.78	5	Moderate Suitable
Matikata	3956	8.31	5	Moderate Suitable
Rishikul	5933	12.48	5	Moderate Suitable
Godagari	3830	8.05	5	Moderate Suitable
Mohanpur	9647	20.29	4	Low Suitable
Pakri	6395	13.44	5	Moderate Suitable

Source: Soil Attributes Suitability Map of ArcGIS 10.1 Model

[13] Shahidul Islam, “The Decline of Soil Quality,” *Environmental Aspects of Agricultural Development in Bangladesh* ed. Saleemul Huq, A. Atiq Rahman and Gordon R Conway (Dhaka: The University Press Limited, 2000), 114.

In soil attribute suitability map prepared, based on 10 attributes of soils of the study area, about 72 per cent (34270 ha) areas are found moderate suitable and about 28 per cent (13293 ha) area are low suitable. Different classes of soil suitability are depicted below in figure 5.12.

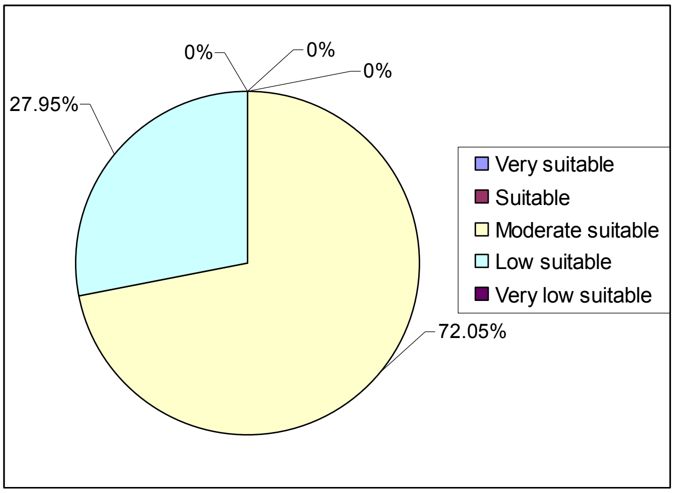

Figure 5.12. Percentage of Soil Attributes Suitability

Five suitability classes were selected for land suitability analysis but very suitable, suitable, and very low suitable classes are not found in the study area. The main reasons of dominance of moderate suitable and low suitable classes and nonexistence of very suitable and suitable areas are the predominance of clay and clay loam texture, low moisture holding capacity, low contents of organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc in the soils of the study area. Prevalence of clay and clay loam texture, low moisture, very low contents of organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc are not conducive for potential yield and sustainable agriculture. The reasons of low suitable class for Char Ashariadaha and Mohanpur union are the low contents of sulfur, and zinc than other unions in comparison to optimum level which agriculture officials now consider important for better production.

5.2.2 Irrigation Water

The irrigation water attributes included for land suitability analysis in this study are pH, electrical conductivity (EC), and temperature of irrigation water. The sources of irrigation water in the study area are exclusively underground sources namely, deep toubewell, and shallow tube wells. Virtually no surface water sources like ponds, canals, rivulets etc. are used for irrigation in the study area. Rainfall is scanty and soil moisture conditions are poor in Godagari upazila and adjacent areas. Therefore, irrigation water is very essential and only source of water for agriculture and crop production. The pH and EC are the two most important attributes for irrigation water and crop. Irrigation water temperature is particularly important in the study area because the climate of Rajshahi district is somewhat extreme in nature for few months which are inextricably linked to irrigation water temperature and sustainable agriculture. In view of above the irrigation water attributes based different suitability areas are cited below in figures 5.13-5.15 and table 5.3.

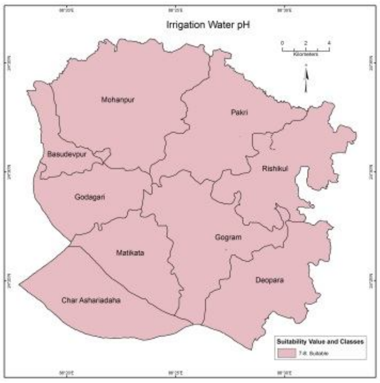

Figure 5.13. Irrigation Water pH

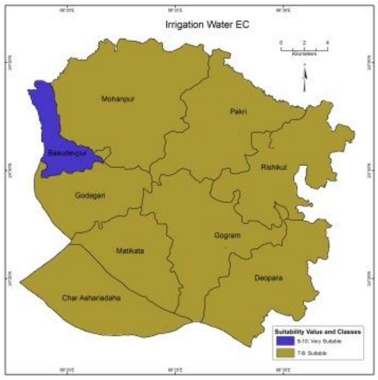

Figure 5.14. Irrigation Water EC

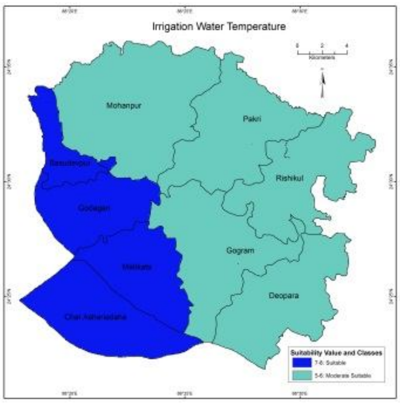

Figure 5.15. Irrigation Water Temperature

Table 5.3. Different Suitability Areas for Irrigation Water Attributes

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
pH	-	-	47563	100	-	-	-	-	-	-
EC	1896	3.99	45667	96.01	-	-	-	-	-	-
Temperature	-	-	13328	28.02	34235	71.98	-	-	-	-

Source: Irrigation Water Attributes Suitability Maps of ArcGIS 10.1 Model

The above table shows that about 100 per cent area is suitable category in respect of pH and EC. Mean pH and EC values in the study area as per 78 irrigation water samples are within acceptable range or no restrictions on use for irrigation and have no adverse effects on crops production. Irrigation water quality in Godagari upazila is good and suitable for potential yield and sustainable agriculture.

On the other hand, about 72 per cent area are moderate suitable in respect of irrigation water temperature. The dry winter season starts from November and continues up to the middle of March, about 5 months. The highest temperature of Bangladesh 45.1°c was recorded in Rajshahi on 18.05.1972. The minimum temperature 3.4°c was recorded on 23.01.2003. Mean maximum and minimum temperature of climate of the study area for the last 10 years (2005-2014) are 41.27°c and 6.2°c respectively which are excessively high and low and affect irrigation water temperature and agriculture and not conducive for sustainable agriculture for a few months. Irrigation water suitability of the study area is presented below in figure 5.16 and table 5.4.

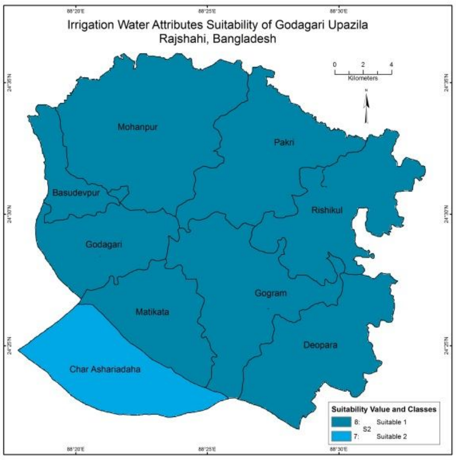

Figure 5.16. Irrigation Water Suitability

Table 5.4. Areas of Different Suitability Class for Irrigation Water

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	8	Suitable
C Ashariada	3646	7.66	7	Suitable
Deopara	5234	11.00	8	Suitable
Gogram	7026	14.78	8	Suitable
Matikata	3956	8.31	8	Suitable
Rishikul	5933	12.48	8	Suitable
Godagari	3830	8.05	8	Suitable
Mohanpur	9647	20.29	8	Suitable
Pakri	6395	13.44	8	Suitable

Source: Irrigation Water Attribute Suitability Map of ArcGIS 10.1Model

It is seen from the table 5.4 that 100 per cent areas (47563 ha) are of suitable category for irrigation water. Union wise level of suitable class of Irrigation water are depicted below.

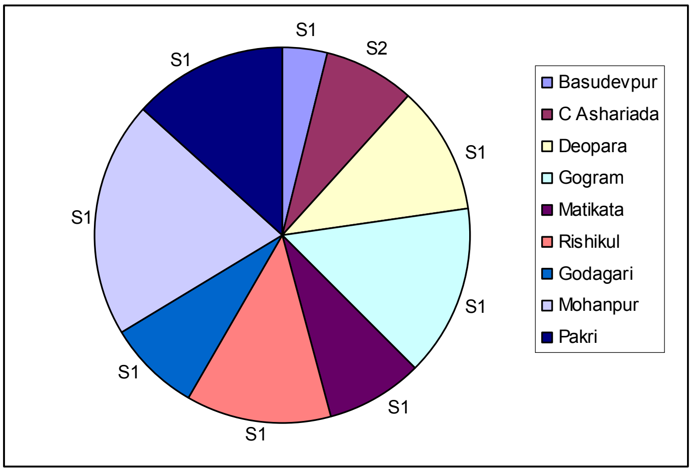

Figure 5.17. Union Wise Irrigation Water Suitability Level

Very suitable, moderate suitable, low suitable, and very low suitable classes are not found in the study area. However, irrigation water in the study area is of good quality and do not pose any adverse effects on potential yield. pH is within normal range (6-7.5) in all unions. The study area is long away from the Bay of Bengal. That is why salinity level means EC level is within normal range in all unions and has no adverse effects on potential yield. EC in Char Ashariadaha union is 722 mmhos/cm which is only 22 mmhos/cm higher than no restriction on use for irrigation as set by Ayers and Westcot,[14] but in many descriptions it is within normal range though it is in the border line. The reason of suitability value 7 for Char Ashariadaha union is probably due to insignificant slightly high value of EC. On the other hand, irrigation water temperature is within normal range (20-30°c) but due to excessively high and low air temperature for some times it creates some problems to potential yield in the study area mainly in the months of December to April.

5.2.3 Climate

Climate is important for good yield and sustainable agriculture. It is important in this study because high and low temperature conditions prevail in the study area which has adverse bearings on agriculture. On the other hand, another component of climate, rainfall is scanty in this area and not enough for sustainable agriculture. As the data of one meteorological station used in the analysis, climate data has no spatial variation which is necessry for spatial and land suitability analysis in GIS. Therefore, assigned weights were given very low accordingly as per ArcGIS model against climate attributes. Climate attributes based suitability of the study area are presented below in figures 5.18-5.19 and table 5.5.

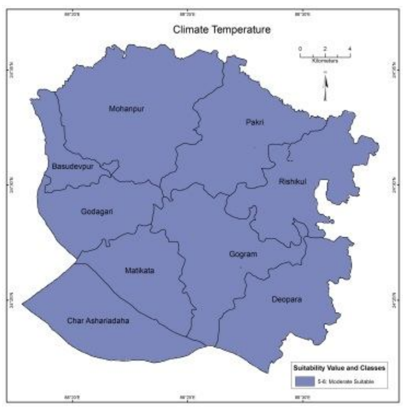

Figure 5.18. Climate Temperature Suitability

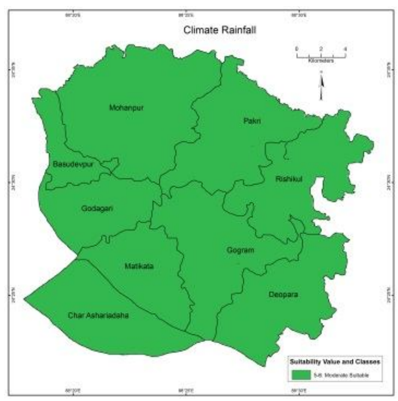

Figure 5.19. Climate Rainfall Suitability

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[14] R. S. Ayers and D. W. Westcot, “Water Quality for Agriculture,” *FAO Irrigation and Drainage Paper* 29, Rev.1 (Rome: FAO of United Nations, 1985), 7.

Table 5.5. Areas Under Different Suitability Class for Climate Attributes

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
Temperature	-	-	-	-	47563	100	-	-	-	-
Rainfall	-	-	-	-	47563	100	-	-	-	-

Source: Climate Attributes Suitability Maps of ArcGIS 10.1 Model

The above table for climate suitability areas for sustainable agriculture shows that 100 per cent of the study area are moderate suitable in case of both temperature and rainfall. The study area is not very suitable mainly due to high and low temperature and relatively low rainfall. Temperature in this region are somewhat extreme than they are in many parts of Bangladesh and most of the Barind Tract has an average of 10 days or more per year when maximum temperature in summer exceeds 40°c. Low temperature prevail in the study area for few months from November to February and affect polination and shed flowers of many crops. Mean maximum and minimum temperature (41.27°c and 6.21°c) for the period of 2005-2014 are found very high and low that affects agriculture. On the other hand, yearly total rainfall for the period of 1975-2014 is 1456 mm in the study area in comparison to 2401 mm of Bangladesh which is very low and insufficient for agriculture development. Climate attributes based suitability value and classes of the study area are depicted below in figure 5.20 and table 5.6.

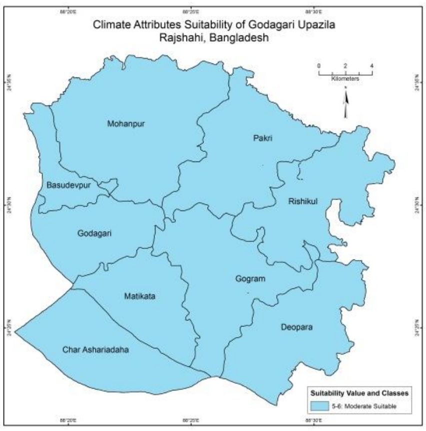

Figure 5.20. Climate Suitability

Table 5.6. Union Wise Different Suitability Class for Climate

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderate Suitable
C Ashariada	3646	7.66	6	Moderate Suitable
Deopara	5234	11.00	6	Moderate Suitable
Gogram	7026	14.78	6	Moderate Suitable
Matikata	3956	8.31	6	Moderate Suitable
Rishikul	5933	12.48	6	Moderate Suitable
Godagari	3830	8.05	6	Moderate Suitable
Mohanpur	9647	20.29	6	Moderate Suitable
Pakri	6395	13.44	6	Moderate Suitable

Source: Climate Attribute Suitability Map of ArcGIS 10.1 Model

It is found in the table 5.6 that all unions are moderate suitable and no other classes are prevalent in the study area. The aggregate average yearly normal temperature of Rajshahi and Bangladesh are 25.24°c and 25.40°c respectively for the period of 1975-2014. This temperature is suitable for a wide range of tropical and subtropical crops to be grown for most of the year and for temperate crops like wheat, potato, vegetables etc. to be grown in the winter season.[15] However, maximum and minimum temperature vary considerably from year to year which were 41.2°c and 4.4°c in 2013 but 42.6°c and 7.0°c respectively in 2014 in Rajshahi. Yearly total rainfall in the study area is very low and without irrigation, crop production in *rabi* and *kharif* 1 season is not possible. The maximum rainfall in the study area occurs between April to September which is 1270 mm out of yearly total 1456 mm that accounts 87.24 per cent. Only 185.75 mm rainfall occurs from October to March which accounts only 12.76 per cent. There are three crop growing seasons which are *rabi* (Nov-March), *kharif* 1(April-July) and *kharif* 2 (August-October),[16] and rainfall distribution (1975-2014) in these three seasons in the study area are 68.66mm (4.71 per cent), 750.60 mm (51.56 per cent), and 636.83(43.73 per cent) mm respectively which are not enough for potential yield and sustainable agriculture. Besides, the dates of onset and ending of the rainy season and the total amounts of rainfall vary considerably from year to year. These climatic situations create problems to agriculture in the study area as it hampers sowing and harvesting of crops in due time, yield, and profit.

5.2.4 Topography

Topography determines the type of cultivation, farm mechanization, flooding, soil and erosion patterns, and the degrees of accessibility.[17] These factors determine the degrees of suitability of land for sustainable agriculture. Topography attributes based suitability areas are presented below in table 5.7 and figures 5.21-5.22.

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[15] Hugh Brammer, *Agro ecological Aspects of Agricultural Research in Bangladesh* (*Dhaka*: The University Press Limited, 2000), 6.

[16] Months are considered adjusting dates with a view to calculating rainfall for crop seasons.

[17] Jasbir Singh and S. S. Dhillon, *Agricultural Geography* (New Delhi: Tata-McGraw-Hill Publishing Company Limited, 1984), 48.

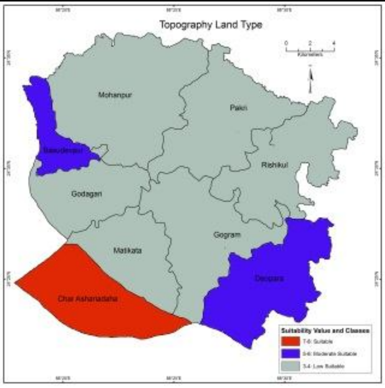

Figure 5.21. Land Type Suitability

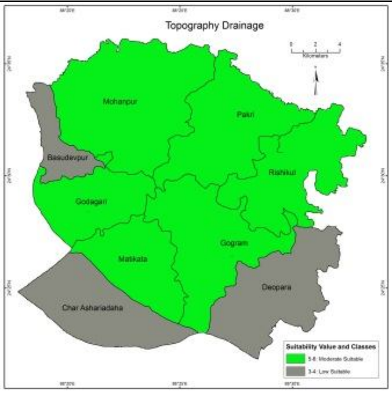

Figure 5.22. Drainage Condition Suitability

Table 5.7. Areas Under Different Suitability Class for Topography Attributes

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
Land Type	-	-	3646	7.67	7130	14.99	36787	77.34	-	-
Drainage	-	-	-	-	36787	77.34	10776	22.66	-	-

Source: Topography Attributes Suitability Maps of ArcGIS 10.1 Model

The above table shows that low suitability category dominates land type; about 77 per cent area are low suitable. The study area has distinct physiographic and topographic characteristics. Medium low land is best for agriculture in this region followed by medium high and low land. Very low and high lands are not good for agriculture which is not like rest of the country. High land and medium high land proportions are 74.35 per cent and 16.66 per cent respectively according to statistics of 78 topography samples. On the other hand, 77.34 per cent area are moderate suitable and 22.66 per cent area are low suitable in terms of drainage condition of the study area. The study area is mainly poor in drainage condition. Below are presented topography suitability value and classes in figure 5.23 and table 5.8.

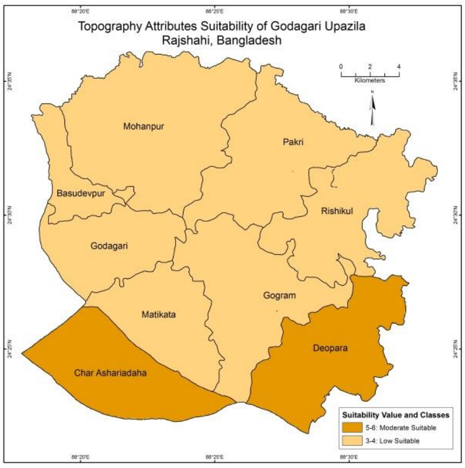

Figure 5.23. Topography Attributes Suitability

Table 5.8. Union Wise Different Suitability Class for Topography

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	4	Low Suitable
C Ashariada	3646	7.66	6	Moderate Suitable
Deopara	5234	11.00	5	Moderate Suitable
Gogram	7026	14.78	4	Low Suitable
Matikata	3956	8.31	4	Low Suitable
Rishikul	5933	12.48	4	Low Suitable
Godagari	3830	8.05	4	Low Suitable
Mohanpur	9647	20.29	4	Low Suitable
Pakri	6395	13.44	4	Low Suitable

Source: Topography Attribute Suitability Map of ArcGIS 10.1 Model

It is found in the table 5.8 that most of the areas are low suitable in the study area. Topography suitability levels of the study area are presented below in figure 5.24.

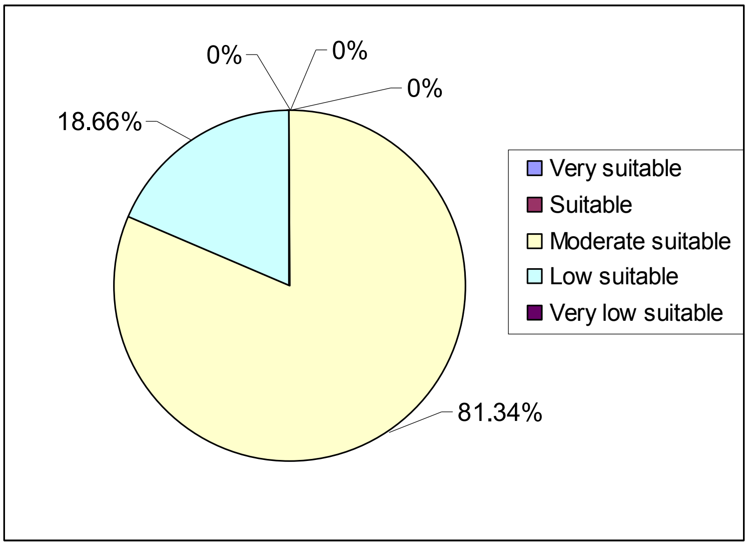

Figure 5.24: Topography Suitability Level

There are no classes of very suitable, suitable, and very low suitable classes in the study area. The study area is mainly terrace area and underlain by the unconsolidated Madhupur clay which generally lie a few meters higher than adjoining floodplain land. These areas are basically poorly drained area. According to statistics of 78 topography samples, 68 per cent areas' drainage conditions are somewhat poor and 32 per cent areas drainage conditions are poor which are not conducive to potential yield. Rather it is uncongenial for potential yield. Different land types significantly determine whether *aus*, transplanted *aman* or *boro* paddy and *rabi* crops can be grown or not and where. Char Ashariadaha and Deopara union are moderate suitable because of the dominance of medium high land than other unions which are good for crops production.

5.2.5 Floodability

Floodability is an important attribute for crop cultivation and yields. Flooding of different depths and durations may occur in a land unit due to variation of elevation of land types.[18] The severity and intensity of flood hazard to crops depend on the depth and duration of flood water. Depth of flooding and duration of flooding are two important variables of floodability which determine agricultural patterns. Floodability suitability areas for sustainable agricultural development are presented below.

[18] Md. Serajul Islam, "Influences of Elevation on Flood Water Concentration in the Brahmaputra-Jamuna Floodplain," *Oriental Geographer* 57, no. 1&2(2015), 91.

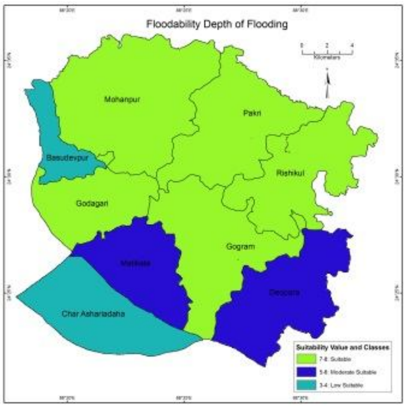

Figure 5.25. Depth of Flooding Suitability

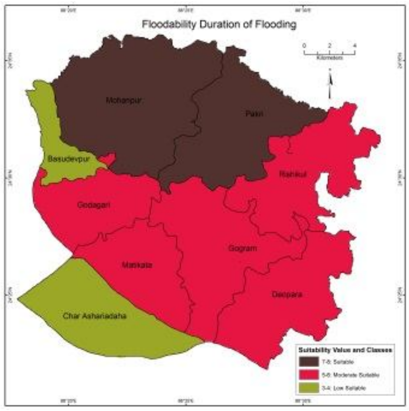

Figure 5.26. Duration of Flooding Suitability

Table 5.9. Areas Under Different Suitability Class for Floodability Attributes

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
Flooding Depth	-	-	32831	69.02	9190	19.32	5542	11.66	-	-
Flooding Duration	-	-	16042	33.72	25979	54.62	5542	11.66	-	-

Source: Floodability Attributes Maps of ArcGIS 10.1 Model

Table 5.9 provides that suitable class dominates (about 69 per cent area) in flooding depth and moderate suitable class dominates (55 per cent area) in duration of flooding in the study area. The seasonal cycle of flooding determines the kinds and varieties of crops which can be grown on most kinds of floodplain land. Floodability attributes based suitability value and classes are presented below in figure 5.27 and table 5.10.

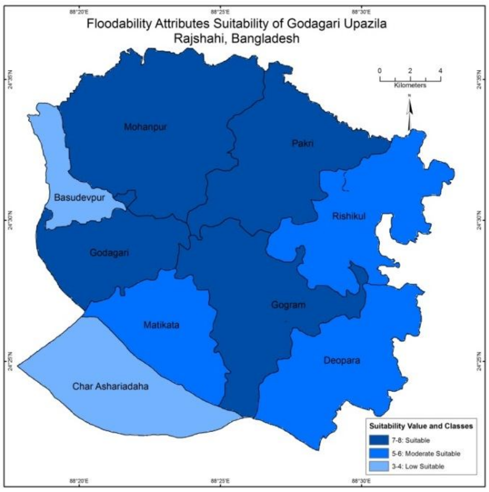

Figure 5.27. Floodability Suitability

Table 5.10. Union Wise Different Suitability Class for Floodability

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	4	Low Suitable
C Ashariada	3646	7.66	3	Low Suitable
Deopara	5234	11.00	6	Moderate Suitable
Gogram	7026	14.78	7	Suitable
Matikata	3956	8.31	6	Moderate Suitable
Rishikul	5933	12.48	6	Moderate Suitable
Godagari	3830	8.05	7	Suitable
Mohanpur	9647	20.29	8	Suitable
Pakri	6395	13.44	8	Suitable

Source: Floodability Attribute Suitability Map of ArcGIS 10.1 Model

The figures referred to above show that only suitable, moderate suitable and low suitable class are found. Floodability suitability levels are depicted in figure 5.28.

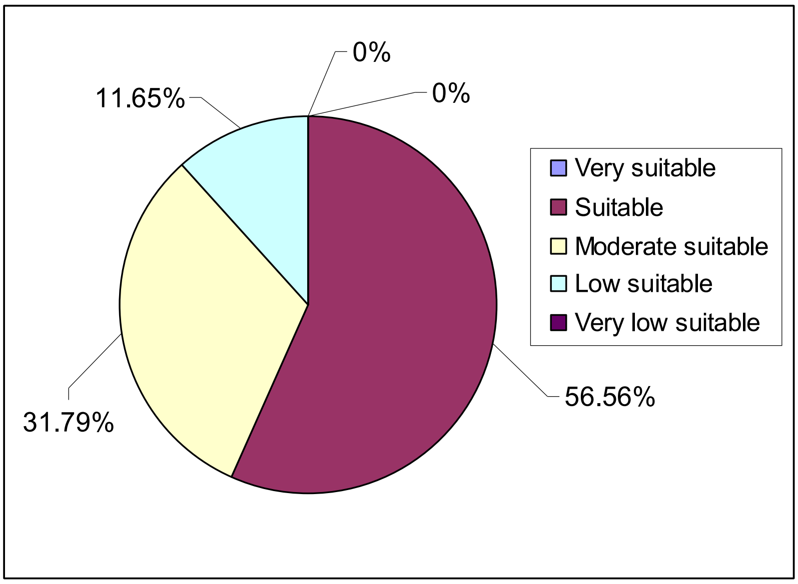

Figure 5.28. Floodability Suitability Level

Most of the areas are shallowly flooded by rainwater in the monsoon, but occasional flash floods in the Padma, the Mahananda, and the Baral rivers spread water over adjoining Barind areas. Farmers cultivate agriculture land in swallow flooded area and grow crops. Flooding depth and flooding duration determine where and when *aus, aman, boro* paddy and *rabi* crops can be cultivated or not. Char Ashariadaha and Basudevpur union are more affected unions which cover about 12 per cent land area where depth of flooding and duration of flooding create problems to agriculture mainly in the rainy season than other unions.

5.2.6 Accessibility

Road and market accessibility are the dire needs as they play an important role in giving inputs into the farm and marketing surplus produces in a short time and with reasonable costs for the development of inherent agricultural potentials of an area. The bulky and perishable products need quick access to markets. Accessibility dependent suitability areas in the study area are presented below in figures 5.29-5.30 and table 5.11.

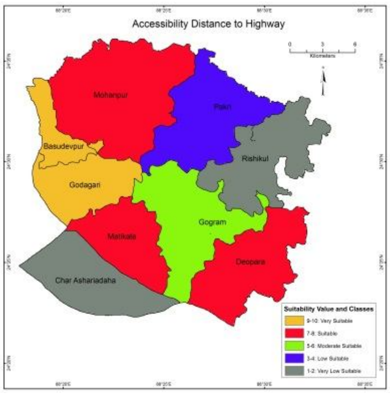

Figure 5.29. Distance from Highway Suitability

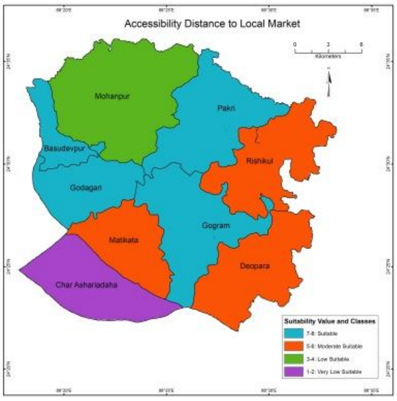

Figure 5.30. Distance from Local Market Suitability

Table 5.11. Suitability Class and Areas for Accessibility

Attributes	Very Suitable		Suitable		Moderate Suitable		Low Suitable		Very Low Suitable	
	ha	%	ha	%	ha	%	ha	%	ha	%
Distance from Highway	5726	12.03	18837	39.60	7026	14.80	6395	13.44	9579	20.13
Distance from Local Market	-	-	19147	40.25	15123	31.79	9647	20.28	3646	7.68

Source: Accessibility Attributes Suitability Maps of ArcGIS 10.1 Model

The above table shows that suitable and very low suitable class dominate the study area in respect of distance to highway. On the other hand, suitable and moderate suitable class are dominant in distance to local market. Accessibility attributes based suitability area are presented below in figure 5.31 and table 5.12.

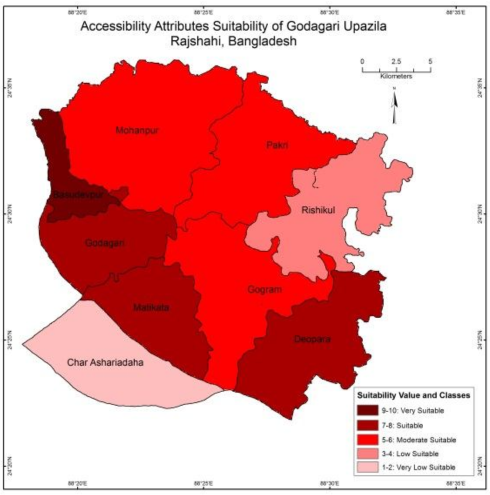

Figure 5.31. Accessibility Suitability

Table 5.12. Areas of Suitability Class for Accessibility

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	9	Very Suitable
C Ashariada	3646	7.66	2	Very Low Suitable
Deopara	5234	11.00	7	Suitable
Gogram	7026	14.78	6	Moderate Suitable
Matikata	3956	8.31	7	Suitable
Rishikul	5933	12.48	4	Low Suitable
Godagari	3830	8.05	8	Suitable
Mohanpur	9647	20.29	6	Moderate Suitable
Pakri	6395	13.44	6	Moderate Suitable

Source: Accessibility Attribute Suitability Map of ArcGIS 10.1 Model

It is seen in the above table that moderate suitable class dominates the study area. Suitability levels of the study area are shown below.

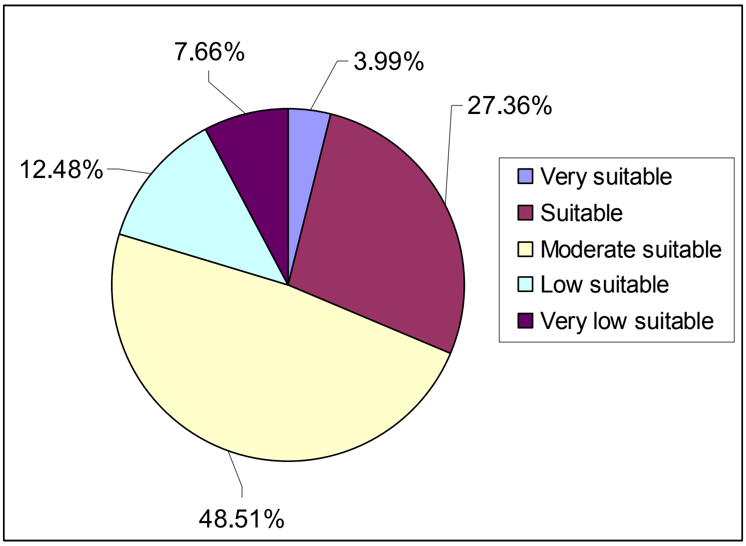

Figure 5.32. Accessibility Suitability Level

Char Ashariadaha union is very low suitable because the mighty river Padma disconnected this union from the main part of the study area and there is no local market in this union, therefore, accessibility is very poor for buying and selling agricultural commodities. The Padma river is 4 to 8 km wide and river distance itself is a major problem to buying inputs and selling agriculture produces of Char Ashariadaha union. Yield is good but farmers do not get proper price such as, in 2016 the price of 40 kg maize is 800 BDT in the mainland which was 500-600 BDT in Char Ashariadaha union only due to market and communication problem. On the other hand, farmers have to buy all inputs with an inflated price such as they have to buy fertilizers per 40 kg minimum 100 BDT more than mainland farmers. It takes 90/100 BDT per 40 kg to cross mighty the Padma river to send to local market Bidirpur bazar in the main land. Rishikul is far from highway and it takes a lot to reach to highway and markets. Mohanpur, Pakri, and part of Gogram union are moderately distanced from highway and it costs more for selling their produces.

5.3 Overall Land Suitability

The overall land suitability is the general picture of all crops in the study area. It is the general condition of total agriculture. Notables are different varieties of rice, wheat, maize, jute, cotton, sugar cane, potato, vegetables, pulses, oil seeds, fruits, spices etc. The overall land suitability shows that 100 per cent area (47563 ha) are moderately suitable for agriculture in the study area. No union is found as very suitable or suitable or marginally suitable or not suitable class in the study area. The selected 21 attributes based overall land suitability of the study area are presented below in figures 5.33-5.38 and table 5.13.

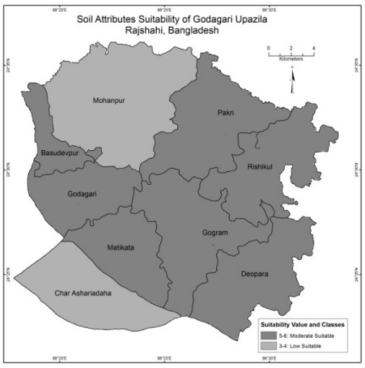

Figure 5.33. Soil Suitability

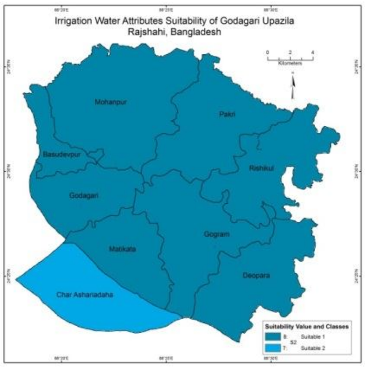

Figure 5.34. Irr. Water Suitability

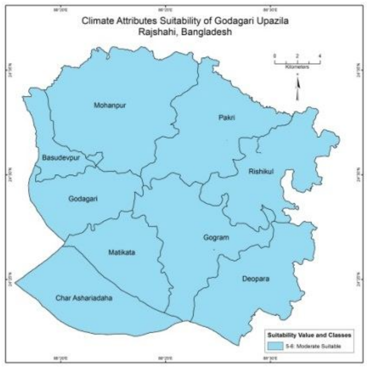

Figure 5.35. Climate Suitability

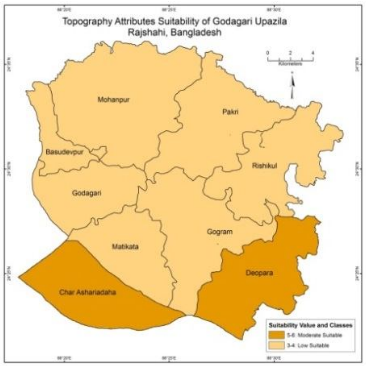

Figure 5.36. Topography Suitability

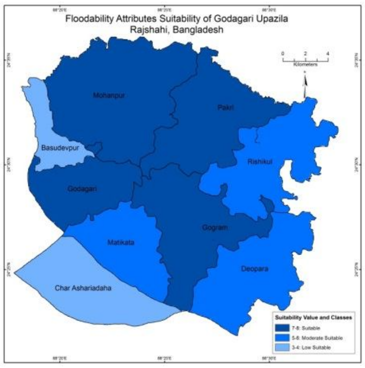

Figure 5.37. Floodability Suitability

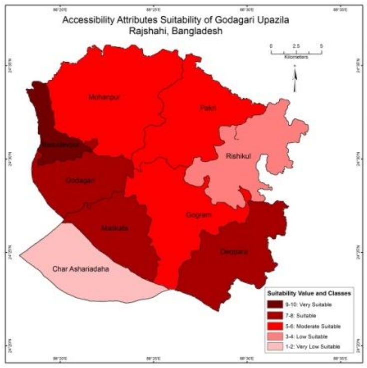

Figure 5.38. Accessibility Suitability

Table 5.13. Overall Land Suitability

Union	Area(ha)	Area%	Soil	Irrigation	Climate	Topography	Floodability	Accessibility
Basudevpur	1896	3.99	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Low Suitable	Very Suitable
Char Ashariadaha	3646	7.66	Low Suitable	Suitable	Moderate Suitable	Moderate Suitable	Low Suitable	Very Low Suitable
Deopara	5234	11.00	Moderate Suitable	Suitable	Moderate Suitable	Moderate Suitable	Moderate Suitable	Suitable
Gogram	7026	14.78	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Suitable	Moderate Suitable
Matikata	3956	8.31	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Moderate Suitable	Suitable
Rishikul	5933	12.48	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Moderate Suitable	Low Suitable
Godagari	3830	8.05	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Suitable	Suitable
Mohanpur	9647	20.29	Low Suitable	Suitable	Moderate Suitable	Low Suitable	Suitable	Moderate Suitable
Pakri	6395	13.44	Moderate Suitable	Suitable	Moderate Suitable	Low Suitable	Suitable	Moderate Suitable

Source: Soil, Irrigation Water, Climate, Topography, Floodability and Accessibility Attribute Maps of ArcGIS 10.1Model

The above table provides the scenarios of overall land suitability classes and their areas in respect of 21 attributes of soil, irrigation water, climate, topography, floodability, and accessibility characteristics. Highly influencing factors of moderately suitable class are soil components. Ten properties of soil were taken into consideration for land suitability analysis considering the importance of soils for agriculture. Clay and clay loam dominate the textural class and together they constitute 55 per cent. Moisture condition is predominantly low in the whole study area. Organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc status in the study area are much lower than required. The soils in this region have deficiencies in nutrients. Rainfall is insufficient for crops cultivation. The study area is predominantly high land which is not good for most crops cultivation. Drainage condition is predominantly somewhat poor and poor category and absence of well or moderate well drainage class. Overall land suitability value and classes are presented below in figure 5.39 and tables 5.14-5.15.

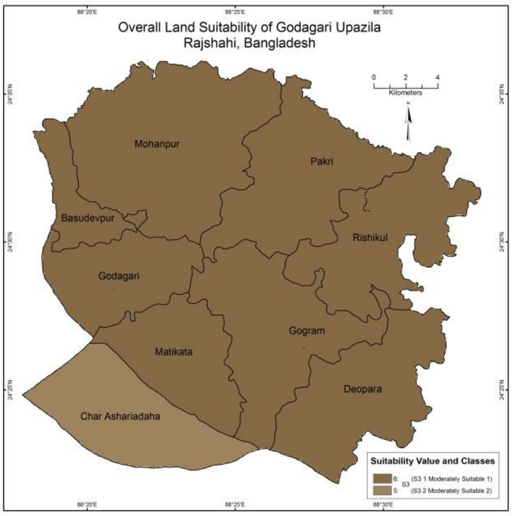

Figure 5.39. Overall Land Suitability

Table 5.14. Overall Land Suitability Class and Area

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	6	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	6	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	6	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.15. Suitability Class for Overall Land Suitability

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1 Model Map of Overall Land Suitability

The above table shows that all unions are moderately suitable with respect to overall land suitability means general agriculture. Moderately suitable is sub classified into two; moderately suitable 1 (suitability value 6) and moderately suitable 2 (suitability value 5). Only Char Ashariadaha union has suitability value 5 and all other unions have suitability value 6. Suitability classes of overall land suitability of the study area are presented below in figure 5.40.

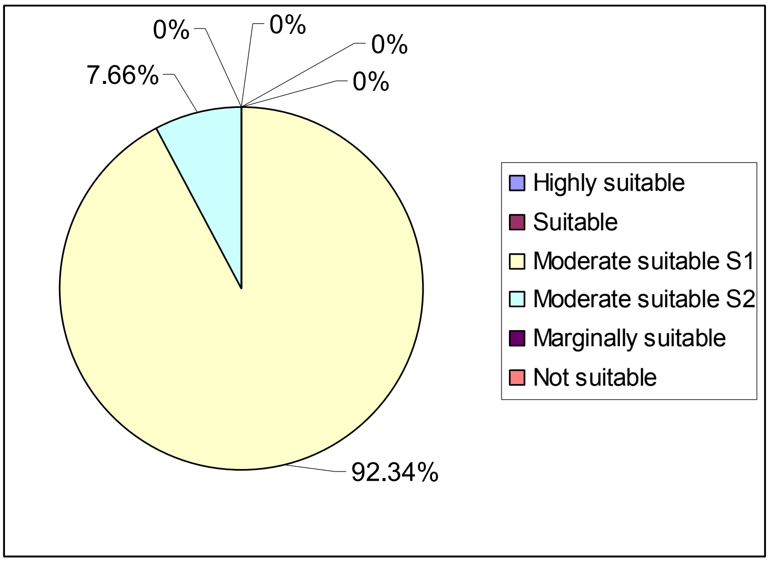

Figure 5.40. Overall Land Suitability Level

The main determining factors of moderately suitable category in the study area are preponderance of clay and clay loam textural class, low moisture holding capacity, low content of organic matter, NPK, sulfur, and zinc in soil properties, prevalence of high land, poor drainage condition, insufficient rainfall and poor accessibility, depth of flooding, duration of flooding, distance from highway, and distance from local market factor created by the mighty river Padma that described earlier. As the overall land suitability is found moderate, farmers' income from agriculture sector in the study area are medium. Therefore, their profit margins are limited and logically socio-economic conditions in the study area are not developed and political strength, life style, and culture are not also sound and strong.

5.4 Land Suitability for Leading Agricultural Crops

Leading agricultural crops in the study area are rice, wheat, maize, potato, pulses, oil seeds, fruits, and vegetables. Rice, wheat, maize, potato, pulses, oil seeds, and spices are the main crops, which account about 93 per cent area and the rest crops namely jute, sugarcane, fruits, and other crops constitute about 7 per cent land in the study area. Land suitability analysis in the present study are done for only leading agricultural crops namely, rice, wheat, maize, potato, lentil (main variety of pulses), mustard (main edible oil seeds), and onion and chili (two most important and main cash spices crops) crop cultivation.

5.4.1 Land Suitability for Rice Cultivation

Rice is the dominant crop cultivated throughout the year in the study area. It is grown in three distinct rice growing seasons namely, *aus* (April-August), *aman* (July-November), and *boro* (December-May). Rice ranks first position among the cereal crops and is the major source of livelihood. Agriculture sector is dominated by crop sub-sector which is dominated by rice cultivation. Land under rice cultivation in the study area occupies about 79 per cent as a percentage of gross cropped area. Land suitability of the study area for rice cultivation is presented below in figure 5.41 and tables 5.16 and 5.17.

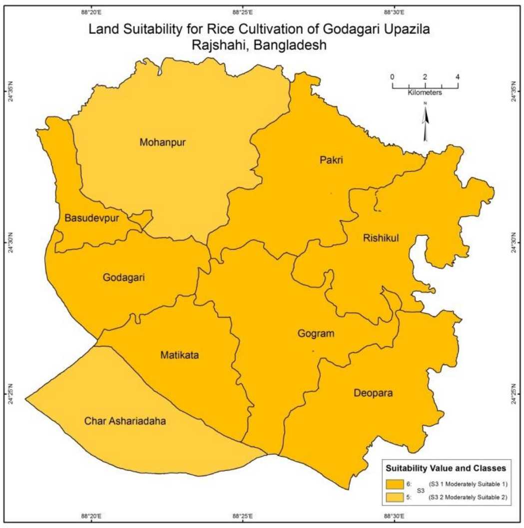

Figure 5.41. Land Suitability for Rice Cultivation

Table 5.16. Union Wise Areas of Different Suitability Class for Rice Cultivation

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	6	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	6	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.17. Areas Under Different Suitability Class for Rice Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Rice Cultivation

The above table 5.17 shows that the whole study area is moderately suitable for rice cultivation which (rice) is cultivated in about 79 per cent area. The determining characteristics which significantly influenced the suitability category of rice cultivation are mainly soil characteristics, high land type, and poor drainage conditions of topography. Soil is the most important factor for any crop production and existing soil texture, moisture, organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc condition are not congenial for potential rice yield.

The optimum growth and development require 30-32°c day-time temperature and 20°c night-time temperature but temperature in few months goes beyond this level. Besides, soil texture is not ideal for potential yield. Prevailing high land and poor drainage condition are not conducive for potential rice cultivation. The average rice (*aus+aman+boro*) production in the study area is 651 kg per 33 decimals land which are lower than potential yield chiefly due to lower nutrients availability of soil, high land, and poor drainage conditions.

Moderately suitable 1(suitability value 6) are the unions of Basudevpur, Deopara, Gogram, Matikata, Rishikul, Godagari, and Pakri which cover about 72 per cent area. On the other hand, Char Ashariadaha and Mohanpur unions are in the category of moderately suitable 2(suitability value 5) which account about 28 per cent land in the study area. Char Ashariadaha and Mohanpur union have low contents of sulfur and zinc of soil, flooding depth and duration and accessibility difficulties.

Rice is cultivated in about 79 per cent area and farmers' income from about 79 per cent farms come from rice cultivation. But, rice is the least economically viable crops in the study area and profits (net revenue) are 805-1856 BDT for *aus*, *aman* and *boro* rice cultivation in 33 decimals land which are considered negligible and are not enough to support any family. Small (0.05-2.49 acre), medium (2.50-7.49 acre), and large (7.50 acre and above) farm holdings in the study area are 24493, 8042, and 978 respectively which mean that about 97 percent farmers are small and medium and about 3 per cent farmers are only large farmers. Therefore, about 97 per cent farmers' income are very limited and their socio-economic conditions, political strength, cultural condition etc. are not in sound position. On the other hand, *boro* rice is not environment friendly due to need of excess irrigation water which is cultivated in 30358 acres out of total 129715 acre gross cropped area of the study area. Hence, it is necessary to cultivate non-traditional high net return generating crops for agricultural development scaling down rice cultivation.

5.4.2 Land Suitability for Wheat Cultivation

Wheat is an important crop in the study area and cultivated in 2.56 per cent land. Wheat grows in the dry or *rabi* season in Bangladesh to use fully the cool winter period for maximum yield. Yield decreases markedly with sowing dates after mid-December. Depending on variety and weather condition, 100-110 days are required from sowing to harvest. Suitability areas for wheat cultivation in the study area are presented below.

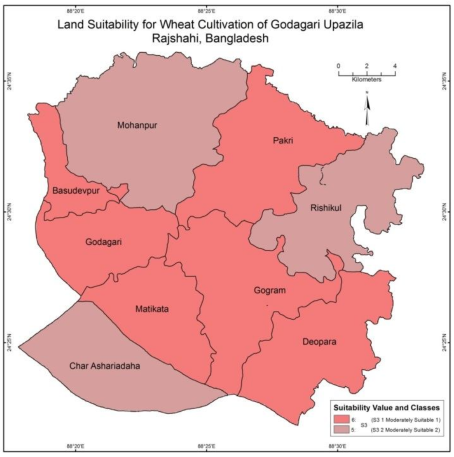

Figure 5.42. Land suitability for wheat cultivation

Table 5.18. Areas of Different Suitability Class for Wheat Cultivation

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	6	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.19. Areas Under Different Suitability Class for Wheat Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Wheat Cultivation

The above table shows that all unions are moderately suitable for wheat cultivation. The main influencing factors for wheat cultivation are soil characteristics. Loam soil is the best and clay loam and sandy loam soils are moderately suitable for wheat cultivation. Wheat prefers dry soil with soil pH 6.4. The optimum growing temperature is about 25°c. It favors low temperature between 20 and 30°c with minimum temperature of 3-4 °c and maximum 30-32°c. Well distributed rainfall ranging from 40-110 cm is optimum for wheat growth. Other influencing factors are high land, poor drainage condition, insufficient rainfall, and accessibility. The study area is mainly highland and medium highland which are suitable for wheat cultivation.

Moderately suitable 1(suitability value 6) are the unions of Basudevpur, Deopara, Gogram, Matikata, Godagari, and Pakri which cover 59.57 per cent area. On the other hand, Char Ashariadaha, Rishikul, and Mohanpur unions are in the category of moderately suitable 2 (value 5) which accounts 40.43 per cent study area. Soil characteristics are not good except pH. Boron level is in the border line and wheat is susceptible to high soil boron. Other soil characteristics are low in comparison to optimum level. Temperatures for normal growth for wheat cultivation are found suitable in the study area. Soil having good moisture holding capacity and good drainage condition are suitable for wheat production but the study area lacks in these respects. Char Ashariadaha, Rishikul, and Mohanpur union have low contents of sulfur, zinc, and potassium than other union. Flooding depth, duration, and accessibility difficulties also exist in Char Ashariadaha union.

Wheat yield is comparatively low in the study area than Northern Bangladesh and per 33 decimal net return from wheat cultivation is found only about 2367 BDT and out of major 15 crops of the study area, wheat ranks 11. Hence, farmers economic return from wheat cultivation are not enough though wheat cultivation requires low irrigation. Therefore, it is necessary to search alternate crops which require low irrigation but brings higher returns than wheat.

5.4.3 Land Suitability for Maize Cultivation

Maize is an another important agricultural crop and cultivated in 2.90 per cent land in the study area. It is the third most important cereal crop in Bangladesh followed by rice and wheat. Maize grows well in well drained highland soil between wheat and *aus* or *aman* and no other crop could be such high yielding within such short growing period. Land suitability for maize cultivation and different suitability area are presented below in figure 5.43 and tables 5.20 and 5.21.

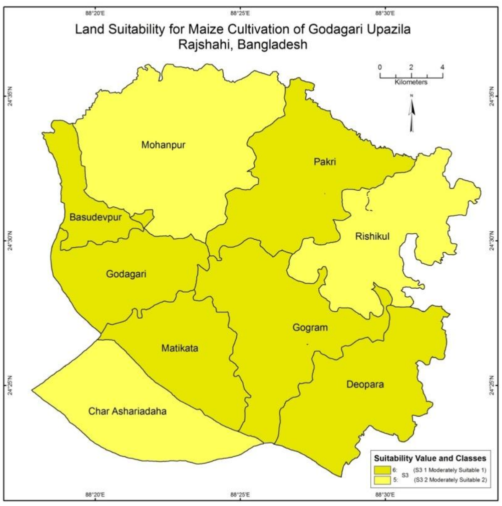

Figure 5.43. Land Suitability for Maize Cultivation

Table 5.20. Maize Cultivation Suitability Class and Area

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	6	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.21. Areas of Different Suitability Class for Maize Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Maize Cultivation

The above table 5.21 shows that 100 per cent land are moderately suitable for maize cultivation in the study area. The main determining factors of moderately suitable for maize cultivation in the study area are soil characteristics that described above. Maize grows well in temperature between 30-35°c. The requiring rainfall is 460-600 mm. It can be grown well on a deep, moist, and well aerated loam soil. Sandy loam and heavy clay loam soil are suitable for maize cultivation.[19] The crop is fairly acid tolerant and can be grown on soils with pH range between 4-9 but pH 6-7 to be optimum for its growth. Other influencing factors are high land, poor drainage condition, insufficient rainfall, and accessibility. Distance from highway and distance from local markets caused by mighty river the Padma for Char Ashariadaha and other remote unions mainly Rishikul and Mohanpur assign low score for land suitability.

Moderately suitable 1(suitability value 6) are the unions of Basudevpur, Deopara, Gogram, Matikata, Godagari, and Pakri which cover about 60 per cent areas. On the other hand, Char Ashariadaha, Rishikul, and Mohanpur unions are in the category of moderately suitable 2 (suitability value 5) which accounts about 40 per cent of the study area. Char Ashariadaha, Rishikul, and Mohanpur union have low presence of sulfur, low zinc, and potassium in Char Ashariadaha and Mohanpur union and high boron level in Rishikul union than other unions. Flooding depth, duration, and accessibility problem are in Char Ashariadaha union which are to some extent barrier for agriculture development.

Maize requires comparatively low rainfall and yield is good and net returns from per 33 decimals land is BDT 10448 which are good and much more than main crop rice. Therefore, it is a cash crop and emphasis can be laid on this crop in the study area.

5.4.4 Land Suitability for Potato Cultivation

Potato is the fourth most important crop in Bangladesh and it is widely cultivated in the study area. The cultivated area for potato is 539 acres out of total 129715-acre gross cropped area which accounts 0.41 per cent land. Potato is a *rabi* crop which grows in the winter season. Well fertilized, sunny weather with sufficient soil moisture is appropriate for potato plantation. Different suitability areas for potato cultivation in the study area are depicted below in figure 5.44 and tables 5.22 and 5.23.

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[19] Hussain, Chowdhury and Chowdhury, *Land Suitability Assessment and Crop Zoning of Bangladesh*, 43.

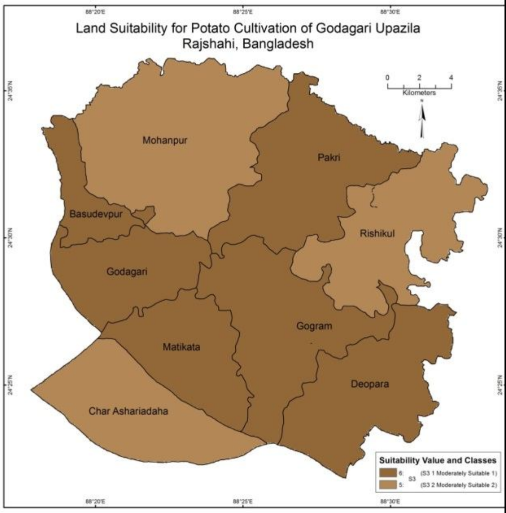

Figure 5.44. Land Suitability for Potato Cultivation

Table 5.22. Potato Cultivation Suitability Class and Area

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	6	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	6	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.23. Areas of Different Suitability Class for Potato Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1Model Map on Land Suitability for Potato Cultivation

Table 5.23 shows that 100 per cent area are moderately suitable for potato cultivation. Potato is grown well in sandy loam and loam soils. But, the study area has slightly predominance of clay and clay loam soils. Organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc values are lower than optimum level. The optimum growth and development takes within 15-21°c. The growth rate decreases with the increase in temperature. Foggy weather, high temperature, and humidity could cause incidence of disease and insects and low yield.

Moderately suitable 1 are the unions of Basudevpur, Deopara, Gogram, Matikata, Godagari, and Pakri which cover about 60 per cent area. On the other hand, Char Ashariadaha, Rishikul, and Mohanpur union are in the category of moderately suitable 2 which accounts about 40 per cent land in the study area. The lower suitability factors for potato cultivation in Char Ashariadaha, Rishikul, and Mohanpur union than other 6 unions are low sulfur, potassium, and zinc in Char Ashariadaha and Mohanpur union and high boron level in Rishikul union etc. Flooding depth, duration, and accessibility difficulties are present in Char Ashariadaha.

Potato yield and quality is roughly good in the study area and net return from 33 decimals farm is BDT 9439 which is also considered satisfactory if production is not hampered.

5.4.5 Land Suitability for Lentil Cultivation

Pulses are abundantly cultivated and a major agriculture crop in the study area which cover about 5 per cent area. Lentil is the main variety of pulses and cultivated in most areas. The optimum sowing time is last week of October to first week of November. Its maturity varies from 95-150 days depending on the varieties and sowing time.

The following table explicates that almost all areas are moderately suitable for lentil cultivation. It grows best in soil pH 6.0-6.5 which is present in the study area. Loam and clay loam soils are suitable for lentil cultivation. Lentil is somewhat drought tolerant but susceptible to water logging and study area is mainly highland which is good. Lentil prefers fully sunny environments, loose, and organic matter rich well-drained soil. Union wise suitable areas for lentil cultivation are presented below in figure 5.45 and tables 5.24 and 5.25.

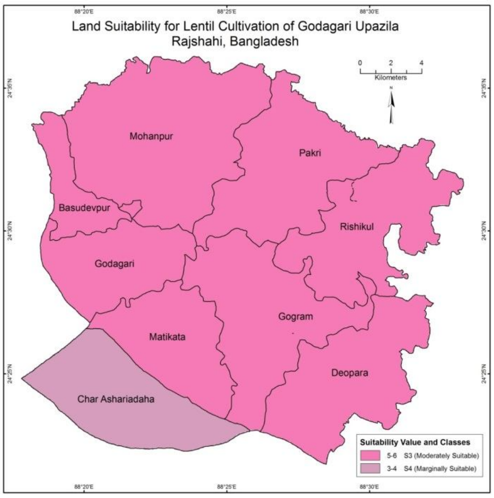

Figure 5.45. Land Suitability for Lentil Cultivation

Table 5.24. Union Wise Areas of Different Suitability Class: Lentil Cultivation

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	5	Moderately Suitable
C Ashariada	3646	7.66	4	Marginally Suitable
Deopara	5234	11.00	5	Moderately Suitable
Gogram	7026	14.78	5	Moderately Suitable
Matikata	3956	8.31	5	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	5	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	5	Moderately Suitable

Table 5.25. Areas of Different Suitability Class for Lentil Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	43917	92.34	3646	7.66	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Lentil Cultivation

Table 5.25 provides the clear picture of union wise suitable areas and suitability classes which indicates that all union except Char Ashariadaha are moderately suitable for lentil cultivation accounting about 92 per cent area. Only Char Ashariadaha union holds marginally suitable category which accounts only 7.66 per cent area. The main reasons of marginally suitable of lentil cultivation in Char Ashariadaha union are low presence of sulfur, and zinc, depth and duration of flooding, and accessibility difficulties etc.

However, lentil cultivation requires low rainfall but net return is only BDT 4124 that are not enough and alternate high yielding and high net return crops should be cultivated.

5.4.6 Land Suitability for Mustard Cultivation

Mustard is the main edible oil seed and oil seeds cover 2.59 per cent land in the study area. Mustard is a *rabi* crop and grows well in winter season. Mustard prefers soil pH range of 5.5-6.8 and clay loam and medium texture containing high organic matter. It can also be grown well in loam and sandy loam soil. It grows well within temperature range 10-20 °c. All these conditions are existent in the study area. Areas of different suitability class for mustard cultivation are presented below in figure 5.46 and tables 5.26 and 5.27.

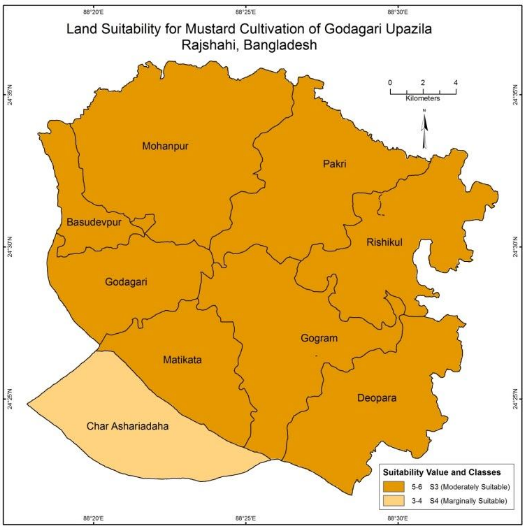

Figure 5.46. Land Suitability for Mustard Cultivation

Table 5.26. Union Wise Areas of Different Suitability Class for Mustard Cultivation

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	5	Moderately Suitable
C Ashariada	3646	7.66	4	Marginally Suitable
Deopara	5234	11.00	5	Moderately Suitable
Gogram	7026	14.78	5	Moderately Suitable
Matikata	3956	8.31	5	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	5	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	5	Moderately Suitable

Table 5.27. Areas Under Different Suitability Class for Mustard Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	43917	92.34	3646	7.66	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability forMustard Cultivation

The above table shows that most of the land (92.34 per cent) in the study area are moderately suitable for mustard cultivation which covers 8 unions namely, Basudevpur, Deopara, Gogram, Matikata, Rishikul, Godagari, Mohanpur, and Pakri union. Only Char Ashariadaha union is categorized as marginally suitable which accounts only 7.66 per cent area. The limiting factors for moderately suitable category in most areas are low soil quality, topographical, and flooding problems. Char Ashariadaha union has low presence of sulfur and zinc, flooding depth, and duration, and accessibility problems to local markets and highway.

5.4.7 Land Suitability for Onion Cultivation

Onion is included into spices category and spices are cultivated in 1102 acres which account 0.84 per cent land in the study area. It ranks second among the spice crops in terms of production. Cold weather is suitable for onion and grows well at temperature 15-25°c. Onion grows best in loam and sandy loam soil, loose, well-drained soil with high fertility, and sufficient organic matter. Land suitability for onion cultivation in the study area are depicted below in figure 5.47 and tables 5.28 and 5.29.

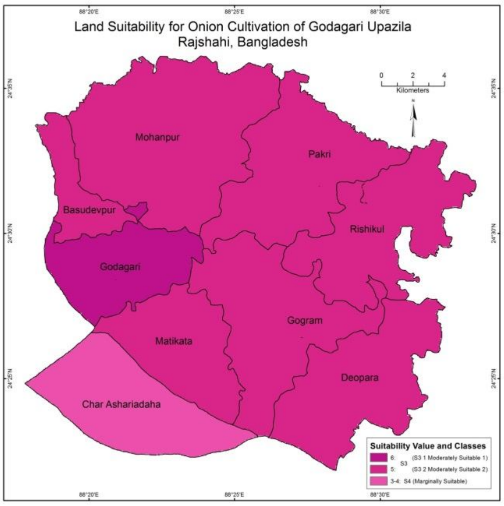

Figure 5.47. Land Suitability for Onion Cultivation

Table 5.28. Union Wise Areas Under Different Suitability Class for Onion

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	5	Moderately Suitable
C Ashariada	3646	7.66	4	Marginally Suitable
Deopara	5234	11.00	5	Moderately Suitable
Gogram	7026	14.78	5	Moderately Suitable
Matikata	3956	8.31	5	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	5	Moderately Suitable

Table 5.29. Areas Under Different Suitability Class for Onion Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	43917	92.34	3646	7.66	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Onion Cultivation

The figures referred to 5.29 table shows that about 92 per cent land in the study area are categorized as moderately suitable for onion cultivation that fall in the union of Basudevpur, Deopara, Gogram, Matikata, Rishikul, Godagari, Mohanpur, and Pakri. Only 7.66 per cent land are categorized as marginally suitable which are in Char Ashariadaha union. Moderately suitable 1(suitability value 6) is the one union Godagari which covers only about 8 per cent area. On the other hand, Basudevpur, Deopara, Gogram, Matikata, Rishikul, Mohanpur, and Pakri unions are in the category of moderately suitable 2 (suitability value 5) which accounts about 84 per cent land in the study area. Char Ashariadaha union lacks sulfur, and zinc and suffers from depth and duration of flooding problems, and accessibility difficulties to local markets and highway.

Though onion cultivation is found moderately suitable but onion and onion seeds are found highly profitable crops in the study area. The net returns are BDT 19082 and 97574 respectively for onion and onion seed in 33 decimals farmhouse which are very potential and can develop agriculture sector significantly.

5.4.8 Land Suitability for Chili Cultivation

Chili is included into spices category and it is an important cash and main spice crop in the country. Chili is grown all the year round but mainly in two seasons; *rabi* and *kharif* 1. Chili grows best in well-drained porous soil rich with organic matter and poor in clay content. The pH value in soil should be within 5.5-6.8. Sufficient water should be available with good drainage facilities. Sandy loams to clay loam soils are suitable for chili cultivation. It cannot withstand flooding. Suitability areas for chili cultivation are presented below in figure 5.48 and tables 5.30 and 5.31.

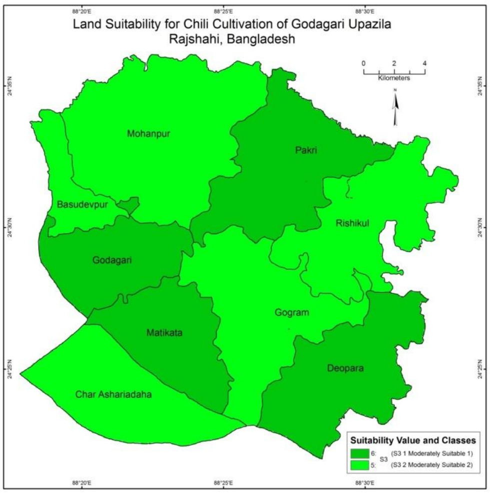

Figure 5.48. Land Suitability for Chili Cultivation

Table 5.30. Union Wise Areas of Different Suitability Class for Chili Cultivation

Union	Area (ha)	Area (%)	Suitability Value	Suitability Class
Basudevpur	1896	3.99	5	Moderately Suitable
C Ashariada	3646	7.66	5	Moderately Suitable
Deopara	5234	11.00	6	Moderately Suitable
Gogram	7026	14.78	5	Moderately Suitable
Matikata	3956	8.31	6	Moderately Suitable
Rishikul	5933	12.48	5	Moderately Suitable
Godagari	3830	8.05	6	Moderately Suitable
Mohanpur	9647	20.29	5	Moderately Suitable
Pakri	6395	13.44	6	Moderately Suitable

Table 5.31. Areas of Different Suitability Class for Chili Cultivation

Highly Suitable		Suitable		Moderately Suitable		Marginally Suitable		Not Suitable	
ha	%	ha	%	ha	%	ha	%	ha	%
-	-	-	-	47563	100	-	-	-	-

Source: ArcGIS 10.1 Model Map on Land Suitability for Chili Cultivation

Table 5.31 shows that 100 per cent land in the study area have been categorized as moderately suitable for chili cultivation. Moderately suitable 1(suitability value 6) are the unions of Deopara, Matikata, Godagari, and Pakri which account about 41 per cent areas. Moderately suitable 2 (suitability value 5) are the unions of Basudevpur, Char Ashariadaha, Gogram, Rishikul, and Mohanpur which accounts about 59 per cent of the study area. Many characteristics in the study area are found good and many are not congenial for potential yield of chili particularly organic matter content, moisture holding etc. Chili crop cultivation is not too much profitable but much more than rice and it has good market demand. Therefore, this crop cultivation is economically moderately viable.

5.5 Land Suitability Model Output Verification

Land suitability model output verification is an important task in GIS based land suitability analysis. Comparison of land suitability outputs with existing land use patterns are usually done for the model output validation. Using sample size determination formula and probability proportional to size (PPS) sampling, 56 samples and their union wise proportions were selected for land suitability model output verification which are described in chapter two "Materials and Methods". The verification points are presented below in figure 5.49.

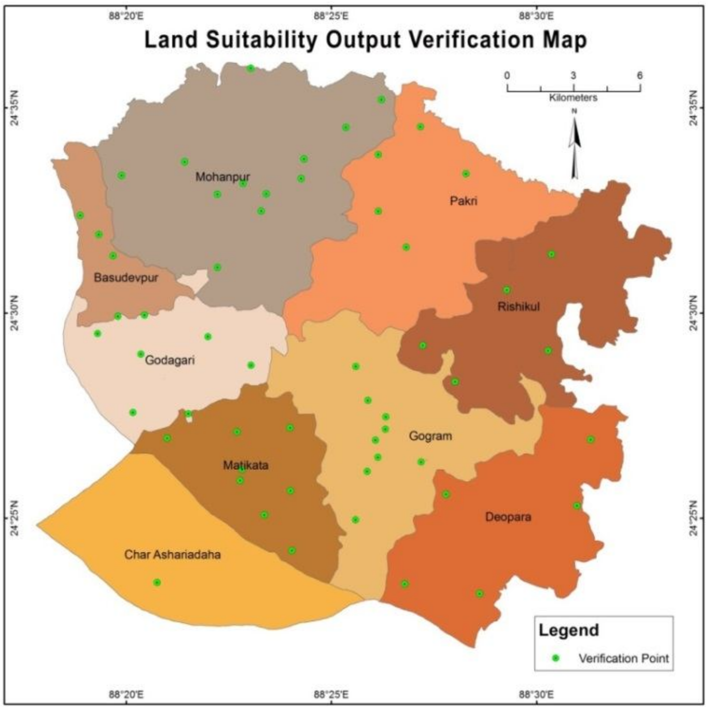

Figure 5.49. Land Suitability Model Output Verification

Field observations were done to compare and verify the land suitability model output generated through ArcGIS 10.1 modeling with field data through direct observation method. Local farmers and union agriculture officials were present and participated in the process of collecting field data through direct observation and the truthiness was verified in this way to check the validation of the land suitability model outputs. Observation technique qualifies as a scientific method of data collection when it is systematically planned and executed with proper controls.[20] Land suitability model output verification was done from March 3 to March 12 of 2016 and a photo of model output field verification is inserted in appendix. It may be mentioned here that some verification works were done with the help of two experts from Soil Resource Development Institute (SRDI), Rajshahi.

The detailed figure relating to land suitability model outputs of overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation and observed field data of overall land suitability and mentioned 8 crops are presented as appendix 2 in this study. Accuracy figure between land suitability model output and observed filed data are presented below in table 5.32.

Table 5.32. Land Suitability Model Output Verification Accuracy

Land Suitability	Verified Model Output No	Correct Output No	Incorrect Output No	Accuracy (%)
Overall Land Suitability	56	52	4	92.85
Rice	56	51	5	91.07
Wheat	56	51	5	91.07
Maize	56	52	4	92.85
Potato	56	50	6	89.28
Lentil	56	51	5	91.07
Mustard	56	50	6	89.28
Onion	56	50	6	89.28
Chili	56	49	7	87.50

Source: Field Verification Data, 2016

In verified 56 sites, model provides acceptable range of accuracy of land suitability. The accuracy rate between land suitability model output and field observation data is found from 87.50 per cent to 92.85 per cent. Therefore, more than 87.50 per cent land suitability ArcGIS 10.1 model outputs are found consistent with field data which are considered good and acceptable.

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[20] M. Nurul Islam, *An Introduction to Research Methods: A Handbook for Business & Health Research* (Dhaka: Mullick & Brothers, 2008), 172.

5.6 Conclusion

MCE approach was used in this study using GIS tool to identify different land suitability area for overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation in the study area. This approach has been used in many studies conducted in different places. However, this approach is relatively a new and original application in the study area for sustainable agricultural development especially for major agricultural crops. It is shown in this study that MCE-GIS jointly could provide acceptable accurate site selection of land suitability for major agricultural crops to make rational decisions for farmers, policy makers, and agriculture extension officials.

Chapter Six
Economic Viability of Major Agricultural Crops

6.1 Introduction

Economic viability analysis of major agricultural crops and cropping patterns is a comparison between the total revenues and the total costs of crops and cropping patterns of the study area. Very simple and widely used techniques- net return analysis and benefit-cost ratios are applied to do it and these techniques are seen to apply in many studies such as Rahman and Hossain,[1] and Islam.[2] A crop is considered economically viable if it produces satisfactory return against investment and economic viability varies from crop to crop, farm to farm and cropping pattern to cropping pattern. It depends on many factors including total variable costs, production, market price, market access etc. Major agricultural crops that are studied for economic viability are *t.aus, t.aman, boro* rice, wheat, maize, potato, lentil, mustard, chili, onion, onion seed, tomato, brinjal, pulses, and cauliflower total 15 crops which account about 93 percent areas of the study area. Present major cropping patterns and land suitability based cropping patterns are also analyzed. Respondents' demographic and educational characteristics are described in chapter eight.

6.2 Cultivated Area of Major Agricultural Crops in the Study Area

Land use in the study area is dominated by agriculture and agriculture is dominated by rice. The area and percentage of major agricultural crops of the study area are presented in table 6.1.

Table 6.1. Area and Percentage of Major Agricultural Crops in the Study Area

Crops	Area (acres)	Percentage
Rice	102546	79.06
Wheat	3319	2.56
Maize	3754	2.90
Potato	539	0.41
Pulses	6407	4.93
Oil Seeds	3349	2.59

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[1] Zubaidur Rahman and Md. Elias Hossain, "Economic Viability and Resource Use Efficiency of Rice Production in Naogaon District," *Society and Progress* 1(February, 2015), 164.

[2] Mohammad Monirul Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2015), 88.

Spices	1102	0.85
Jute	815	0.62
Sugarcane	225	0.17
Fruits	56	0.04
Others	7603	5.87
Gross Cropped Area	129715	100

Source: Census of Agriculture- 2008, Zila Series: Rajshahi (P.403)

The figures referred to above bring out the exposed nature of rice domination. Pulses, wheat, maize, and oil seeds cover about 13 per cent area. Other crops cover very limited areas. Rice is economically less profitable crop, dominance of rice means agriculture sector is still traditional, and farmers are not in economically sound position. Therefore, the socio-economic condition is not also developed.

6.3 Yield of Major Crops in the Study Area

Yield, market price, and total costs are important components of economic viability analysis of agricultural crops in any area. It is observed that there is significant gap between potential yield and actual yield in Bangladesh. This significant gap is attributable to soil, irrigation water, climatic, socio-economic, and cultural characteristics. Production of crops in the study area is presented below in table 6.2.

Table 6.2. Production of Crops Yield in the Study Area, 2016

(Kg/33decimal)

Crops	Yields in the Study Area *	Yields in Northern Bangladesh**
Aus	559.26	570
Aman	613.14	640
Boro	781.84	962
Brinjial	3205	3482
Tomato	3120	4023
Chili	1433	1738
Cauliflower	2996	2838
Mustard	184.77	192
Pulses	140	195
Potato	3244.05	3292
Onion	1470.76	1520
Onion seed	69.92	-
Wheat	471.68	573
Lentil	177.86	195
Maize	1287.12	1067

*Source: * Field Data, 2016*

*Note: **Data collected through questionnaire survey in May-July, 2013 for the crop year2012-2013*[3]

[3] Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh," 151.

It is clear in the above table that yield of *aus*, *aman*, *boro*, brinjal, tomato, chili, mustard, pulses, potato, onion, onion seed, wheat, and lentil are significantly lower than potential yield. Not only is that, the yield of all crops in the study area except cauliflower and maize low in comparison to Northern Bangladesh. Yield of abovementioned 15 crops are considered low yield than many other countries of the globe and even many other parts of Bangladesh. The main reason is the low soil fertility in the study area and due to low yield, the margin of profit of agriculture farm is meagre and currently cultivated major crops are not much profitable. As the yield is low, profit margin is meagre and agriculture related sectors are not developed. Socio-economic conditions of farmers as well as the region are not rationally developed.

6.4 Economic Viability Analysis of Major Agricultural Crops

Economic viability analysis of major crops of any area reveals a clear picture of agriculture of that area as well as socio-economic conditions of the farmers. The study area is agriculture dominated and a few crops dominate agriculture in this region, mainly rice, which is evident in table 6.1. Gross revenue (total income) and production costs (total costs) are first required to gauge the economic viability of crops, which are discussed below. Land rent is included in this study in total cost irrespective of ownership of land (farmers own land or rented land). Total cost is comprised of 11 type of costs and total revenues are prices of main products and by-products. Description of calculating total costs and total revenues are mentioned in questionnaire (Appendix 8).

6.4.1 Gross Revenue

Gross revenue or gross return varies from crop to crop and from farm to farm due to soil fertility, selection of crops and cropping pattern, farm size, selection of seeds, yield, use of chemical fertilizers and insecticides, market demand and price etc. The gross revenue of major crops in the study area are presented below in table 6.3.

Table 6.3. Gross Revenue (BDT/33 decimals) of Major Crops in the Study Area

Crops	Mean Gross Revenue	Maximum	Minimum	Std. Deviation	Ranking
T aus	10974.20	15800.00	8100.00	5086.76570	13
T. aman	11262.32	12400.00	7600.00	998.29435	12
Boro	15816.85	18200.00	11900.00	6494.20737	9
Brinjial	53345.00	69500.00	44060.00	8494.88417	2
Tomato	40326.00	48700.00	34000.00	5001.00928	6
Chili	23645.76	49600.00	19200.00	6662.22856	8

Cauliflower	45500.00	48000.00	43000.00	3535.53391	3
Mustard	8724.33	10600.00	6665.00	694.91412	15
Pulses	14230.00	14260.00	14200.00	42.42641	10
Potato	43373.89	52400.00	39000.00	2617.13721	4
Onion	41746.00	51570.00	35080.00	3691.92091	5
Onion seed	135666.67	160000.00	122000.00	8746.01358	1
Wheat	10471.69	11600.00	9200.00	503.48366	14
Lentil	11710.83	14060.00	8390.00	1161.54277	11
Maize	29618.56	37000.00	11200.00	6058.40540	7

Source: Field Data, 2016

It is found in the above table that gross revenue varies in different crops. A few crops have higher revenue while some have lower revenue. The main crop rice which is cultivated in about 79 per cent areas have lower revenue. The gross return of *aus* in the study area is about BDT 10974, *aman* 11262, and *boro* paddy 15817 BDT. The highest revenue is found against onion seed (about BDT 135667) which is very interesting and economically very significant followed by brinjal (53345 BDT). Gross returns from cauliflower, potato, onion, tomato, maize, chili are higher than *boro* paddy, pulses, lentil, *aman*, *aus,* wheat, mustard etc.

Gross revenue significantly determines the net revenue. As the gross revenue of main crop rice and other dominant crops are lower, the profit farmers are getting lower. Farmers cultivate 80 per cent of their land for rice which means that their gross return are not much and logically farmers economic footing are not sound.

6.4.2 Total Costs

Total costs for production are also important along with gross return to assess the economic viability of crops. Higher production costs reduce the margin of profitability of crops and farms and even can make the crops production and farm losing. Therefore, the production costs are significant determinant of choice of crops to be cultivated and that crop's economic viability. Generally, farmers choose to grow those crops that need lower input costs but higher returns. However, some crops require higher input costs, some lower costs. For example, *boro* rice needs higher input costs due to much irrigation, fertilizers and insecticides whereas wheat, lentil and mustard need about no irrigation and little fertilizers and insecticides. Thus, input costs vary from crop to crop. Requirement of labor and other costs also vary from crops to crops which results in variation of costs for different crops significantly. Production costs of 15 crops in the study area are presented below in table 6.4. Land rent is included with total costs irrespective of land ownership.

Table 6.4. Production Costs (BDT/33 decimals) of Major Crops in the Study Area

Crops	Mean Production Costs	Maximum	Minimum	Std. Deviation	Ranking
T. aus	10168.67	11890.00	7800.00	519.54799	10
T. aman	9835.52	11300.00	7800.00	707.57864	11
Boro	13961.29	17430.00	11700.00	1048.06594	9
Brinjial	36635.00	42000.00	31800.00	3986.15819	2
Tomato	27129.50	32700.00	2300.00	5490.70081	4
Chili	19180.32	41500.00	15400.00	4950.63566	7
Cauliflower	19410.00	39450.00	7900.00	15882.39591	6
Mustard	6883.97	7840.00	5135.00	590.21791	15
Pulses	7830.00	8390.00	7270.00	791.95959	13
Potato	33934.72	38335.00	30500.00	1894.18679	3
Onion	22663.73	32060.00	19700.00	2813.59483	5
Onion seed	38092.92	45000.00	32380.00	3385.51708	1
Wheat	8105.07	9100.00	7090.00	411.63393	12
Lentil	7586.34	11300.00	6255.00	806.58433	14
Maize	19170.28	23700.00	10200.00	2707.50130	8

Source: Field Data, 2016

Table 6.4 shows that production costs vary from crop to crop. The highest production cost is seen against onion seeds. Production costs for brinjal, potato, tomato, onion, cauliflower, chili, maize etc. are higher than rice, wheat, pulses, lentil etc. Farmers have to expend total cost from their pocket and it significantly determines the profit. Therefore, it is difficult to cultivate crops of higher production cost which most farmers cannot do because of their economic footing. Therefore, farmers in the study area like most areas of Bangladesh are found to be in a position which is like vicious circle of poverty. But, crops cultivation which have higher production cost are must to be cultivated for higher profit and for the development of agriculture.

However, higher gross return does not mean higher profit. To conclude regarding profitability of crops, it needs to see net return and BCR of that crop. Net return and BCR include gross return and total costs of concerned crop. Higher gross return and lower total cost increases net return and BCR and vice versa. It varies from crop to crop. Therefore, it needs to analyze economic viability of major agricultural crops to move forward to economically viable cropping pattern which lead to agriculture development.

6.4.3 Economic Viability Determination of Major Agricultural Crops

Economic viability of a crop is the net return deducting total cost from total revenue. Production cost and net return are two important factors which play decisive role in choice of cultivation of crops and economic viability. Net return and benefit-cost ratio of crops are widely used to determine the comparative profitability and economic viability of the crops. Crop production is considered economically viable if net return is positive and higher the net return is, more the economic viability of that crop is. Similarly, benefit-cost ratio of the crop is found greater than 1, that crop is considered as profitable and economically viable. In this study, cost and returns are calculated based on actual price received and paid by the farmers during production and harvesting period of the crops in 2014-2015. Economic viability of major 15 crops in the study area is presented below in table 6.5.

Table 6.5. Economic Viability of Major Agricultural Crops in the Study Area

Crops	GR	TC	NR (GR-TC)	Ranking for NR	BCR(GR/TC)	Ranking for BCR
T. Aus	10974.20	10168.67	805.53	15	1.079	15
T. Aman	11262.32	9835.52	1426.80	14	1.145	13
Boro	15816.85	13961.29	1855.56	12	1.132	14
Brinjial	53345.00	36635.00	16710.00	4	1.456	8
Tomato	40326.00	27129.50	13196.50	5	1.486	7
Chili	23645.76	19180.32	4465.44	9	1.232	12
Cauliflower	45500.00	19410.00	26090.00	2	2.344	2
Mustard	8724.33	6883.97	1480.36	13	1.267	11
Pulses	14230.00	7830.00	6400.00	8	1.817	4
Potato	43373.89	33934.72	9439.17	7	1.278	10
Onion	41746.00	22663.73	19082.27	3	1.841	3
Onion seed	135666.67	38092.92	97573.75	1	3.561	1
Wheat	10471.69	8105.07	2366.62	11	1.291	9
Lentil	11710.83	7586.34	4124.49	10	1.543	6
Maize	29618.56	19170.28	10448.28	6	1.545	5

Source: Field Data, 2016

Notes: GR= Gross Return TC=Total Cost NR=Net Return BCR=Benefit-Cost Ratio

The above table illustrates the economic viability of major agricultural crops of the study area. The total 15 crops which are generally cultivated by the farmers in the study are assessed here. It is found that net returns of onion seeds and cauliflower are BDT 97574 and 26090 respectively which are very profitable and much more than rice which (rice) is cultivated in 79.06 per cent areas of the study area and 78.52 per cent areas of Bangladesh. The next economically viable five crops are onion, brinjal, tomato, maize, and potato respectively on the basis of net return. On the other hand, rice is the economically least viable crop. Economically least viable five crops next to rice are mustard, wheat, lentil, chili, and pulses respectively.

On the basis of benefit-cost ratio, the economically most viable five crops are onion seed, cauliflower, onion, pulses, and maize respectively. On the other hand, economically least viable five crops are rice, chili, mustard, potato, and wheat respectively. *T. aus, t. aman* and *boro* are three least viable crops both in respect of net return and benefit-cost ratios and onion seed is highest which is shown below.

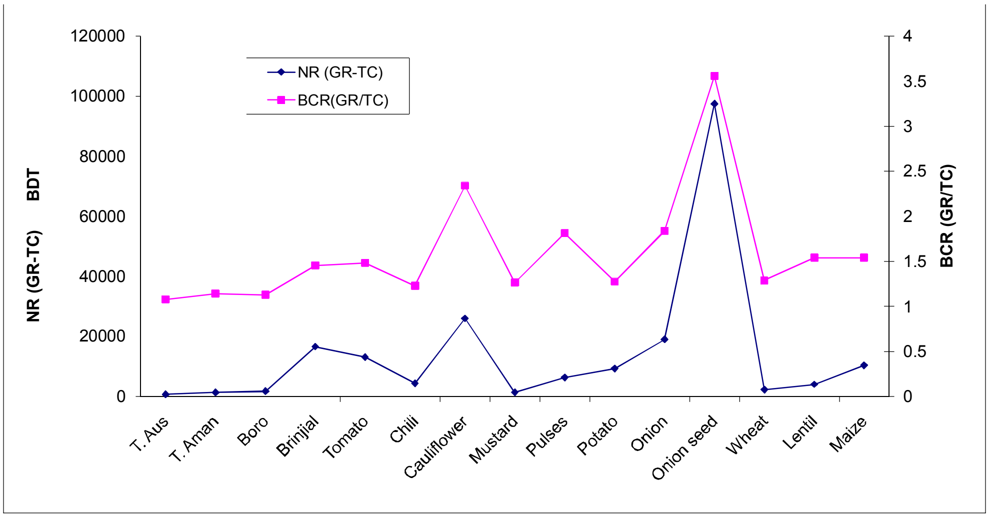

Figure 6.1. Economic Viability of Major Agricultural Crops

Area under rice cultivation as a percentage of total cultivated area was about 78.52 percent in Bangladesh; of which *aus* occupies 8.67 per cent, *aman* occupies 49.87 per cent, and *boro* occupies 41.46 per cent areas.[4] The main reasons of rice cultivation are domestic consumption, food security for family, need huge capital for profitable crops cultivation, climate and market prices' uncertainty, risks to be pauper in profitable crops cultivation etc. as told by the farmers in the study area. However, this dominance of rice cultivation in about 79 per cent land in the study area and Bangladesh is not economically viable and a key obstacle for the development of agriculture, socio-economic development of farmers as well as rural areas of the country.

[4] Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh 2014 (*Dhaka: Statistics and Informatics Division, Ministry of Planning, 2016), 127.

6.5 Economic Viability Analysis of Land Suitability Based Cropping Patterns

Cropping pattern is crucial for agriculture sustainability. However, crop diversification is comparatively low in Bangladesh. Selection of economically viable cropping patterns leads to changes in net returns which ultimately develops the agriculture sector as well as the socio-economy of the farmers and the country. The present main cropping pattern in the study area is rice based cropping pattern which is economically least viable as found in field survey. Agriculture of a very few countries of the world depends on a single crop as high as the case in Bangladesh.[5] Economic viability of presently followed main cropping patterns and land suitability based proposed cropping patterns and their comparison are discussed below.

6.5.1 Economic Viability of Present Cropping Patterns in the Study Area

Farmers follow different cropping patterns in their different farms which depend on many factors. As a corollary, farms having different cropping patterns bring different gross returns, net returns and economic viability.

6.5.1.1 Present Cropping Patterns

Cropping patterns are the cultivation of different crops in three crop growing seasons namely, *rabi* (16 October-15 March), *kharif* 1(16 March-15 July) and *kharif* 2 (16 July-15 October) in a cropping year in a piece of land. Cropping pattern of an area is generally determined by farmers' knowledge, attitude, food habit, family's food security, physical, socio-economic, infrastructure, and technological factors etc. The present cropping patterns of the study area are presented below.

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[5] Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh," 56.

Table 6.6. Present Cropping Patterns in the Study Area

Present Cropping Pattern			Area*(acre)	Area (%)
Rabi Season	*Kharif* 1 Season	*Kharif* 2 Season		
Boro	Fallow	*Aman*	32446	33%
Boro	*Aus*	*Aman*	12782	13%
Fallow	*Aus*	*Aman*	11799	12%
Wheat	*Aus*	*Aman*	4916	05%
Boro	*Aus*	Pulses	4916	05%
Wheat/Potato/Mustard	Fallow	*Aman*	4916	05%
Pulses	*Aus*	*Aman*	3933	04%
Boro	*Aus*	Tomato	2950	03%
Mustard /Potato	*Aus*/Maize/Jute	*Aman*	2950	03%
Fallow	*Aus*	Tomato	2950	03%
Wheat	Fallow	*Aman*	1966	02%
Vegetables	Vegetables	Fallow	1966	02%
Mustard+ *Boro*	*Aus*	Fallow	1966	02%
Maize/Onion	*Aus*	*Aman*	983	01%
Others	--	--	6882	07%
		Total=	98321	100%

Source: Bangladesh Agriculture Development Corporation (BADC), Godagari, Rajshahi, 2016

Notes: Area= net cultivable area, 1 hectare=2.471 acre, 1 acre= 0.40468 hectare*

It is found that the present cropping patterns in the study area are mainly rice dominated. Only rice (*aus, aman* and *boro*) constitutes 58 percentages. Wheat, mustard, potato, pulses, vegetables, maize and onion along with *aus, aman* and *boro* paddy constitute another 35 per cent and rest constitute only 7 per cent. Only rice and rice based cropping patterns constitute about 93 per cent cropping pattern which are not considered good for higher economic return from single dominant sector agriculture of Bangladesh. Agriculture sector dominates socio-economic and cultural conditions of farmers as well as the rural area and profit from agriculture sector matters most which shapes socio-economic and cultural condition. Farmers presently cultivate rice based cropping patterns which are not economically much profitable. For the sake of agricultural development, it needs to change and cultivate economically most viable crops.

6.5.1.2 Economic Viability of Present Cropping Patterns

There are three crop growing seasons in Bangladesh which are *rabi, kharif* 1 and *kharif* 2. Cropping patterns are the cultivation of different crops in mentioned three crop growing seasons in a piece of land in a cropping year which determine profitability. Economic viability of present cropping patterns in the study area is made below in table 6.7 through calculating net return and benefit-cost ratios.

Table 6.7. Economic Viability of Present Cropping Patterns

(BDT /33 decimals)

SL	Present Cropping Patterns	GR	TC	NR (GR-TC)	Ranking (NR)	BCR (GR/TC)	Ranking (BCR)
1	*Boro*+Fallow+ *Aman*	27079.17	23796.81	3282.36	11	1.137	12
2	*Boro+ Aus + Aman*	38053.37	33965.48	4087.89	8	1.120	13
3	Fallow+ *Aus +Aman*	22236.52	20004.19	2232.33	14	1.111	14
4	Wheat+*Aus+ Aman*	32708.21	28109.26	4598.95	7	1.163	9
5	*Boro+Aus*+Pulses(lentil)	38501.88	31716.30	6785.58	5	1.213	6
6	Mustard+Fallow+*Aman*	19986.65	16719.49	3267.16	12	1.195	8
7	Pulses(lentil)+*Aus+Aman*	33947.35	27590.53	6356.82	6	1.230	5
8	*Boro+Aus*+Tomato	67117.05	51259.46	15857.59	1	1.309	3
9	Mustard +*Aus+Aman*	30960.85	26888.16	4072.69	9	1.151	11
10	Fallow+*Aus*+Tomato	51300.20	37298.17	14002.03	2	1.375	1
11	Wheat+Fallow+*Aman*	21734.01	17940.59	3793.42	10	1.211	7
12	Vegetab(Potato)+*Aus*+Fallow	54348.09	44103.39	10244.70	4	1.232	4
13	Mustard+*Aus*+Fallow	19698.53	17052.64	2645.89	13	1.155	10
14	Maize+*Aus+Aman*	51855.08	39174.47	12680.61	3	1.323	2
15	None	-	-	-	-	-	-

Source: Calculated from Crop Wise Field Data, 2016

Notes: GR=Gross Return TC=Total Cost NR=Net Return BCR=Benefit-Cost Ratio

The above table depicts the net returns and benefit-cost ratios of present cropping patterns. There are a lot of cropping patterns but the present study analyzed only major cropping patterns. The highest net returns cropping patterns are *boro+aus*+tomato, fallow+*aus*+tomato, maize+*aus+aman*, vegetables(potato)+*aus*+fallow, *boro+aus*+ pulses(lentil) etc. In case of three rice based cropping patterns, *boro+aus+aman* brings slightly higher net returns than boro+fallow+*aman* and fallow+*aus+aman*. The lowest net return comes from fallow+*aus+aman* cropping pattern.

With respect to benefit-cost ratio (BCR) for different cropping patterns, highest benefit-cost ratio is found in fallow+*aus*+tomato cropping pattern followed by maize+*aus+aman*. The lowest BCR is found in fallow+*aus+aman* followed by *boro+aus+aman* cropping pattern. Other lower cropping patterns are mainly rice based and higher cropping patterns are vegetable based.

In view of above field data it is clear that present rice based cropping patterns are not economically viable which are also supported by many studies in Bangladesh. Farmers are not getting benefitted practicing present cropping pattern. Hence, it needs to be changed for the sake of higher income and socio-economic development of rural area.

6.5.2 Economic Viability of Land Suitability Based Cropping Patterns

It is seen in many studies including the present one that non-rice based cropping patterns are economically more viable than rice based cropping patterns. Degrees of economic viability of different crops and cropping patterns depend on production, market prices, input costs etc. If the proportion of area under a high value crop increases, it is likely to result in an increase in total returns from the sector. Hence, selection of high net return cropping patterns is important for agriculture development and its sustainability.

The economic viability of land suitability based proposed cropping patterns are described below which are the opinion of agriculture officials of the study area (Godagari upazila, Rajshahi). Agriculture officials have considered land suitability maps produced through GIS modeling in this study for rice, wheat, maize, potato, lentil, mustard, onion, and chili cultivation and overall land suitability. They have also taken into account the secondary sources they have in their office, their long time field experiences to propose land suitability based cropping patterns for the study area after discussing it in their monthly meeting in upazila office with union agriculture officials. The aforementioned agriculture officials' proposed cropping patterns are treated as land suitability based cropping patterns in this study which are presented below in table 6.8.

Table 6.8. Economic Viability of Land Suitability Based Cropping Patterns

(BDT /33 decimals)

SL	Land Suitability Based Cropping Patterns	GR	TC	NR (GR-TC)	Ranking (NR)	BCR (GR/TC)	Ranking (BCR)
1	Potato+Maize+ *Aman*	84254.77	62940.52	21314.25	6	1.338	6
2	Lentil+ *Aus* + *Aman*	33947.35	27590.53	6356.82	13	1.230	12
3	Tomato+ *Aus* +*Aman*	62562.52	47133.69	15428.83	7	1.327	7
4	Wheat+*Aus*+ *Aman*	32708.21	28109.26	4598.95	14	1.163	14
5	Onion+*Aus*+Pulses(lentil)	64431.03	40418.74	24012.29	5	1.594	4
6	Mustard+Jute+*Aman*	32486.65	25369.49	7117.16	11	1.280	10
7	Onion seed+*Aus*+*Aman*	157903.19	58097.11	99806.08	1	2.717	1
8	Cauliflower+*Aus*+Tomato	96800.20	56708.17	40092.03	3	1.706	3
9	Mustard +*Aus*+*Aman*	30960.85	26888.16	4072.69	15	1.151	15
10	Chili+*Aus*+*Aman*	45882.28	39184.51	6697.77	12	1.170	13
11	Wheat+Jute*+*Aman*	34234.01	26590.59	7643.42	10	1.287	9
12	Potato+Chili+Fallow	67019.65	53115.04	13904.61	8	1.261	11
13	Onion+*Aus*+Brinjal	106065.52	69467.40	36598.12	4	1.526	5
14	Maize+Mug*+*Aman*	51855.08	39174.47	12680.61	9	1.323	8
15	Thai guava+ Thai guava+ Thai guava*	86370	34565	51805	2	2.498	2
	Others (7% area)	-	-	-	-	-	-

Source: Field Data, 2016

*Notes: GR=Gross Return TC=Total Cost NR=Net Return BCR=Benefit-Cost Ratio *= Gross Return and Total Costs of Thai Guava, Jute, and Mug are calculated from case study results and opinion from two farmers and one Union Sub-Assistant Agriculture Official*

The above table presents net return and benefit-cost ratio of proposed 15 cropping patterns for the study area. It is found that onion seed+ *aus*+ *aman* cropping pattern offers highest net return (about 1 lac BDT) which is only BDT 4088 for present *boro*+ *aus*+ *aman* cropping pattern. The second and third highest net returns are Thai guava+ Thai guava+ Thai guava and cauliflower+ a*us*+ tomato cropping patterns respectively. On the other hand, mustard+ a*us*+ *aman*, wheat+ *aus*+ *aman*, and lentil+ a*us* + *aman* cropping patterns are lowest net return cropping patterns. These three cropping patterns are rice dominated. It is also seen that non-rice based cropping patterns are highly profitable. These findings (high profitability in non-rice based cropping patterns) are in concurrent with findings of many other research works in Bangladesh.

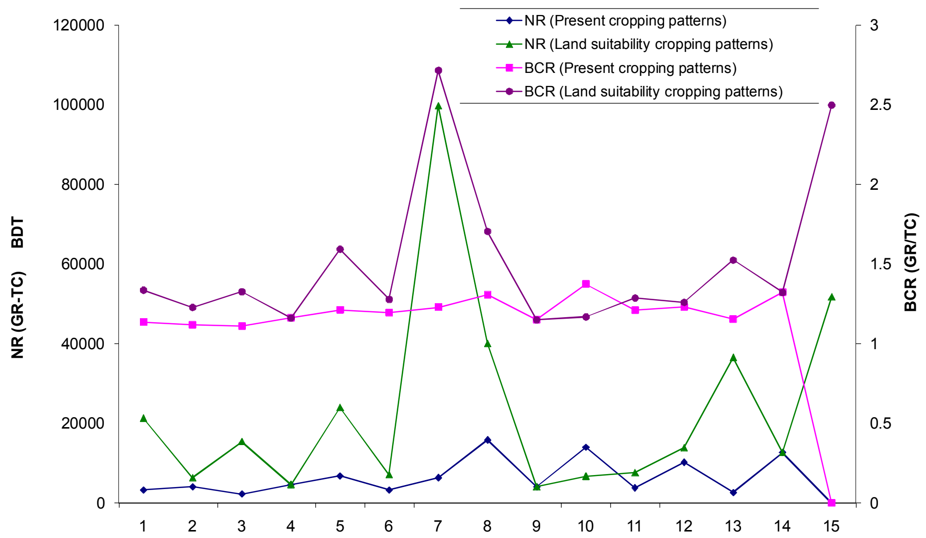

Figure 6.2. Comparison of Economic Viability of Present Cropping Patterns and Land Suitability Based Cropping Patterns

Note: 1, 2, 3,…, 15 are serial numbers of column 1 in tables 6.7 and 6.8

From the above discussion, it is evident that present rice based cropping patterns are economically less viable. It is also lucid that non-rice dominated land suitability based proposed cropping patterns are economically more viable than present rice based cropping pattern. Therefore, it is necessary to take effective measures to motivate farmers to adopt land suitability based economically viable cropping patterns which are depicted in table 6.8 and figure 6.2. Selection and cultivation of proper cropping patterns will enhance total and net revenues and benefit-cost ratios significantly which will change the total scenario of agriculture sector in the study area. The changes of net return of present cropping patterns and land suitability based proposed cropping patterns are presented below.

Table 6.9. Net Return Changes in the Study Area through Changing Cropping Pattern

Present Cropping Patterns	NR (acre)	Area (acre)	Total NR (BDT)	Proposed Cropping Patterns	NR (acre)	Area acre)	Total NR (BDT)
Boro+Fallow+ *Aman*	9847.08	32446	319498358	Potato+Maize+ *Aman*	63943	30117	1925771331
Boro+ *Aus* + *Aman*	12263.67	12782	156754230	Lentil+ *Aus* + *Aman*	19070	11806	225140420
Fallow+ *Aus* +*Aman*	6696.99	11799	79017785	Tomato+ *Aus* +*Aman*	46286	10892	504147112
Wheat+*Aus*+ *Aman*	13796.85	4916	67825315	Wheat+*Aus*+ *Aman*	13797	4533	62541801
Boro+*Aus*+Pulses(lentil)	20356.74	4916	100073734	Onion+*Aus*+Pulses(lentil)	72037	4533	326543721
Mustard+Fallow+*Aman*	9801.48	4916	48184076	Mustard+Jute+*Aman*	21351	4533	96784083
Pulses(lentil)+*Aus*+*Aman*	19070.46	3933	75004119	Onion seed+*Aus*+*Aman*	299418	3630	1086887340
Boro+*Aus*+Tomato	47572.77	2950	140339672	Cauliflower+*Aus*+Fallow	120276	2722	327391272
Mustard +*Aus*+*Aman*	12218.07	2950	36043307	Mustard +*Aus*+*Aman*	12218	2722	33257396
Fallow+*Aus*+Tomato	42006.09	2950	123917966	Chili+*Aus*+*Aman*	20093	2722	54693146
Wheat+Fallow+*Aman*	11380.26	1966	22373591	Wheat+Jute+*Aman*	22930	1814	41595020
Vegetab(Potato)+*Aus*+Fallow	30734.1	1966	60423241	Potato+Chili+Fallow	41714	1814	75669196
Mustard+*Aus*+Fallow	7937.67	1966	15605459	Onion+*Aus*+Brinjal	109794	1814	199166316
Maize+*Aus*+*Aman*	38041.83	983	37395119	Maize+Mug+*Aman*	13825	905	12511625
				Thai guava+ Thai guava+ Thai guava*	155415	6882	1069566030
Total=		91439	**1282455972**	**Total=**		91439	**6041665809**
Others	--	6882	--				
NR Increase = 604,16,65,809 - 128,24,55,972 = 475,92,09,837 BDT							

Source: Calculated from Tables 6.7 and 6.8

*Note: *Thai guava cultivation area (6882 acre) is found reducing area proportionately from all cropping patterns). According to agriculture officials, about 7 thousand acres land should be allocated for Thia guava cultivation in the study area.*

It is found in the above table that net returns significantly increase changing present cropping patterns including high net return generating crops into cultivation such as onion seed, Thai guava, cauliflower, brinjal, tomato, maize etc. This finding is also supported by many studies in Bangladesh such as Islam.[6] It is found in that study that cultivating potato+ *aus*+ *aman* cropping pattern instead of *boro*+ *aus*+ *aman* cropping pattern, net return (NR) increases BDT 20523 per acre. While net return increases BDT 75690 per acre cultivating vegetables+ *aman*+ vegetables cropping pattern instead of *aus* +*aman*+ *boro* cropping pattern.

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[6] Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh,"163.

Cropping pattern changes are easy and effective methods to enhance net revenue significantly in agriculture. It also develops soil quality, environment, social and economic condition of farmers and the area. The agriculture economy of whole Bangladesh could be changed through changing present cropping patterns. The net return increase through changing cropping pattern in the study area Godagari upazila, Rajshahi district, Rajshahi division, and Bangladesh are presented below.

Table 6.10. Net Return (NR) Changes in the Study Area (Godagari Upazila), Rajshahi District, Rajshahi Division, and Bangladesh through Changing Cropping Pattern

Area	Net Cultivable Area(acre)	NR Increase in BDT
Godagari Upazila	98321*	511,74,03,542
Rajshai District	460834	2398,54,46,557
Rajshahi Division	1827641	9512,49,12,557
Bangladesh	18815381**	979301445057

Source: Calculated from Table 6.9

*Notes: **Cultivated Area, *= Calculated for Total Net Cultivable Area (98321 acre) from 93 Per Cent (91439 acre) Net Cultivable Area*

The above table shows the net returns increase about BDT 511.74, 2398.54, 9512.49 and 97930.14 crores for the study area, Rajshahi district, Rajshahi division and Bangladesh respectively changing cropping patterns which are very interesting and encouraging. If it is possible to practice land suitability based cropping patters, agriculture sector alone could contribute a lot to develop Bangladesh. Near about 1 lac crores BDT extra income from agriculture sector changing only cropping pattern is very encouraging which is about 56 per cent of total export (173783.11 crores BDT in 2013-2014[7]) of Bangladesh. Therefore, it is necessary to take effective measures for cultivating land suitability based and economically viable cropping pattern that could develop socio-economy, culture, and environment in rural area in particular and Bangladesh as whole.

It is noteworthy to mention here that the aforementioned land suitability based proposed cropping patterns may not be suitable to all areas particularly coastal saline belts and hilly areas, it is merely agriculture officials' assumption in respect of Godagari upazila.

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[7] Bangladesh Bureau of Statistics, *Statistical Year Book of Bangladesh 2014*(Dhaka: Statistics and Informatics Division, Ministry of Planning, 2016), 273.

6.6 Case Studies

A selected number of case studies have been undertaken for the identification of causes of most economically viable crop cultivation instead of rice cultivation by the farmers and their sustainability. Selected numbers are four; two cases for onion seeds and two for cauliflower. Case study includes the examination of causes, problems, limitations, risks and sustainability of the most profitable crops - onion seeds and cauliflower. Case studies were done through repeated informal interview and observation.

Onion Seed Cultivation: Case Study 1

Name of the Farmer: Md. Mahamudun Nabi Age: 29 Village: Rajabari Hat Union: Deopara Upazila: Godagari District: Rajshahi. Farm Size: 33 decimals.

This land was used for *t.aman* and lentil pulse in the past and profit was marginal. Onion seed was first cultivated in 2014 following the advice of agriculture extension officials with a view to get higher profit. To cultivate land for onion seeds the total costs were BDT about 42700 for 33 decimal farm. The production was about 67 kg in 2014 and 64 kg in 2015. Onion seed is sold 40 kg by BDT 85000-105000 and profits were about BDT 107400 and 94600 in 2014 and 2015 respectively. This higher profit is impossible in any other crops. If I cultivate this land for rice I can get net returns BDT two or three thousands only. Boro rice cultivation needs huge irrigation and due to lack of irrigation production was hampered.

There is risk of attack by mycelium (virus), *leth* insects. Storms and fog can damage onion seeds. Fog can damage even destroy flowers pollen and consequently onion seeds could not be good. Farmers have lack of knowledge. Market demand has been declined and buyers are not coming this year as they came in 2014 and 2015 and buyers are offering half prices.

Onion Seed Cultivation: Case Study 2

Name of the Farmer: Mollah Md. Badshah Alam Age: 47 Village: Kasimpur Union: Basudevpur Upazila: Godagari, District: Rajshahi. Farm Size: 66 decimals.

Paddy cultivation was done in this land from our childhood. But, for the last 8 to 10 years it is seen that rice cultivation is not profitable and we could not afford family expenses properly. Neighbor farmers are becoming gainer cultivating vegetable and varieties crops. Seeing this and as per advice of agriculture officials I started onion cultivation in 2015 in my 66 decimals high land farm near my homestead. Initially it took huge investment and I have to spend BDT about 76000 for onion cultivation in 66 decimals farm. I got onion seeds about 98 kg which was sold BDT 244000. The net profit I got about BDT 168000 which is impossible in rice cultivation even cultivating in 50 *bigha*(1650 decimals) farm.

Hailstorm, storm, fog and climatic problems can destroy onion seeds farm. Fog damages flower's pollen. Bees are less in this area, that is why pollination is less, and onion seeds become less healthy. Onion seeds cultivation needs knowledge.

Case Study Results of Onion Seeds Cultivation

Onion seeds need high investment and there is a risk of heavy losses. Hailstorm, storm and fogs are problem to onion seed cultivation. However, for the last few years' onion seeds cultivation is found profitable and farmers got heavy return. If the prices and demands last farmers will be benefitted cultivating onion seeds. But, this crop may suffer from future market demand. Market demand and prices have already declined.

6.7 Sustainability Risks of Onion Seed Cultivation

Onion seeds cultivation are profitable and Bangladesh Agriculture Development Corporation (BADC) and the Department of Agriculture Extension (DAE) are propagating to cultivate vegetables in lieu of rice particularly *boro* rice. Many farmers are switching from rice to onion seeds cultivation in the study area in the last few years. Onion seed cultivation needs heavy investment and if farmers become seriously looser, they will not be able to stand in future. Onion seeds demand is not very high and it is found during case study that this year (2016) farmers are not getting buyer to sell their onion seeds at the price they got in previous years and buyers are very limited this year. The prices buyers are offering are half than previous year and farmers are suspecting that after two or three years selling of onion seeds might be a major problem.

Farmers are switching without anticipating future market of onion seeds. There are many evidences in Bangladesh that cultivation of same product in huge land and in huge amount did not sustain after a few years. Farmers are foreseeing sustainability risks regarding future markets as told by two onion seeds cultivators of two case studies.

Marketing and storing facilities are not developed properly in Bangladesh. The country has no surplus of cereals. Therefore, if people cultivate onion seeds largely it will not ensure food security. Consequently, social sustainability, political sustainability, strategic sustainability, health sustainability and agriculture economics sustainability might be hampered. There were food crises many times in Bangladesh and in those times, social, political, strategic and health sustainability were also affected. In view of above, there are reasons to conclude that onion seeds cultivation has sustainability risks which need to be mitigated.

Cauliflower Cultivation: Case Study 1

Name of the Farmer: Md. Abdus Sattar Age: 57 Village: Raja Rampur Union: Godagari Upazila: Godagari District: Rajshahi Farm Size: 33 decimals.

The land which I am cultivating for cauliflower was used for *aus* and *boro* paddy and fallow in the rest period. I at first cultivated cauliflower in 2013 taking advice from union sub-assistant agriculture officer. As per their advice I make the farm cutting drains after few yards in the whole land and cultivated cauliflower. The investment is slightly high near about BDT 25000 for 33 decimals. However, the gross return is good and it was about BDT 95000, 76000 and 69000 in 2013, 2014 and 2015 respectively against 33 decimals. The net profit was about BDT 70000, 50000 and 45000 respectively in 2013, 2014 and 2015.

Cauliflower cultivation is like gambling. If the farmers fail to harvest earlier he will be seriously looser which is virtually impossible in rice cultivation. Cauliflowers can be rotten if rainfall is very high in August or September.

Cauliflower Cultivation: Case Study 2

Name of the Farmer: Md. Kamal Uddin Age: 44 Village: Mahadevpur Union: Rishikul Upazila: Godagari, District: Rajshahi. Farm Size: 33 decimals.

Boro and *aman* paddy were cultivated in the past since my father's life. But, recently paddy cultivation is virtually profitless and we get only the profit of our own labor. I cultivated cauliflower first in 2014 following the advice of union sub-assistant agriculture officer defying my parents' objection. I did everything as per the advice of agriculture department. As per their advice I made the farm and cultivated cauliflower. The investment was higher to me than rice which was about BDT 29000 for 33 decimals. But, the gross return was amazing in the first year (2014) and it was about BDT 93000 and I got BDT 89000 in 2015. The net profit was about BDT 64000 and 60000 respectively in 2014 and 2015.

Like most vegetable cultivations, cauliflower cultivation is one kind of risky cultivation. Farmers economic base can be seriously broken in one season if he fails to harvest when the market prices is high which is not possible in rice cultivation. Excess rainfall in August and September damages cauliflowers.

Case Study Results of Cauliflower Cultivation

Cauliflower cultivation needs higher investment and excess rainfall in august and September creates problem. In spite of that cauliflower cultivation is found profitable in the study area. Farmers can earn higher profits and there are market demands, though the profit of cauliflower significantly depends on the timing of harvesting.

6.8 Sustainability Risks of Cauliflower Cultivation

Vegetables are profitable and agriculture departments are encouraging farmers to cultivate vegetables in lieu of *boro* rice. Many farmers are switching from rice to vegetables cultivation in the study area in the last few years. Cauliflowers have good demand and it is assumed that its demand will not diminish in the near future because population is increasing.

Cauliflower cultivation needs much investment and there is a risk of loss if cauliflower is harvested in late. Market demand and prices of cauliflower are higher in early season and lower in late season. Besides, storing and marketing facilities are not developed properly in Bangladesh. In view of above circumstances, there are reasons to say that cauliflower cultivation has sustainability risks but lower than onion seed and these sustainability risks need to be addressed.

6.9 Conclusion

An endeavor was made in this chapter to analyze the economic viability of major agricultural crops and cropping patterns in the study area. Different crops have different economic viability. The main crops of the study area rice are found economically the least viable. This is a major concern and farmers, agriculture extension officials, and policy makers should take it seriously and search for alternate options. Cropping pattern changes could be a good solution and it can with no trouble substantially enhance the net returns from agriculture farm. The present rice based cropping pattern is found economically least viable which is practiced in most farms. Non-rice based cropping patterns such as onion seed+ *aus*+ *aman*, Thai guava+ Thai guava+ Thai guava, cauliflower + *aus*+ tomato etc. are found economically more viable in the study area.

Cropping pattern changes could increase net returns about BDT 511.74 and 97930.14 crores for the study area Godagari upazila and Bangladesh respectively which could change Bangladesh significantly. Agriculture sector alone can contribute a lot to developing Bangladesh if farmers follow land suitability based cropping patterns.

Chapter Seven
Land Use Changing Pattern and Sustainable Agriculture

7.1 Introduction

Land use in rural Bangladesh is mainly for agriculture. Agriculture is the main source of livelihood for most people of rural Bangladesh that covers about 94 per cent area of Bangladesh. However, land use, cropping patterns, crop cultivation areas, soil conditions, culture etc. are changing which have implications on sustainable agriculture. Changes in land uses over time occur due to interactions of various factors- the factors being human motives and capacities together with the characteristics of the available resources.[1] In the study area, soil properties, crop cultivation areas and agriculture land uses are also changing which have implications on land suitability based land uses and agriculture development. Therefore, it is necessary to see the changing pattern of land uses in the study area and to see whether these changes are consistent with sustainable agricultural development.

7.2 Changing Pattern of Soil Properties

Soil properties are very essential for plants normal growth and development. Crop and yield suffer due to deficiency or excess accumulation of elements in the soil. The study area lies in the Barind Tract having low natural fertility and low moisture holding capacity. Therefore, the changes in soil suitability are very important for agriculture sustainability. Hence, to see the changing pattern of soil properties is necessary for exploring the possible ways and means of agriculture development. Changing pattern of soil state is presented below in table 7.1 from 1991 to 2015.

Table 7.1. Changing Pattern of Soil Properties in the Study Area

Year	Texture	Moisture	pH	OM	N	P	K	S	Zn	B
1991	Clayand clay loam predominance	Low	6.17	1.08	0.21	29.26	0.25	24.25	0.18	1.84
2015	Clay and clay loam predominance	Low	7.06	1.53	0.08	15.09	0.25	12.59	1.15	0.59

Source: Soil Resource Development Institute (SRDI), 1991 and 2015

Notes: pH=1-14 Organic Matter (OM)=% Nitrogen (N)=% Phosphorus (P)=µg/g Potassium (K)= meq/100gm Sulfur (S)=µg/g Zinc (Zn)=µg/g Boron (B)=µg/g

[1]Nasreen Ahmed, "Temporal Changes in Agricultural Land Use in Bangladesh," *Environmental Aspects of Agricultural Development in Bangladesh,* ed. Saleemul Huq, A. Atiq Rahman and Gordon R Conway (Dhaka: University Press Limited, 2000), 93.

Soil properties mean values are presented in table 7.1. These values are calculated using 101 samples in 1991 and 78 samples in 2015. It is seen in the above table that pH and organic matter have been increased from 1991 to 2015 which is good for agriculture particularly organic matter probably due to residues, straws, and grass created from more crop cultivation. Nonetheless, organic matter is still in the very low category because optimum range is 3.5-5.5 per cent. Nitrogen, phosphorus, sulfur, and boron have decreased significantly, which are vital for potential yield and alarming for sustainable agriculture in the study area. On the other hand, zinc level has increased noticeably probably due to excess use of zinc in agriculture farms, nevertheless the present level is in the medium category and sustainable agriculture needs optimum level.

7.3 Changing Pattern of Crop Cultivation Areas

The pattern of crops cultivation areas in India as well as in Bengal province changed significantly after the Second World War. Following the Bengal famine in 1943 and simultaneously the Second World War with the consequent dislocation of imports exposed that India as a whole was acutely short of food and must produce food crops as much more as possible.[2] The Government of India in that connection launched a "Grow More Food" campaign. As a corollary, more emphasis is laid on growing more food crops as against commercial crops and changes in crop cultivation areas occurred. Crop cultivation areas in Bangladesh are also changing due to land use changes, profit maximization, population boom, rapid urbanization, industrialization, various development activities etc. which need to be analyzed with a view to see the changing pattern and explore the ways and means of agricultural development considering land suitability.

The first agriculture census was conducted in 1944-45 in India. Agriculture census in the area now constituting Bangladesh was conducted in 1960 and 1977 but both the two were sample survey basis covering only 10 per cent and 6 per cent of the agricultural holdings respectively.[3] These two censuses also could not produce agricultural statistics below district level means any upazila level estimation. The study

[2] Department of Agriculture, Forest and Fisheries, *Agriculture Statistics by Plot to Plot Enumeration in Bengal 1944-45*, Part 1(Calcutta: Bengal Government, 1946), 1.

[3] Bangladesh Bureau of Statistics, *Report on the Agricultural Census of Bangladesh 1977: National Volume* (Dhaka: Statistics Division, Ministry of Planning, 1981), Preface.

area is Godagari upazila. This is why 1977 census was not included and 1983-84, 1996 and 2008 censuses are only taken into consideration for changing pattern analysis of crop cultivation areas.

The study area is mainly rice dominated. Rice accounts 79.05 per cent of gross cropped areas in 2008 census that were 78.99 per cent and 83.50 per cent in 1996 and 1983-84 census respectively. The changing patterns of land uses for agriculture crop cultivation are presented below in table 7.2.

Table 7.2. Changing Pattern of Agriculture Crop Cultivation Areas

(In acres)

Census	1983-84	1996	2008
Net Temporary Cropped	66884	61917	70273
Gross Cropped	103543	83063	129715
Local Paddy	-	13523	20753
*Aus**/HYV *Aus* Paddy**	28079*	3039**	17473**
*Aman**/HYV *Aman* Paddy**	50187*	40415**	32310**
*Boro**/HYV *Boro* Paddy**	3319*	8636**	30358**
HYV*/Hybrid *Boro***	4879*	-	1652**
Wheat	4491	5313	3319
Maize	-	274	3754
Jute	318	663	815
Cotton	0	4	4
Sugar Cane	681	382	225
Potato	-	459	539
Vegetables	1331	493	5716
Pulses	7478	7279	6407
Oil Seeds	3991	1579	3349
Fruits	-	-	56
Spices	754	845	1102

Sources: The Bangladesh Census of Agriculture and Livestock: 1983-84 ZilaSeries: Rajshahi (P.204), Census of Agriculture-1996 Zila Series: Rajshahi (P.357) and Census of Agriculture-2008 Zila Series: Rajshahi (P.403).

*Notes: Aus/Aman/Boro/HYV=*HYVAus/HYV Aman/HYV boro/Hybrid boro=***

The figures referred to above clearly indicates that HYV *aus* and *boro* and hybrid *boro* cultivation have been significantly increased in the study area instead of local *aus, aman* and *boro*, which is a shift and significant change in cultivation of HYV rice. On the other hand, HYV *aman*, wheat, pulses, sugarcane cultivation are decreasing. Maize, jute, potato, spices, fruits, oil seeds, vegetables cultivation area are increasing.

The above figure shows that rice cultivation areas are increasing which are not profitable and particularly *boro* rice cultivation is not good for environment. On the other hand, non-traditional profitable crop areas are not increasing significantly such as vegetables, pulses, oil seeds, fruits, and other crops. As a corollary, economic returns from agriculture sector are not significantly increasing and socio-economic development in rural areas are not occurring properly. In view of above, crop cultivation areas are to be changed which are economically as well as environmentally sustainable.

7.4 Changing Pattern of Agriculture Land

Land covers or the surface covers are the all physical and biological features over the earth surfaces and land uses are the total arrangement and activities that human beings undertake on the landforms.[4] The Landsat program began in 1972.[5] Changing pattern of land uses (land cover) in the study area are seen in the agriculture census years 1977, 1988[6], 1996, 2008 and the current year 2016 which are depicted below in figures 7.1-7.5 and tables 7.3-7.7. Agriculture census years were selected with a view to making disuccsion of images with census year's crops cultivation areas data of the study area.

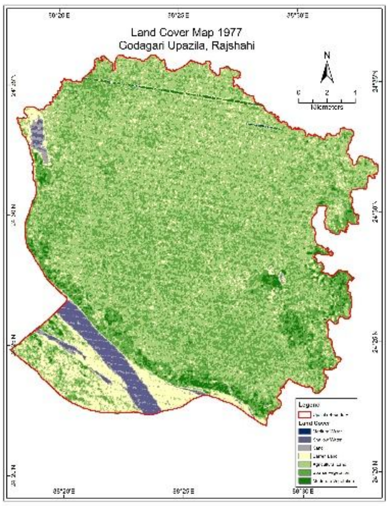

Figure 7.1. Land Cover in 1977

Table 7.3. Land Cover in 1977

Land cover category	Area (acre)
Agricultural land	42035.30
Sparse vegetation	21618.16
Moderate vegetation	9608.07
Barren land	13211.10
Sand bar	12010.09
Shallow water	9608.07
Medium water	12010.09
Total	120100.87

Source: glovis.usgs.gov

[4] S Shakeel and T. A. Kanth, "Land Form and Land Use Analysis of Liddar Basin, Kashmir," *Journal of the Institute of Indian Geographers* 34, no. 2 (2012), 260.

[5] Gyanesh Chander, Brian L. Markham and Dennis L. Helder, "Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-ALI Sensors," *Remote Sensing of Environment* 113(2009), 893. www.pancroma.com/downloads/Landsat_Calibration_Summary.pdf. (accessed August 14, 2016).

[6] Image of agriculture census year 1984 was not found in good condition in USGS archive. That is why, image of 1988 was used for analysis in this study.

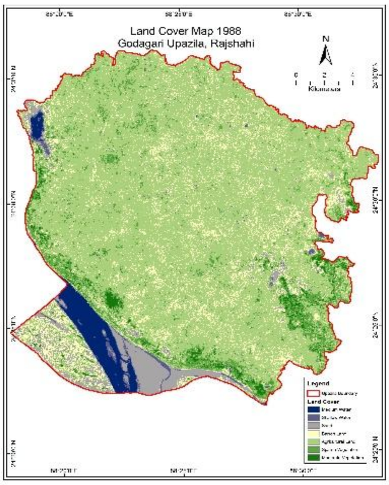

Figure 7.2. Land Cover in 1988

Table 7.4. Land Cover in 1988

Land cover category	Area (acre)
Agricultural land	44437.32
Sparse vegetation	16814.12
Moderate vegetation	6005.04
Barren land	14412.10
Sand bar	10809.08
Shallow water	13211.10
Medium water	14412.10
Total	120100.87

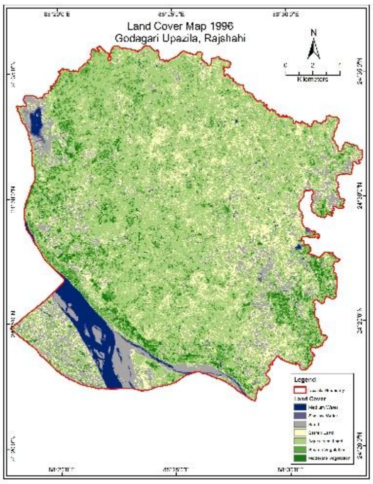

Figure 7.3. Land Cover in 1996

Table 7.5. Land Cover in 1996

Land cover category	Area (acre)
Agricultural land	45638.33
Sparse vegetation	19216.14
Moderate vegetation	7206.05
Barren land	10809.08
Sand bar	8407.06
Shallow water	15613.11
Medium water	13211.10
Total	120100.87

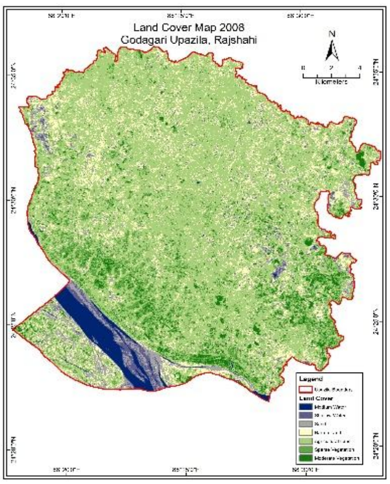

Figure 7.4. Land Cover in 2008

Table 7.6. Land Cover in 2008

Land cover category	Area (acre)
Agricultural land	48040.35
Sparse vegetation	18015.13
Moderate vegetation	8407.06
Barren land	8407.06
Sand bar	10809.08
Shallow water	13211.10
Medium water	13211.10
Total	120100.87

Source: glovis.usgs.gov

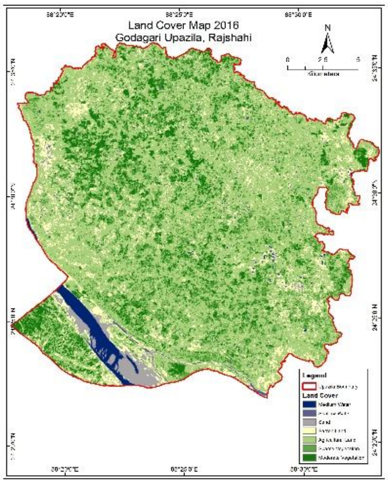

Figure 7.5. Land Cover in 2016

Table 7.7. Land Cover in 2016

Land cover category	Area (acre)
Agricultural land	50442.36
Sparse vegetation	16814.12
Moderate vegetation	10809.08
Barren land	6005.04
Sand bar	13211.10
Shallow water	14412.10
Medium water	8407.06
Total	120100.87

Source: glovis.usgs.gov

It is seen in figures 7.1 to 7.5 that land use changes are occurring in all categories. Changes in area of different land use categories are presented below in table 7.8 to show the changes from 1977 to 2016 in a visible way.

Table 7.8. Land Cover Changes of Godagari Upazila, Rajshahi

(In acre)

Year	Agriculture Land	Sparse Vegetation	Moderate Vegetation	Barren Land	Sand Bar	Shallow Water	Medium Water	Total
1977	42035.30	21618.16	9608.07	13211.10	12010.09	9608.07	12010.09	120100.87
1988	44437.32	16814.12	6005.04	14412.10	10809.08	13211.10	14412.10	120100.87
1996	45638.33	19216.14	7206.05	10809.08	8407.06	15613.11	13211.10	120100.87
2008	48040.35	18015.13	8407.06	8407.06	10809.08	13211.10	13211.10	120100.87
2016	50442.36	16814.12	10809.08	6005.04	13211.10	14412.10	8407.06	120100.87

Sources: Landsat Images of 1977, 1988, 1996, 2008, and 2016

It is found that 8407 acre agriculture land area have been increased from 1977. The changing patterns of agriculture land in the study area are presnted below in figure 7.6.

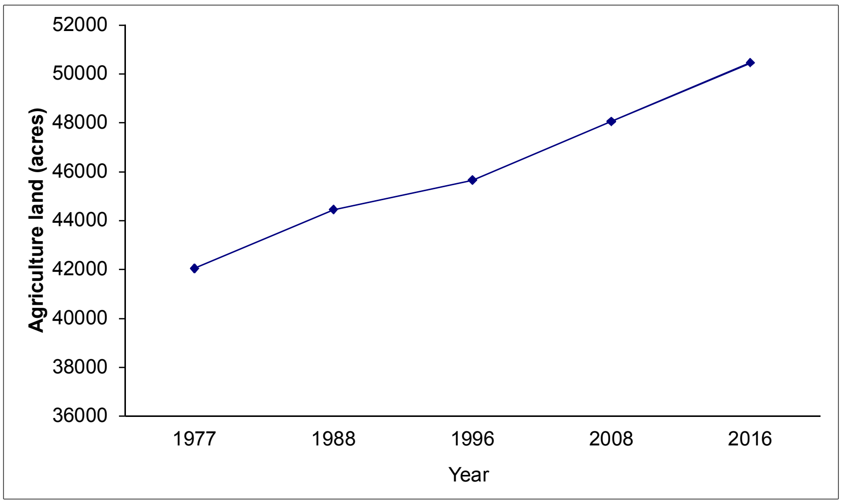

Figure 7.6. Changing Pattern of Agriculture Land

Barren land areas have decreased to 7206 acres. The increased 8407 acres' agriculture land area are mainly barren land which have been possible due to arrangement of irrigation after installation of deep tube well (DTW) as told by agriculture officials and farmers. About 1200 acres' sandbar or *char* land area have been increased from 1977 to 2016 due to siltation in the mighty Padma river resulting from drastic upstream flow reduction. Many *char* land areas are seen for cultivation of different crops. Sparse vegetation areas of about 4800 acres have been reduced and about 1200 acre areas are increased as moderate vegetation areas. It is known from farmers and agriculture officials that some sparse vegetation areas have been converted into agriculture farm after providing irrigation facilities installing DTW. Moderate vegetation areas are significantly increased after massive afforestation program in the Barind region after the function of BMDA (Barind Multipurpose Development Authority).

Agriculture land was 42035.30 acres in 1977. Agriculture land area have been increased 5.71 per cent in 1988 from 1977, 2.70 per cent in 1996 from 1988, 5.26 per cent in 2008 from 1996, and 4.99 per cent in 2016 from 2008. If it is possible to increase agricultural land further and properly use already added agricultural land to produce high value crops it would contribute a lot to develop the agriculture sector of the study area significantly.

It is noteworthy to mention here that total area of the study locale found in images is slightly more than SRDI map used for the present study, which is probably because of recently accreted *char* land areas from mighty the Padma river. The Padma river has been narrowed down mainly after large withdrawal of upstream flow from Farakka barrage in India after 1975. This is also supported by Land Department (AC Land Office, Godagari).

7.5 Error Matrix Analysis Cross-Tabulation of Landsat 8 Image, 2016

Verification of Landsat classified image of 2016 (dated February 23, 2016) of Godagari upazila of Rajshahi district is necessary to find out the correctness of classification and comparison with field data. The images of 1977, 1988, 1996, and 2008 were not verified because of old data and nonavailability of high resolution satellite data and resource limitations. Using sample size determination formula and probability proportional to size (PPS) sampling, 56 samples and their union wise proportions were selected for classified image verification. Further 56 samples were distributed to 7 land cover classes namely, Agricultural Land (AL), Sparse Vegetation (SV),Moderate Vegetation (MV), Barren Land (BL), Sand Bar (SB), Shallow Water (SW), and Medium Water (MW) according to their areas (AL=24, SV=8, MV=5, BL=3, SB=6, SW=7, and MW=3 total 56) found in 2016 image which are mentioned in Table 7.8 (row 6).

Field observations were done to compare and verify the image classification with field data through direct observation by a group of people comprising of researcher, union sub assistant agriculture officers, and local farmers. The usefulness of the method makes it an indispensable primary source of data and a supplement to other source.[7] Field verification was done from June 6 to June 22 of 2016 and a photo of field verification of classified image is inserted in appendix.

The classification of Landsat 8 image is ordinal data. Hence, non-parametric tests are required and Kappa –statistic, Kendall rank correlation, and Pearson Chi-Square are selected and employed to measure the strength of dependence between two variables. The results show that Kappa-statistic value is .809, Kendall's tau-b is .758 and Pearson Chi-Square value is 285.430 that are very good agreement between classified image and field data. The tables of cross-tabulation of classified image data and field data, comparison of classified image data and observed field data, Kappa –statistic and

[7] M. Nurul Islam, *An Introduction to Research Methods* (Dhaka: Mullick & Brothers, 2018), 172.

Kendall rank correlation, interpretation of kappa-statistic measure of agreement and Pearson Chi-Square values are given in appendices as appendix 3, appendix 4, appendix 5, appendix 6, and appendix 7 respectively.

The classification error matrix for the Landsat 8 image of 56 field verification sites shows that the incorrectly classified sites based on field verification in 56 spots is 7. Forty-nine sites out of 56 sites were found correctly classified that hold accuracy of 87.50 per cent. Thus, 87.50 per cent image classifications are accurate. Hence, the verification results are representative and acceptable to apply in other areas for land suitability analysis. In view of above, it is assumed that classified images used in this study have acceptable range of validation and pioneering in this regard.

7.6 Cultural Changes in Agriculture

Cultural changes are very important and it has implications on many things including farming practices and economy. Culture is the fourth pillar of sustainable development along with ecological, social, and economic sustainability.[8] Many experts now argue that cultural sustainability should always be included into any development process of any country. Agriculture is still the mainstay of rural Bangladesh. Rural area of Bangladesh (138703 sq.km) constitutes about 94 per cent area and accommodates 66.7 per cent population.[9] 23.3 per cent urban population living in urban area (urban area = 8867 sq. km = 6 per cent area of Bangladesh) are connected to village and agriculture in Bangladesh. Hence, cultural changes in agriculture are important for rural areas in particular and for the whole Bangladesh in general.

It is noticed that agriculture related cultural changes are happening in many aspects. Culture is the way in which farmers live, their customs, traditions, methods of cultivation and all agricultural, social, and economic activities occur. Farmers' perception of the environment, chiefly the land, determines the cultural practices that affect the use of land.[10] Each aspect of the culture of a society is related to all the other

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[8] David Yencken and Debra Wilkinson, *Resetting the Compass: Australia's Journey Towards Sustainability* (Collingwood: CSIRO Publishing, 2000), 9.

[9] Bangladesh Bureau of Statistics, *Population & Housing Census 2011, National Report*, Volume-1 Analytical Report (Dhaka: Statistics and Informatics Division, Ministry of Planning, 2016), xiii.

[10] M. Aminul Islam, "Environmental Perceptions and Agriculture," *Environmental Aspects of Agricultural Development in Bangladesh,* ed. Saleemul Huq, A. Atiq Rahman and Gordon R Conway (Dhaka: University Press Limited, 2000), 153.

aspects of its culture. If changes in one aspect of culture are introduced these are certainly having an effect on other aspects.

Land use of an area explains the socio-economic condition of the population and agricultural land use in an agrarian society defines the lifestyle of its population.[11] Socio-economic condition and lifestyle are important for culture. The importance of agriculture in the socio-economic and cultural fabric of Bangladesh is much from the fact that the livelihood of majority of the country's population depends on agriculture. Hence, cultural changes are important. However, more important is to see whether these changes are proactive or reactive (positive and negative) to our culture. Cultural changes in agriculture that have taken place in the study area are described below.

7.6.1 Local Varieties Seeds, Hybrid Seeds and Genetically-Modified (GMO) Seeds

Traditionally the agriculture sector went through its own sustainability in Bangladesh but with the advent of modern development; the sector heavily depends on HYV seeds, fertilizer, insecticide, herbicide, and others that are not environmentally sustainable at all.[12] Excessive use of hybrid seeds in local farming to boost production would affect local plant varieties and eventually lead them to extinction. Hybrid seeds cause different problems including buildup toxicity through improper use of pesticides, fertilizer, herbicide etc. GMO seeds are far more unnatural and cause harm to our environment as well as to our health.

Hybrid seeds and genetically modified seeds are new and alien species that are not suitable in our land as told by experts. Hybrid seeds require irrigation, mechanization, heavy application of chemical fertilizers and pesticides to get higher yields. It needs much water that depletes groundwater. Uses of these new varieties have adverse effects in the end and offsetting our indigenous farming culture. In addition, a lot of indigenous varieties seeds are about to extinct which were part of our indigenous agriculture and culture of rural Bangladesh and farmers are cultivating hybrid varieties and these hybrids and genetically modified seeds are becoming part of our agriculture.

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[11] Md. Zahirul Islam, "Crop Diversification and Food Security in Northern Bangladesh" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2015), 23.

[12] Bangladesh Bureau of Statistics, *Compendium of Environmental Statistics 2009* (Dhaka: Statistics Division, Ministry of Planning, 2010), 13.

Rice cultivation area in Bangladesh as a percentage of total cultivated area is about 78.52 per cent areas; of which *aus* occupies 8.67 per cent, *aman* occupies 49.87 per cent and *boro* occupies 41.46 per cent areas. Out of *boro* cultivation area, local *boro* occupies 1663954 acres; hybrid *boro* occupies 2103256 acres and HYV *boro* in 6344337 acres land.[13] Hybrid *boro* cultivation was not found to cultivate in a single acre of land in 1983-84 and 1996 census.

Genetically modified seeds are not suitable to grow food in a healthy and sustainable way. Genetically modified seeds are a trick to destroy local self-reliance, local food systems and foster dependence on purchased seeds, expensive technologies and much use of chemicals and drugs for pest and insects' management in the disguise of short period's higher production. It is widely believed and many studies have found that the changes are occurring in hybrid seeds and genetically modified seeds that are reactive to our agriculture practices and altering our traditional cultures.

7.6.2 Chemical Fertilizer and Insecticide Use

In Bangladesh, the use of modern pesticides started in 1957 but it was very low until1980's before the green revolution in Bangladesh. These new technologies of using synthetic fertilizer and insecticide were increased significantly in agriculture mainly after 1990 resulting a new dimension of agriculture practices. Consequently, our rural independent farming culture has been changed to a dependent culture. Use of chemical fertilizer and insecticide in farming practice has now become integral part of the society's farming culture. It influences other aspects of sustainability such as food quality and purity, costs of production, health problems etc. Their overall effects on ecosystems including human health and environment are very much harmful due to increasing pesticides hazards.[14] The quantities farmers are using are not favorable for sustainable farming system. Changes in farming system in use of chemical fertilizer and insecticides are affecting other parts of the complex system of farming culture and these changes are reactive.

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[13] Bangladesh Bureau of Statistics, *Statistical Yearbook of Bangladesh 2014,* 34th ed.(Dhaka: Statistics and Informatics Division, Ministry of Planning, 2016), 127.

[14] Md. Ameerul Islam, "Consequences of Increased Pesticide Use," *Environmental Aspects of Agricultural Development in Bangladesh,* ed. Saleemul Huq, A. Atiq Rahman and Gordon R Conway (Dhaka: University Press Limited, 2000), 118.

7.6.3 Food Culture

Food cultures are changing in this region due to changes in agricultural practices. Parboiled rice (*siddha chal*) is widely being introduced in lieu of sunned rice (*atap chal*) and rice is interwoven with Bangali culture. In the past, vegetables cultivated in homestead were mainly consume in the family, but now purchased fishes and meat are extensively eaten instead of vegetables. Horticulture areas are reduced due to population growth and fragmentation of homestead areas and as a result, vegetables cultivation and production in the homestead areas for domestic consumption by farmers have been declined. Hence, farmers eat vegetables purchasing from markets, which have excess chemicals causing health problems. In the past, farmers grow and eat vegetables like Indian spinach (*pui shak*), gourd, sweet gourd, white gourd, pumpkin, sweet pumpkin, *danta shak* (stem amaranth), ribbed gourd (*jhinga*), cucumber etc. Due to mechanization, cows rearing is no more an inseparable part of farming culture and consequently milk intake, a balanced diet, by mass people in rural areas have been substantially declined which are weakening their physical fitness.

Pitha,[15] *payesh*[16] were made and eaten several times in a year but now it is eaten hardly once in a year. Homemade beaten paddy, homemade puffed or popped rice (*muri*), hand parched rice (*khai*), sweet drop(*laddu*) were eaten in the past but now these are eaten less and people eat purchasing from markets. Palmyra palm juice, palmyra palm *pitha*, date-palm juice, date-palm juice *pitha*, date-palm juice *payesh* were commonly made and very popular dessert but now these are rarely eaten. White gourd (*chal kumra*), *kumrar*(pumpkin) *bari*, black gram (*mashkalai*) *bari* and grass pea/chickling vetch (*khesari*) *bari* were extensively eaten but now it is very rare. The diversification of diets away from the traditional dominance of rice is observed, current food consumption patterns in Asia are showing signs of convergence towards a western diet.[17] In the past, farmers and labors were fed with soaked/watered rice (*panta bhat*)[18] and molasses in the morning and rice with cheap vegetables like Indian spinach, sweet

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[15] A type of traditional foods made of rice powder, molasses, sugar etc. in rural Bangladesh.

[16] Sweet meal prepared from the juice of the Palmyra palm or date-palm.

[17] Prabhu Pingali, "Westernization of Asian Diets and the Transformation of Food Systems: Implications for Research and Policy," *ESA Working Paper* 04-17 (FAO of the United Nations, September, 2004), 281-298. www.sciencedirect.com/science/ article/ pii/S0306919206000893 (accessed July 27, 2016).

[18] Rice cooked overnight and kept steeped in water to eat in the morning.

gourd, gourd, ash gourd, bottle gourd, brinjal, black gram, grass pea pulses etc. at noon in the rainy season. Now there are no practices of breakfast or lunch for farm laborers.

7.6.4 Health Risks

In the past, all agricultural works were done manually such as sowing, transplanting, weeding, irrigation, harvesting, transportation, threshing, boiling etc. Tillage, leveling etc. were also done manually with the help of cows or buffaloes. However, mechanizations took place instead of manual practices in our agricultural systems that has been changed our working culture at farming as well as have some adverse effects on health. Tillage, insects' management, fertilization, transportation, threshing, irrigation, husking, drying, marketing etc. through mechanized equipment involve health risk. The mechanized pathway is troubled with the danger of adverse social consequences.[19]

Synthetic fertilizer and pest control medicines involve inhalation and health risks. Due to mechanization, many people are physically affected and their fingers, hands, legs or other body parts are cut or dysfunctional which were not the parts of the previous farming culture. Due to motorization of agriculture activities, flying of soils, sands, debris of crops etc. are increasing causing air pollution and health problems. No health measures or safe techniques are taken to avoid any harm coming to themselves except use of masks in few cases. Diseases are increasing due to heavy use of synthetic fertilizer, insecticides, flying of residues of crops, nutritional quality declining etc.

7.6.5 Agriculture Farm Working Culture

The working culture in agriculture farm in the past was very different from present working culture in agriculture. The timing of work, type of works, mode of working, payment medium etc. have been changed substantially. The past culture of working time of farmers were generally dawn to dusk which have been from 7 a.m. to 2 p.m. total 7 hours in recent years. Due to mechanization, preparation of land now only takes 5/6 days as against 15-25 days in the past. Except land leveling, sowing and harvesting most of the works like tillage, irrigation, insects' management, fertilization, threshing, husking, winnowing, drying, boiling, transportation, marketing etc. are now done through mechanized way that were done manually in the past.

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[19] Hugh Brammer, *Land Use and Land Use Planning in Bangladesh* (Dhaka: University Press Limited, 2002), 43.

7.6.6 Costumes of Farm Workers

Farmers' costumes were only *lungi* and napkin when they work in farmhouse in the past. Now they wear *lungi* and *genji* or *lungi* and shirt. Some farmers also put on pant and *genji* or pant and shirt.

7.6.7 Foods of Farm Workers

In the past, farm workers were given roti and onion, chili and salt or watered rice and salt or watered rice and molasses in the morning as breakfast. For lunch they were fed with rice and cheap vegetables like Indian spinach (*pui shak*), potato, sweet potato, gourd, sweet gourd, white gourd, pumpkin, brinjal, pointed gourd, *mukhikachu*, black gram, grass pea pulses (*dal*) etc. However, no feeding system prevails now, only payment systems.

7.6.8 Household Working Culture

Women used to play a significant role in agricultural activities in the past that were occurred in household. These include cooking for agriculture workers, food processing, seed preservation, storage and germination, many post-harvest operations including threshing, winnowing, boiling, drying of both paddy and straw to be used as livestock feed, husking, production of horticulture crops, vegetable gardening, homestead gardening, livestock caring, poultry raising and fish culture etc. Women took care of what had done in the household. Women took part in feeding and caring of livestock in homesteads includes cows, goats, chicken, ducks and pigeons. However, after modernization of agriculture and mechanization process, women’s role and activities have significantly changed.

Women have now no role in cooking for agriculture workers, food processing, threshing, winnowing, boiling, drying of both paddy and straw, husking, transportation etc. In the past, women used foot operated wooden rice pounder (*dhenki*) to process rice for household consumption even small rice traders also sold rice processing by seesaw. But, women now do not use seesaw and rice used for domestic consumption are processed in rice mill. Agriculture equipment have also changed in the household. Women used dried cow dung and stick of jute and wood stick (*lakri*) as fuel for cooking but now many of them use rice cooker, cylinder gas for cooking.

It is found in above discussion that cultural changes in farming system have occured significantly. These changes are also changing the complex system of total culture of agriculture farming in rural Bangladesh, and rural Bangladesh covers about 94 per cent area of Bangladesh.

7.7 Opinions about the Potentialities of Sustainable Agriculture in the Study Area

Agriculture is the foundation of the economy of Bangladesh and any development in this sector will affect the entire gamut of sectors of the country. The first and foremost step is to find out the ways and means of developing the agriculture of the specific areas. Experts can provide professional advice and comments on a range of areas relating to agricultural development. This process implies very refined ways and means of agricultural development strategy and policy options providing actual knowledge and information which are considered very effective and fruitful. Opinions of 6 agriculture officials as experts about the ways and means of sustainable agriculture are described below.

7.7.1 Sustainable Agriculture

Sustainable agriculture idea has come from sustainable development. Brundland Commission definition about sustainable development is widely accepted which is, 'sustainable development is a development that meets the needs of the present without compromising the ability of the future generations to meet their needs.[20] Sustainable development has been described in terms of three domains which are "economic, environmental and social" or "ecology, economy and equity". Some authors and researchers have pointed out that fourth domain 'culture' should be added to the dimension of sustainable development. The circles of sustainability approach distinguish the four domains of economics, ecology, politics and culture of sustainability.

[20] Niko Roorda, *Fundamentals of Sustainable Development* (London: Rout ledge Taylor & Francis Group, 2012), 26.

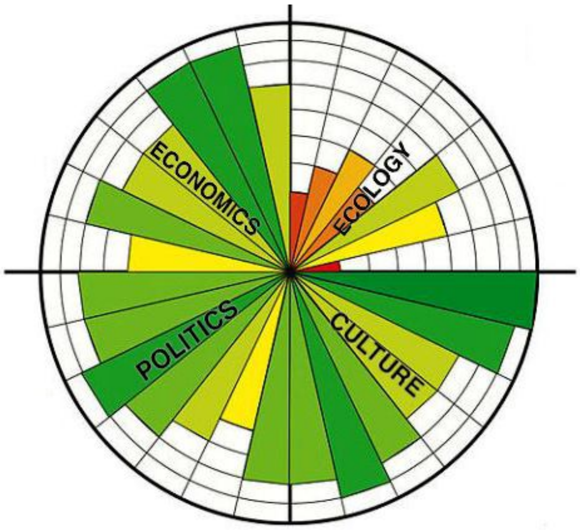

Figure 7.7. Circles of Sustainability

Sustainable agriculture is one of the important issues in land suitability based land use. Sustainable agriculture is the production of crops and plants using farming techniques that protect the human communities, public health, and environment for the long run. It involves preventing adverse effects to soil, water, biodiversity, surrounding resources and working or living people in the farm or in neighboring areas. The primary benefits of sustainable agriculture are depicted below as four pillars in figure 7.8.

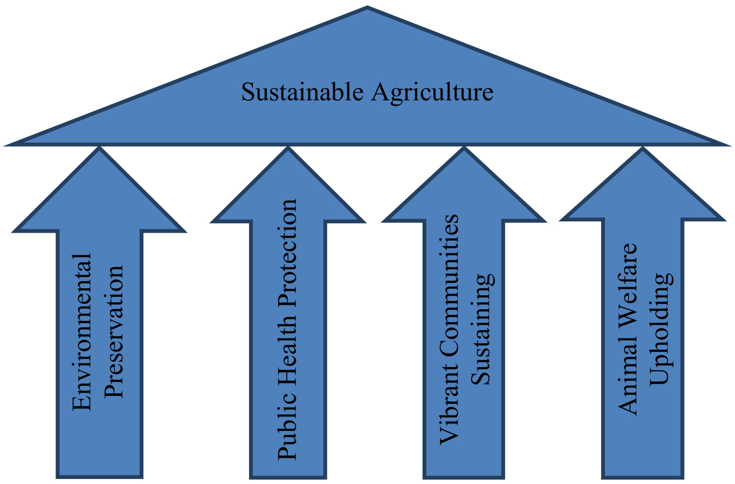

Figure 7.8. Pillars of Sustainable Agriculture

In view of abovementioned themes of sustainable agriculture, changing pattern of land cover and crops cultivation areas, present land characteristics and land suitability variables, the sustainable agriculture of the study area centering 7 themes are explored through the opinion of agriculture extension officials.

7.7.2 Opinion of Agriculture Extension Officials

Successful transformations of agriculture require finding the proper ways and means to drive the process forward. Agriculture officials are the focal persons of agriculture development. They have scientific and indigenous, in-depth and practical knowledge that are very invaluable in this regard than that of alien experts. Agriculture experts recognize the importance of transforming agriculture and are concordant that there are potentialities to achieve higher productivity and sustainability. Six officials' opinion are collected on 7 themes regarding land suitability and agricultural development of the study area. The collected opinions are sequentially described below.

Theme 1. High proportion of clay and clay loam soil texture, low moisture and nutrient deficiencies in soil does not ensure sustainable agriculture

1. Md. Mozder Hossain, Additional Deputy Director, Department of Agriculture Extension, Rajshahi (Former Upazila Agriculture Officer, Godagari upazila) says that we have nothing to do about clay and clay loam texture soil and low moisture. Farmers can apply organic matter and organic fertilizer in huge amount in farmland for agriculture. To meet up moisture they can apply irrigation water. Application of balanced fertilizer and green leaf fertilizer should be increased.

2. Toufiqur Rahman, Upazila Agriculture Officer, Godagari upazila, Rajshahi says that organic matter use could be enhanced and organic fertilizer use could be mandatory and legally binding. Farmers should be encouraged and motivated to cultivate crops which need low irrigation such as lentil, mustard, mungbean, blackgram, gram/chickpea etc. Besides, it is proved that Thai guava cultivation is economically profitable in this area.

3. Mst. Moriom Begum, Agriculture Extension Officer, Godagari upazila, Rajshahi says that clay loam soil texture and low moisture and nutrient deficiencies are not major barrier to ensure sustainable agriculture in Godagari upazila. Thai guava cultivation is proved successful in high land and present soil conditions that do not need huge irrigation. Several types of pulses are suitable for cultivation in the existing condition.

4. Syed Zillur Bari, Assistant Engineer (Irrigation and Agriculture Expert), Barind Multipurpose Development Authority (BMDA), Godagari Zone, Rajshahi says that

farmers should apply organic matter to balance the soil nutrients and cultivate such crops which require low moisture. These will help agriculture be sustained.

5. Md. Lutfar Raman, Sub-Assistant Agriculture Officer, Char Ashariadaha union, Godagari upazila, Rajshai says that balanced and organic fertilizer and green leaf fertilizer should be used. Existing conditions are not creating any major problems to agriculture sustainability.

6. Md. Habibur Rahman, Sub-Assistant Agriculture Officer, Deopara union, Godagari upazila, Rajshai says that under existing soil conditions Thai guava, pulses, mustard, tomato, flowers have potentialities. To make soil fertile and agriculture sustainable, green leaf manure, straw and residuals of crops, plants and human excreta should be dumped into farm. Crops that need less water should be cultivated such as wheat and pulses.

Theme 2. High land and somewhat poor drainage condition are not favorable for sustainable agriculture

1. Md. Mozder Hossain says that high land is suitable for Thai guava cultivation that is very profitable and there are potentialities to cultivate in the existing situations. Thai guava can be cultivated in more than 30,000 ha areas mainly in high land out of the total study area 47563 ha. Therefore, high land is not problem at all for sustainable agriculture in Godagari upazila.

Somewhat poor drainage condition is not also any barrier to sustainable agriculture because only 500 ha areas out of 47563 ha are water stagnated which could be used for aquaculture excavating ponds or canals with horticulture in the rounding of ponds.

2. Toufiqur Rahman says that highlands are not hurdle to sustainable agriculture because highlands are cultivable round the year if facilities of irrigation are ensured. Vegetables and fruits could be cultivated in highland and rice could be cultivated in lowland. Drainage problems are not acute in the study area to his observation.

3. Mst. Moriom Begum says that though the study area is mainly highland but the agriculture and the farmers do crop cultivations accordingly and it is sustained. Drainage condition is good and no problem to agriculture except a few exceptions.

4. Syed Zillur Bari says that highlands are not problem to agriculture and crops production, the problem is irrigation. If sufficient and timely irrigation is ensured, sustainable agriculture is possible. There is no drainage problem because it is highland area.

5. Md. Lutfar Raman says highlands are also favorable for agriculture and farmers are doing these decades after decades. The need is to arrange irrigation with minimum cost in *rabi* season and planned drainage in the rainy season.

6. Md. Habibur Rahman says that the crops that are suitable for high land should be cultivated and farmers and agriculture officials are doing this. High land creates no problem to sustainable agriculture.

Theme 3. Agriculture development challenges in existing flooding and accessibility problems

1. Md. Mozder Hossain says that flooding problem is not a major threat or problem to agriculture development due to changes in cropping pattern. Flood is an asset to agriculture because it makes land fertile and produces excess crops for the next few years. There is no solution of accessibility problems of Char Ashariadaha union. Nevertheless, infrastructure developments can be done for transportation of agriculture produces.

2. Toufiqur Rahman says that flood is not a major hurdle to sustainable agriculture. Crop intensification should be increased when floodwater recedes and cropping pattern should be adjusted.

3. Mst. Moriom Begum says that flooding problem does not prevail in this area. It creates moderate problems in few years in two or three unions that are very common. Government can solve accessibility problems by developing road networks and arranging subsidized easy and speedy transportation boats.

4. Syed Zillur Bari states that situation of flood is good and is not a problem at all to agriculture in this region. Besides, low-lying areas and water bodies could be used as fish farming instead of crops cultivation that is profitable. To solve accessibility problems, use of mechanized and speedy boats and development of roads are solutions.

5. Md. Lutfar Raman articulates that flood is not a major problem to agriculture in the study area. Rather it is good if flood comes after few years to enrich agriculture land. Accessibility problem has no solution. There are no markets in Char Ashariadaha union,

which accounts 7.66 per cent area to buy inputs and sell their agriculture surpluses that is divided from mainland by the mighty Padma River. They have to buy inputs with an inflated rate and sell produces with lower rate. 'Border *haat*' between India and Bangladesh could be a good solution to explore the potentialities this sector has.

6. Md. Habibur Rahman says that flood is not a major problem for agriculture in this area. Canals, ponds and low-lying areas should be used as fish farms after excavating.

Theme 4. Potentialities of crop cultivation in sparse and moderate vegetation areas

1. Md. Mozder Hossain utters that there is no good possibility of crop cultivation in vegetation areas. Turmeric and few others creeper up type crops cultivation are possible. However, I think this will not be very productive, rather vegetation areas could be used for forest reservation.

2. Toufiqur Rahman says that intercropping is possible in the vegetation area. Potato, sweet potato, lentil and other types of pulses are cultivable.

3. Mst. Moriom Begum says that forest area should be made dense forest rather than use for agriculture.

4. Syed Zillur Bari says that there are potentialities of creeper vegetables cultivation, mango, guava or other fruits in vegetation area and in the embankments of roads and highways.

5. Md. Lutfar Raman says that it is possible to cultivate guava and many other fruits in the vegetation or forest areas.

6. Md. Habibur Rahman says that lemon, sweet orange (*malta-1*), Burmese grape (*latkan*), pointed gourd (*patol*), ridge gourd (*jhinga*), gourd, ground potato (*mete alu*), papaya etc. are to be cultivated in the sparse and moderate vegetation areas.

Theme 5. Vegetable cultivation is better than *boro* rice cultivation in *rabi* season (Nov to Mar)

1. Md. Mozder Hossain articulates that vegetable cultivation is not profitable to *boro* rice cultivation. Profitable are onion seed, pulses, mustard, wheat and maize cultivation. Vegetables cultivation is sometimes risky for farmers.

2. Toufiqur Rahman says that vegetable cultivation is better than *boro* rice cultivation in *rabi* season and *boro* rice cultivation areas are gradually decreasing in Godagari upazila.

3. Mst. Moriom Begum speaks that vegetable cultivation is better than *boro* rice cultivation as it consumes less water as well as brings more profit than *boro* rice.

4. Syed Zillur Bari says that vegetable cultivation are not better and all farm lands are not suitable for cultivation of vegetables and there are ample examples that farmers become serious looser cultivating vegetables and many of them become pauper. But, the crops that need less irrigation water are better to cultivate. These crops are mustard, lentil, wheat, tomato etc.

5. Md. Lutfar Raman says that vegetable cultivation is undoubtedly better than *boro* rice cultivation but it fully depends on market price which is uncertain. *Boro* cultivation is not profitable at all, it consumes much water, and consequently ground water level goes down.

6. Md. Habibur Rahman says that vegetable cultivation is better than *boro* rice cultivation because *boro* rice needs much water and vegetable needs less water but profit is more in vegetable cultivation.

Theme 6. Mechanization leads to social unrest and cultural changes

1. Md. Mozder Hossain admits that mechanization created unemployment and cultural changes but to his opinion it is inevitable and mechanization has made agricultural activities easier. It does agriculture works in less time and less expenses. For example, land preparation, threshing, boiling etc. In fact, mechanization is developing agriculture.

2. Toufiqur Rahman says that mechanization is better than manual practices and agriculture of Bangladesh should be more mechanized.

3. Mst. Moriom Begum speaks that everything has its side effects. But mechanization is good for agricultural development and it makes low wastages of production.

4. Syed Zillur Bari says that mechanization has some problems like physical problems, unemployment, health problems etc. But people have no problems to get works in other sectors and actually farms and agriculture activities are suffering from labor shortages.

5. Md. Lutfar Raman says that these social unrest and cultural changes are nothing in our country. Unemployment is no problem rather it is problem to get labors sometimes. Mechanization is developing agriculture.

6. Md. Habibur Rahman says that mechanization is good for agriculture and I do not see any problems that you mentioned. People should be cautious while they use motorized equipment.

Theme 7. Exploring potentialities in agriculture maintaining sustainability

1. Md. Mozder Hossain says that there are boundless potentialities of sustainable agriculture in Godagari upazila which many people cannot imagine. This area is mainly highland which has immense potentialities of Thai guava cultivation. It is possible to cultivate more than 30,000 ha areas out of the total study area (47563 ha) which can change the total scenario of agriculture drastically. There are potentialities of *bablah* (babul) and ber garden which are drought and excess rainfall tolerant and profitable. After three years, *bablah* fruits could be produced much which are good source of fodder. In the *bablah* garden, creeper vegetables, sweet gourd, ash gourd (*chalkumra*), ridge gourd (*jhinga*), ground potato (*mete alu*) etc. could be cultivated. Goose and ram cultivation could be raised in *bablah* and other gardens. Lowland areas could be used as fish farms and horticulture in the rounding or embankments. Besides, under the integrated agriculture, goose and ram cultivation could be raised along with crops cultivation.

2. Toufiqur Rahman says that there is potentiality of Thai guava cultivation. In addition, potentiality of flowers like tuberose (*rajanigandha*), marigold (*gada*), gladulas and onion seed, moringa etc. are also significant.

3. Mst. Moriom Begum says about the potentiality of Thai guava and moringa. There is scope to cultivate fishes in low-lying areas and water bodies in rainy seasons as mixed farming.

4. Syed Zillur Bari says that there are many *khas* (government lands) ponds in this area that can be used as fish farm and horticulture. There is also possibility of cotton cultivation in pond adjoining areas because cotton needs less water. Duck could be raised in ponds and low-lying areas.

5. Md. Lutfar Raman says that there are potentialities of fruits garden such as guava, mango, aonla (*amlaki*), ber (*kul/barai*), golden apple (*amra*), moringa etc. Moringa is possibly a profitable crop to cultivate in this area. There are also potentialities of cultivating flowers such as gladulas, tuberose (*rajanigandha*), marigold (*gada*), rose etc. In addition, *bablah* cultivation has also potentiality.

6. Md. Habibur Rahman says that there are potentialities of onion seed, moringa, coriander (*dhania*), ginger (*ada*), turmeric, flowers etc. There are also potentialities of fish cultivation in low lands and canals.

7.7.3 Findings from the Opinion of Agriculture Extension Officials

Agriculture extension officials are focal persons in agriculture extension services and their up to date knowledge are in-depth and valuable. Findings found from the opinions of 6 agriculture officials are presented below on above mentioned 7 themes.

Theme 1: Present soil conditions are not barrier to sustainable agriculture. Existing soil conditions are favorable for Thai guava, pulses, mustard and many other crops cultivation. Use of organic matter and green leaf manure will increase the quality of soil.

Theme 2: High lands are not barrier to sustainable agriculture; rather it is favorable for cultivating Thai guava, *bablah*, moringa (*sajna*), flowers etc. Lowlands are only 1162 ha of which about 500 ha are very low land which are also favorable for fish cultivation and adjoining areas for horticulture.

Theme 3: Flood is not a threat to agriculture in Godagari upazila because duration and intensity of flooding is trifling. Accessibility is a major problem in Char Ashariadaha union but 'border *haat*' between Bangladesh and India could be possible solution for buying agriculture inputs and selling surpluses.

Theme 4: There are not good scopes to use sparse and moderate vegetation areas for crop cultivation. Intercropping is possible in vegetation areas but little potentiality is there.

Theme 5: Vegetable cultivation is better than *boro* rice cultivation because *boro* rice needs huge irrigation that is responsible for underground water depletion. However, onion seeds, oil seeds, mustard, lentil, maize, wheat etc. are better than vegetable cultivation in *rabi* season in the study area.

Theme 6: Mechanization is necessary for agriculture and makes low wastages of production. The problems mechanizations are creating can be minimized being cautious and taking safety measures.

Theme 7: There are boundless potentialities of agriculture in the study area. Thai guava, ber, *bablah*, moringa, flowers, mango etc. have immense possibility. Low lands and ponds are favorable for fish farming as well as for horticulture in rounding of fish farms. Goose and ram raising are profitable along with crops in integrated agriculture as propagated by the Department of Agriculture Extension (DAE).

7.7.4 Case Study

When the questionnaire survey was conducted it is seen that farmers are transferring from rice cultivation to Thai guava cultivation in the study area. The immense potentialities of Thai guava cultivation in the study area have also found from the opinion of agriculture officials. In view of above situation, it deems necessary to investigate Thai guava cultivation to find out the factors that responsible for the swapping from rice cultivation to Thai guava cultivation and sustainability to associate with other data. To do it, case studies were done and two cases were selected of Thai guava cultivation in the study area for investigation.

Thai Guava Cultivation: Case Study 1

Name of the Farmer: Md. Ali Hossain, Age: 32 years, Village: Bijaynagar, Union: Deopara, Upazila: Godagari District: Rajshahi. Farm Size: 330 decimals. Farmer had cultivated this land for *aman* and *boro* rice cultivation in the past. That time the production was low and profit was meager even in some years they become looser. Per 33 decimal rice productions was 400-560 kg for *aman* rice and 680-840 kg for *boro* rice. Rice was sold 40 kg by 560-620 BDT. Deducting all costs, they get virtually no profit or so meager profit that they cannot afford their 7-member family. They started Thai guava cultivation in that land in 2014 expending 34,000 BDT per 33 decimals. There is now huge profit in Thai guava cultivation and the minimum profit is BDT 50,000 per 33 decimal farms. Besides, there remain higher risks in rice cultivation but virtually no risks in Thai guava cultivation. It needs only higher investments. We get Thai guava whole year and it continues up to 6/7 years.

Thai Guava Cultivation: Case Study 2

Name of the Farmer: Md. Mokhlesur Rahman (Mukul), Age: 48 years, Village - Gopalpur, Union: Matikati, Upazila: Godagari, District: Rajshahi. Farm Size: 990 decimals. In the past farmer cultivated this land for *aus* and *boro* rice from his father's period. But, the production in that time was 400-560 kg for *aus* rice and 680-840 kg for *boro* rice against 33 decimal lands. Forty kg rice was sold 560-620 BDT and deducting all input costs and land rent they attain little profit that they could not afford their all expenses of 6-member family. Even in many years, they became looser and day by day, they were becoming poor and started to sell lands to meet the expenses of the family. They started Thai guava cultivation in that land in 2013 expending 31,000 BDT per 33 decimal selling ornaments and taking loans. The first two years were investing year and return was low. However, after two years there is lucrative return and 50,000-70,000 BDT profit per 33 decimal farms. Not only that rice cultivation has risks such as climatic uncertainty, market price, insects, flood, drought etc. On the other hand, there remain virtually no risks in Thai guava cultivation. After 4 years, little risks of virus have but insignificant comparing to rice. The problem is that it needs huge investments. After planting guava plants once, we get production all the year and harvesting lasts about 6 years.

Case Study Results

Farmers cultivated their land in the past for *aus*, *aman* and *boro* rice. Because of the low production (400-560 kg *aman* and 680-840 kg *boro* rice against 33 decimal lands) and lower market prices (40 kg rice 560-620 BDT), they get no profit or so meager profit that they could not afford their all family expenses. Even in many years, they became looser and day by day, they were becoming poor and started to sell lands to meet the expenses of their family. They started Thai guava cultivation in that land and after two years 50,000-70,000-BDT profit per 33 decimal farms. Rice cultivation has risks such as climatic uncertainty, market price, insects, flood, drought etc. but virtually no risks in Thai guava cultivation.

The above-described results are the typical findings of Thai guava cultivation instead of rice in the study area.

7.7.5 Sustainability Risks of Thai Guava Cultivation

The Department of Agriculture Extension (DAE) is propagating to cultivate Thai guava in Godagari upazila and their target to cultivate Thai guava in more than 30,000 ha out of total 47563 ha of the study area in next ten years and farmers are rushing to Thai guava and other more profitable crops cultivation scaling down rice and traditional crops cultivation. Thai guava cultivation in per 33 decimal brings about minimum 50,000-BDT profit per year. However, if more than 30,000 ha areas are cultivated as Thai guava garden then where farmers will sell their guava is a big question of uncertainty. In many such cases in Bangladesh, it is seen in the past that cultivation of same product in huge land and in huge amount did not sustain after a few years. Thai guava cultivation has this type of sustainability risk. Farmers are anticipating these sustainability risks regarding future markets such as Thai guava cultivators of two case studies Md. Ali Hossain and Md. Mokhlesur Rahman.

Demand of Thai guava is not unlimited in Bangladesh and marketing channels and facilities are not developed properly. People require cereals for their domestic consumption and ensure food security. Thai guava harvests all the year and no other crops grow in that land. As a corollary, social sustainability, political sustainability, strategic sustainability, health sustainability and agriculture economics sustainability might be hampered. In 1943, Bengal faced famine and 3 million people were starved to death in Bengal province in 1943,[21] and food crisis in 1974 created social and political problem in Bangladesh. In view of above, there are reasons to conclude that these wholesale switching to Thai guava cultivation from rice will incur sustainability risks.

7.8 Direction Between Land Use Changing Pattern and Sustainable Agriculture

As the study locale is agriculture dominated, direction between land use changing pattern and sustainable agricultural is important for proper planning of agriculture development in the study area. The level of pH, organic matter, and zinc are increasing which are good for sustainable agriculture. Organic matter is very important for crops and despite deficiencies of other properties, only organic matter can ensure good yield. But, nitrogen, phosphorus, sulfur, and boron are decreasing significantly which are now

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[21] Department of Agriculture, Forest and Fisheries, *Agriculture Statistics by Plot-to-Plot Enumeration in Bengal 1944-45, Part 1*(Calcutta: Bengal Government, 1946), 1.

regarded as important for potential yield. In case of crop cultivation area, rice cultivation area is increasing and HYV rice varieties are also in the increasing trend and local varieties rice are decreasing. Higher economic return crops like vegetables, pulses, oil seeds, and other crops cultivation areas are not increasing significantly which are not good for sustainable agriculture. According to image data, agriculture land areas are continuously increasing in the study area from 42035 acres in 1977 to 50442 acres in 2016 which are encouraging for exploring agriculture potentialities. Cultural changes are occurring which are not in positive trend to flourish indigenous culture rather changes are against local culture.

The study area has immense potentialities of Thai guava, ber, *bablah*, flowers, moringa etc. But people are still following traditional practices mainly rice cultivation which is not good for sustainable agriculture. The study area has 1162 ha low land area of which about 500 ha is very low land and there is also potentiality of fish cultivation. Goose and ram cultivation raising are possible in crop field as integrated agriculture.

Nevertheless, farmers are not moving to that direction like integrated agriculture, crop diversification, fish cultivation, and high value crops cultivation etc. for sustainable agriculture except negligible portion of farmers switching to Thai guava and other crops cultivation. In view of above, it is said that land use changing pattern are not towards sustainable agricultural development in the study area. Therefore, it is necessary to take effective measures like motivation, incentives; legally binding measures etc. to land suitability based high value crops cultivation so that farmers move towards sustainable agriculture.

7.9 Conclusion

Sustainable agriculture is an approach of proper management of agriculture resources for human needs encompassing aspects of natural, economic, social, and cultural issues. This could be done based on present land characteristics, changing pattern of land uses, indigenous ways and means and involvement of main stakeholder farmers. Experts' opinion could be a good starting point for formulating measures to improve the integrated agriculture of the study area. Expert opinions are found very encouraging about the potentialities of sustainable agriculture. There are potentialities of Thai guava, *bablah*, flowers, moringa etc. Lowlands are favorable for fish cultivation along with horticulture in the rounding of fish farms. Integrated land use planning is the key to balancing land use, underpinned by the right policy instruments to promote sustainable agriculture.

Chapter Eight
Farmers Perception about Land Suitability and Agriculture Development

8.1 Introduction

Unwise use of lands for crops cultivation, soil degradation, excessive use of chemical fertilizers and insecticides, less use of organic fertilizer and bio manure, decreasing ground water level, soil erosion etc. are obstacles for sustainable agriculture stated by agriculture experts, farmers, environmentalists, ecologists and other experts. It is seen in many studies that farmers are the main stakeholder of agriculture who are always left out from any decision making and implementation process mainly in underdeveloped countries like Bangladesh. It is assumed that agricultural development is possible when measures are taken and implement with participation of main stakeholder farmers. Participation and involvement of farmers can be fruitful when their perception level to that issue will be optimal. An actual picture of land availability for different purposes, land suitability for various crops, knowledge, attitude, and capability of farmers about various agricultural practices have to be known to formulate a plan for optimal use of our limited land resources.[1]

Farmers Perception is a process of understanding and interpreting land suitability based crops cultivation and agriculture development which are important in this case. Farmers have to adopt crops diversification, cropping pattern changes depending on land suitability, use of organic fertilizer, minimum use of chemical fertilizer and insecticide and integrated pest management etc. to usher agriculture development taking into account soil, irrigation water, climate, topography, floodability, market etc.

8.2 Farmers Perception

Farmers lie in the center of agriculture and its development. The development of agriculture is dependent on farmers' adequate perception and their activities about land suitability. Farmers' perception of the environment, chiefly the land, determines the

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[1] Nasreen Ahmed, "Temporal Changes in Agricultural Land Use in Bangladesh," *Environmental Aspects of Agricultural Development in Bangladesh,* ed. Saleemul Huq, A. Atiq Rahman and Gordon R. Conway (Dhaka: The University Press Limited, 2000), 94.

pattern of land use.[2] Land use pattern is important for agriculture development. Perception is the process of understanding and interpreting to conduct any activities. It is the organizing process through which we come to know the objects in our environment.[3] The perception of agricultural sustainability differs from farmer to farmer and is influenced by the socio economic characteristics and information seeking behavior of the farmers.[4] Assessment of farmers' perception about land suitability and agriculture development could lead to a proper prediction of farmers' activities that can be applied to sustainable agricultural development.

Knowledge, attitude, and practice constitute a triad of interactive factors characterized with unique interdependence. Knowledge is the capacity to acquire, retain, and use information; a mixture of comprehension, experience, discernment, and skill. Attitude refers to inclinations to react in a certain situation or activities; to see and interpret events according to certain predispositions; to organize opinions into coherent and interrelated structure. Practice is the application of knowledge and attitude that leads to a certain action. In this research, perception means perceived knowledge or knowledge of farmers regarding land suitability and sustainable agriculture development. The influence diagram of knowledge, attitude and practice are presented below.

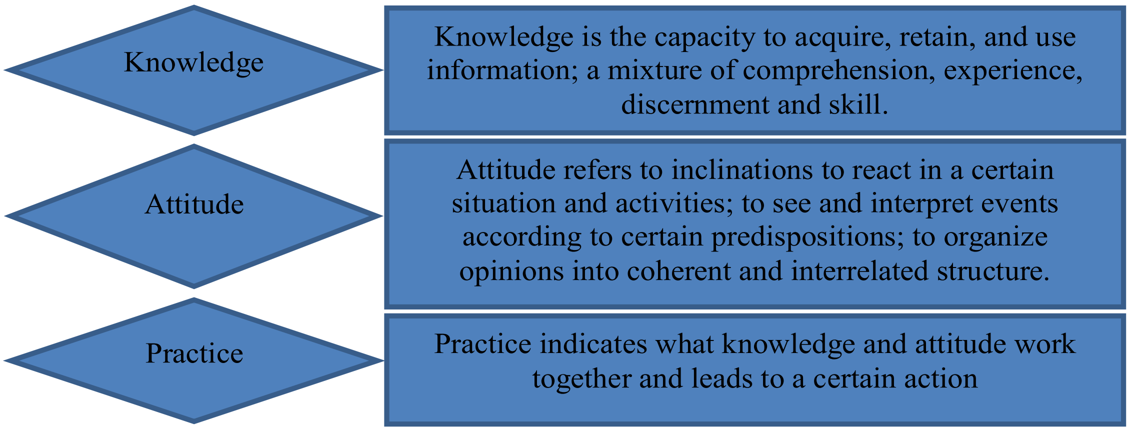

Figure 8.1. The Influence Diagram of Knowledge, Attitude and Practice

Adopted from: Rafia Bano et al. (2013)

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[2] M. Aminul Islam, "Environmental Perceptions and Agriculture," *Environmental Aspects of Agricultural Development in Bangladesh,* ed. Saleemul Huq, A. Atiq Rahman and Gordon R Conway (Dhaka: The University Press Limited, 2000), 153.

[3] Henry E. Garrett, *General Psychology,* 2nd ed. (New Delhi: Eurasia Publishing House, 1964), 169.

[4] S Abolhasan Sadati et al., "Farmer's Attitude on Sustainable Agriculture and its Determinants: A Case Study in Behbahan County of Iran," *Research Journal of Applied Sciences, Engineering and Technology* 2, no. 5 (2010), 422. www.maxwellsci.com/print/rjaset/v2-422-427.pdf·PDF file (accessed June 13, 2016).

The triad of knowledge, attitude and practice in combination governs all aspects of life in human societies including behavior of farmers towards land suitability and agriculture development. The knowledge-attitude-practice model is based on the cognitive-affective-behavior theory of social psychology and this model indicates that an increase of knowledge affects attitude and attitude changes behavior which is applicable to farmers' perception towards land suitability and sustainable agriculture development.

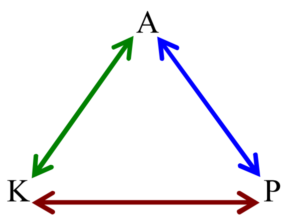

Figure 8.2. Knowledge-Attitude-Practice Model (Schwartz, 1976)

To ensure agriculture development maintaining environment, economic and social sustainability, farmers should have knowledge about soil, irrigation water, climate, topography, floodability, marketing etc. and have to adopt different farm level practices. It includes crops diversification, cropping pattern changes, use of organic fertilizer, minimum use of chemical fertilizer and insecticide, integrated pest management, soil and irrigation water quality, climatic uncertainties, topographical condition, timing and duration of flooding, timing of sowing and harvesting of crops etc. and their judicious use for optimum benefits.

Sustainable agriculture as a system of producing foods and fibers is more knowledge intensive than input intensive and needs proper knowledge, proactive attitude, efficient practice with good management and skills. Perception is an important element in accepting practices for agricultural development. To transfer this knowledge, attitude, skills and management to farmers, it is necessary to make desirable changes in the perception of farmers as first step, therefore, assessing perception in connection with principles and concepts of sustainable agriculture provides a solid base on which planning could be made to achieve agricultural development.[5] Hence, purpose of this research is to assess the farmers' perception level toward land suitability for sustainable agriculture development.

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[5] Sadati et al., "Farmer's Attitude on Sustainable Agriculture and its Determinants: A Case Study in Behbahan County of Iran," 426.

8.3 Statements and Scales for Perception Assessment

Statements and scales are important in perception study. Nineteen statements have been formulated regarding land suitability and sustainable agriculture to assess the perception of farmers in this study. Five point Likert scale is used in statements to measure farmer's perception.

8.3.1 Statements for Perception Assessment

Nineteen statements are used in this study to assess the perception level of farmers about land suitability and agricultural development. Statements are related to following issues:

Table 8.1. Issues of Statement

Land Suitability Meaning	Soil Texture	Farmers Knowledge Deficiency About Land Suitability
Acid Soil and Alkaline Soil	Land Type	Use of Chemical Fertilizer and Insecticide
Macronutrients of Soil	Irrigation Water	Use of Organic Fertilizer
Micronutrients of Soil	Climate	Crop Diversification and Cropping Pattern Changes etc.

8.3.2 Scales for Perception Assessment

Five-point Likert scale is used in statements to compare one type of statement with another. Because of Likert scale's simplicity, both in construction and interpretation, this scale is frequently used method for creating composite measures in contemporary social research.[6] Five-point statements in which the subject being offered five alternatives from which to choose, yield a normal distribution.[7]

According to Likert scale, the responses were strongly agree, agree, neutral (neither agree/nor disagree), disagree and strongly disagree. For statements, responses are well known/very much, moderately known/medium, neutral, little known/low and very little known/very low. For each positive statement, the score was 5 for strongly agree, score 4 was for agree, score 3 was for neutral, score 2 for disagree and score 1 for strongly disagree. For reverse statement, the score was 1 for strongly agree, 2 for agree, 3 for neutral/don't know, 4 for disagree and 5 for strongly disagree. The highest possible score value against 19 statements for the perception in the abovementioned scale is 95 (19×5) and the lowest score

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[6] Abu Jafar Mohammad Sufian, *Methods and Techniques of Social Research,* 2nd ed. (Dhaka: University Press Limited, 2009), 28.

[7] Rensis Likert, "A Technique for the Measurement of Attitudes," *Archives of Psychology,* ed. R. S. Woodworth, vol. 22, no.140 (June, 1932), 21. http://www. voteview. com/pdf/ Likert_1932.pdf.(accessed November 6, 2015).

is 19 (19×1). Higher value indicates good perception and lower value indicates little perception toward land suitability and agriculture development. Respondents were farmers and 381 farmers were selected following sample size determination formula. Statements used for survey for this study are presented in appendices as appendix-8.

8.4 Validation of the Statements

The statements used in this study are validated in many respects. Issues of statements were first pointed out from objectives, from chapters three "Land Characteristics and Land Suitability Variables" and chapter five "Land Suitability Analysis of the Study Area", and from other things. Discussions were made with agriculture field officials and they added a few points and issues. In this way, issues were selected and statements were made breaking down issues. Then, statements and scales were primarily finalized in consultation with a Professor, Department of Psychology, University of Rajshahi. When the statements and scales are prepared in this way for research they are considered generally validated.

This general validation is considered proper when found respondents ease of comprehension, relevance to the proposed topics, the effectiveness to the provision be aligned with useful information, and to what extent the statements are interpreted and understood by different individuals.[8] It is a preliminary test on a small group of representatives of the study population. After preparing statements, a pre-testing was conducted and analyzed for validation. Pre-testing was done on farmers as well as on field level agriculture officials. Land suitability is comparatively a new theme among farmers and field level agriculture officials are better aware of it than the farmers are. After completing these procedures, the statements were modified to incorporate pertinent things so that it reflects the results of the pretesting. After it, pilot survey was done and statements were finalized for the present study.

8.5 Perception Assessment Procedure

Perception of respondents regarding land suitability and agriculture development was calculated by the interval standard deviation from mean. This technique is widely used for perception assessment as found in many studies, such as Sadati et al. (2010),[9]

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[8] Md. Nazrul Islam, "Irrigation Practice in Rice Cultivation and its Sustainability in Bangladesh: Issues and Challenges" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2013), 162.

[9] Sadati et al., "Farmer's Attitude on Sustainable Agriculture and its Determinants: A Case Study in Behbahan County of Iran," 423.

Rahman (2005)[10] etc. In the present study, the farmers' perception (perceived knowledge) was classified into four categories to generate perception level. Total score and mean value of farmers' perception against 19 statements of individual 381 farmers were calculated using data collected through questionnaire survey. Then mean score, standard deviation, maximum mean, and minimum mean value were calculated from 381 farmers mean scores, which are depicted below.

ID	K_1	………	K_{18}	K_{19}	Mean
1	x_{11}	………	x_{18}	x_{19}	$Mean_1$
2	x_{21}	………	x_{28}	x_{29}	$Mean_2$
3	x_{31}	………	x_{38}	x_{39}	$Mean_3$
4	x_{41}	………	x_{48}	x_{49}	$Mean_4$
.	.	………	.	.	.
.	.		.	.	.
P	x_{p1}	………	x_{p8}	x_{p9}	$Mean_P$

Where, P = 381 is the number of respondents

K= Knowledge statements (there are 19 knowledge statements regarding different issues)

X = Response variable

The mean score and standard deviation are found 3.6885 and 0.2728 respectively from individual 381 farmers' mean score. The maximum mean value is found 4.6316 and minimum mean value is found 2.5 of 381 farmers' mean values. Then, we have categorized into 4 levels of respondents (farmers) mean based on mean and standard deviation of 381 respondents' mean, which are mentioned below.

VL = Very Low: Min $\leq$ VL $<$ Mean-Std.

L = Low: Mean- Std. $\leq$ L $<$ Mean

M = Moderate: Mean $\leq$ M $<$ Mean + Std.

H = High: Mean + Std. $\leq$ H $\leq$ Max

8.6 Demographic and Educational Features of Farmers

Demographic and educational features are important for perception study and they have important role in agriculture activities as well as their perception level. Age, education level and agriculture training in combine govern significantly farming practices

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[10] Md. Mafizur Rahman, "Solid Waste Management of Dhaka City: Issues and Challenges" (PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2005), 158.

regarding which crops to be produced in which lands, inputs, farming mechanizations, tendency to adopt modern practices, marketing places etc. The discussion of demographic and educational characteristics of farmers and agriculture development help provide a better understanding for the concerned planners and decision makers.

8.6.1 Age of the Farmers

Farmers age is a factor that influence the farming practices of main stakeholder farmers. Higher aged farmers can predict better in case of climatic uncertainty, insects attack, market's volatility etc. than lower aged farmers. Table 8.2 provides the farmers age characteristics of the study area.

Table 8.2. Age of Farmers

Age	Frequency	Percent	Cumulative Percent
22-33	110	28.90	28.90
34-45	190	49.90	78.70
46-57	73	19.20	97.90
58 above	8	2.10	100.00
Total	381	100.00	

Source: Field Data, 2016

It is seen in above table that about 50 per cent farmers (190) are in the age category of 34-45 years old. The mean age of farmers in the study area is 39.67 years which means that majority are middle aged farmers. It is easy to motivate young farmers than middle or old age farmers and predominance of middle age farmers in the study area is not good for developing perception level as well as implementing measures easily for sustainable agricultural development. Due to predominance of middle age, extra motivation may require to elevate perception level of farmers in the study area.

8.6.2 Educational Status of the Farmers

Education level is treated as an important indicator of human capital which provides knowledge, attitude, skills, experience, tendency to adopt new and modern technologies, and risks etc. It also provides adequate knowledge and experience of farming.[11] The following 8.3 table presents the education level of farmers in the study area.

[11] Mohammad Manirul Islam, "An Economic Analysis of Crop Diversification in Northern Bangladesh"(PhD dissertation, Institute of Bangladesh Studies, University of Rajshahi, 2015), 99.

Table 8.3. Education Status of Farmers

Education Level	Frequency	Percent	Cumulative Percent
Primary	154	40.40	40.40
Class six to Eight	179	47.0	87.40
Class Nine to Ten	21	5.50	92.90
Higher secondary	27	7.10	100.00
Total	381	100.00	

Source: Field Data, 2016

The above table shows that majority farmers (87.40 per cent farmers) have poor literacy and only 7.10 per cent farmers have HSC level education.

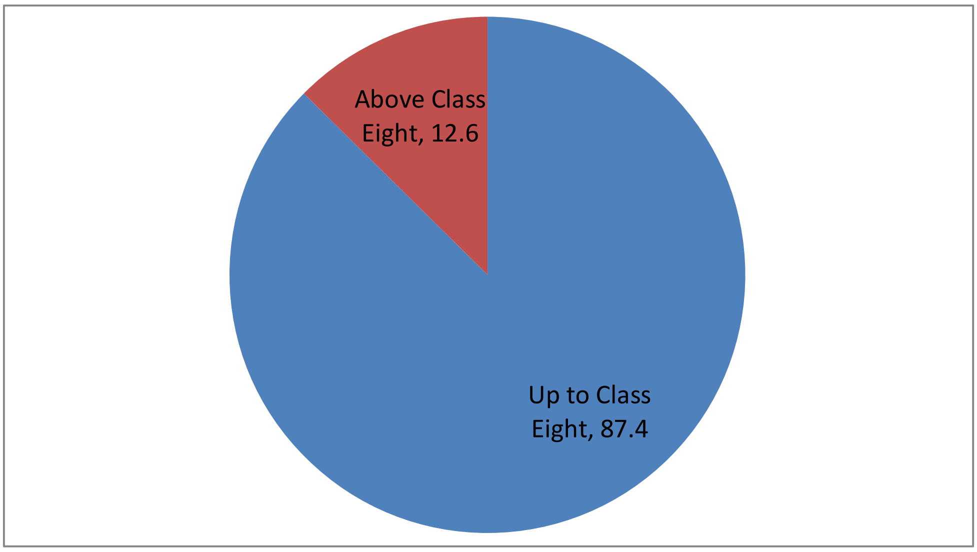

Figure 8.3. Education Level of Farmers

As 87.40 per cent farmers have education from class one to class eight, education level of farmers is very poor and it is natural that their perception level will be lower. In this education level, it is difficult to elevate farmers' perception level and to make them eager to adopt land suitability based crops cultivation.

8.6.3 Agriculture Training

Agriculture training can contribute significantly to farming practices as proper knowledge and awareness of a farmer lead him to take proper decision in agricultural activities. Table 8.4 shows the training experiences of farmers in the study area.

Table 8.4. Agriculture Training of Farmers

Agri training	Frequency	Percent	Valid percent	Cumulative Percent
Yes	76	19.90	19.90	19.90
No	305	80.10	80.10	100.00
Total	381	100.00	100.00	

Source: Field Data, 2016

It is found in above table that agriculture training has got by only about 20 per cent farmers and 80 per cent farmers do not get any agriculture training. This result tells that majority of farmers do not have any up to date knowledge and idea regarding modern and land suitability based farming practices. Lack of this up to date farming knowledge and idea have negative impact on knowledge of farmers and agriculture development. Therefore, education level increase is imperative with a view to elevate the knowledge level of farmers. In this situation, it is necessary to bring all farmers of the study area under intensive and long term agriculture training focusing on land suitability and sustainable agriculture development for the development of agriculture in the study area.

8.7 Farmers Acquaintance with Land Suitability

The acquaintance level of farmers on land suitability was investigated. The results regarding acquaintance are shown in table 8.5.

Table 8.5. Farmers' Acquaintance with Land Suitability

Acquaintance	Frequency	Percent
Yes	280	73.50
No	101	26.50
Total	381	100.00

Source: Field Data, 2016.

It is clear from above table that significant portions (26.5 per cent) of farmers are fully ignorant about land suitability. This ignorance is not conducive for land suitability based cultivation and the present situation indicates that farmers need proper knowledge and training regarding land suitability based cultivation and sustainable agriculture. The farmers having acquaintance with land suitability were further asked question with a view to investigating their level of acquaintance. The results of farmers' level of acquaintance are presented below in table 8.6.

Table 8.6. Level of Acquaintance of Farmers with Land Suitability

Acquaintance Level	Frequency	Percent	Mean	Std.	CV
Well known	-	-	2.85	.396	13.89
Known	4	1.4			
Moderately known	230	82.1			
Little known	46	16.4			
Do not known	-	-			
Total	280	100.0			

Source: Field Data, 2016.

It is seen that farmers having acquaintance with land suitability, most of the farmers 230 (82.1 per cent) moderately known land suitability which mean that most of the farmers have superficial acquaintance with land suitability. The above result also indicates that agriculture development in the study area would need much effort to develop farmers understanding level about land suitability.

8.8 Farmers Perception about Land Suitability and Agriculture Development

Farmers knowledge is an indispensable component in agriculture development and is very important in the present knowledge based era. Farmers are the main players in land suitability based cultivation and sustainable agriculture. Therefore, their knowledge regarding land suitability and sustainable agriculture are important to motivate them to practice land suitability based crop cultivation and sustainable practices. Farmers' knowledge about 19 statements regarding land suitability and sustainable agriculture are presented below.

Table 8.7. Farmers Perception (Knowledge) about Land Suitability and Agriculture Development

Statements	Strongly Agree		Agree		Neutral		Disagree		Strongly Disagree		Missing Response		Total	
	fq	%	fq	%	fq	%	fq	%	fq	%	fq	%	fq	%
Land suitability is cultivation of crops according to soil, irrigation water, climate, topography, floodability, and accessibility attributes	58	20.71	222	79.29	-	-	-	-	-	-	101	*	381	100
Crops selection depending on acid soil and alkaline soil will increase production	6	2.16	49	17.69	1	0.37	219	79.06	2	0.72	104	*	381	100
Crops selection depending on soil organic matter leads to optimum yield	23	6.0	254	66.7	104	27.3	-	-	-	-	-	-	381	100
Balance of macronutrients in soil leads to potential yield	47	14.28	246	74.78	36	10.94	-	-	-	-	52	*	381	100
Balance of micronutrients in soil leads to optimum yield	7	1.8	315	82.7	55	14.4	4	1.0	-	-	-	-	381	100
Selection of crop based on land type is necessary for potential yield	238	62.5	103	27.0	40	10.5	-	-	-	-	-	-	381	100

For maximum production, crop should be selected based on soil texture	269	70.6	96	25.2	16	4.2	-	-	-	-	-	-	381	100
To select proper crop to get maximum yield soil test at times is imperative	29	7.6	329	86.4	23	6.0	-	-	-	-	-	-	381	100
Crop selection depending on water quality can give good production	13	3.4	361	94.8	7	1.8	-	-	-	-	-	-	381	100
Crop should be selected which require less water in *rabi* season	10	2.6	336	88.2	12	3.1	23	6.0	-	-	-	-	381	100
Temperature of irrigated water in summer and winter season has impact on potential yield	10	2.6	348	91.3	12	3.1	11	2.9	-	-	-	-	381	100
To select proper crop for getting maximum yield water test at times is imperative	13	3.4	357	93.7	3	0.8	8	2.1	-	-	-	-	381	100
Cultivation of summer and winter critical temperature tolerant crop can increase yield			21	5.5	27	7.1	304	79.8	29	7.6	-	-	381	100
Selection of crop based on monthly total rainfall is necessary			25	6.6	19	5.0	315	82.7	22	5.8	-	-	381	100
Farmers have deficiency of knowledge to cultivate land as per land suitability	40	10.5	165	43.3	16	4.2	143	37.5	17	4.5	-	-	381	100
Use of chemical fertilizer is necessary for crop production in the present soil condition	162	42.5	180	47.2	10	2.6	14	3.7	15	3.9	-	-	381	100
Use of chemical fertilizer instead of organic fertilizer is not too much harmful to crops *	34	8.9	24	6.3	35	9.2	209	54.9	79	20.7	-	-	381	100
Extensive use of insecticide is harmful to sustainable agriculture	196	51.4	98	25.7	34	8.9	33	8.7	20	5.2	-	-	381	100
Crop diversification and cropping pattern changes according to land suitability is necessary for sustainable agriculture	6	1.6	315	82.7	21	5.5	18	4.7	21	5.5	-	-	381	100

Source: Field Data, 2016

*Notes: * = Reverse Statement, fq. = Frequency, * Separately Percentage Calculated*

Land Suitability Meaning: The above result regarding land suitability meaning reveals that majority of farmers understand land suitability. However, 101 farmers out of 381 farmers, means 26.51 per cent farmers do not know land suitability that is significant. It is not good for agricultural development and it is necessary to make 26.51 per cent farmers aware about land suitability through training and different knowledge building steps.

Soil and Land Type: Majority of farmers (about 57 per cent) are disagree with the statement ‘crops selection depending on acid soil and alkaline soil’. It is worthwhile to mention here that 104 farmers (27.3 per cent) out of 381 farmers do not know about the acid and alkaline soil. On the other hand, with respect to other issues of soil and land type, majority of farmers are agree with these.

It is assumed from above opinion of farmers regarding soil and land type that despite agreeing answers by majority, good number of farmers have lack of knowledge to understand properly the importance of soil reaction (pH), organic matter, macronutrients and micronutrients to crops selection, yield and agriculture development. Lack of knowledge regarding aforementioned aspects has effects on agriculture development that are important for cultivating lands as per suitability. Therefore, building of knowledge about the mentioned aspects is necessary, as soil is the main determining factor of yield and profitability.

Irrigation Water: Regarding four statements of irrigation water, majority of farmers in the study area understand the relationship of irrigation water and agriculture development. The agriculture in the study area is heavily dependent on irrigation particularly in *rabi* and *kharif* 1 seasons and farmers' perception are good and helpful for sustainable agriculture.

Climate: About climate issues, 80 to 83 per cent farmers disagree. It means that most of the farmers failed to understand the delicate relation between critical temperature in summer and winter season and monthly rainfall in *rabi* and *kharif* 1 seasons with crops selection and yield. However, it is necessary to make farmers understand the relation of climatic parameters with crops selection, potential yield and profitability.

Farmers' Knowledge Deficiency about Land Suitability, Chemical and Organic Fertilizer, and Insecticide: The above results show that about half of the farmers thought that farmers have deficiency of knowledge which is real picture in the ground. About 90 per cent farmers considered use of chemical fertilizer is necessary for crops production in the present soil condition, while about 24 per cent farmers opined that use of chemical fertilizer is not too much harmful to crops. These results are alarming for farmers' proper perception and it would be difficult to move forward to land suitability based cultivation and sustainable agriculture. The important thing is to take measurs to raise farmers' proper perception to realize the long term adverse effects of chemical fertilizer and insecticide use in agriculture farms for crop production and to practice sustainable agriculture.

Crops Diversification and Cropping Pattern Changes: Regarding 'crop diversification and cropping pattern changes', 82.7 per cent farmers agreed which is positive and it would be possible to initiate crop diversification and cropping pattern changes which are very much important for sustainable agriculture and economic viability. In this circumstance, agriculture department should initiate steps to encourage farmers to adopt crop diversification and high value crop cultivation.

8.9 Perception Assessment of Farmers

There are 19 statements related to acid soil, alkaline soil, macronutrients, micronutrients, soil texture, land type, irrigation, climate, knowledge deficiency, chemical fertilizer, organic fertilizer, insecticide, crop diversification and cropping pattern changes etc. which are used to assess the perception of farmers.

8.9.1 Perception Assessment about Land Suitability and Agriculture Development

Farmers' perceptions have been assessed based on individual statements. Accumulating all 19 statements, perception level of farmers is finally assessed. Farmers' perception about 1st statement "land suitability is cultivation of crops according to soil, irrigation water, climate, topography, floodability, and accessibility attributes" is presented below in table 8.8.

Table 8.8. Farmer's Perception about Land Suitability Meaning

Scale	Percent	Frequency	Scale Point***	Total Score Point**	Weighted Mean*
Strongly Agree	20.71	58	5	290	4.20
Agree	79.29	222	4	888	
Neutral	-	-	3	-	
Disagree	-	-	2	-	
Strongly Disagree	-	-	1	-	
Total	100	280	1-5	1178	

Source: Field Data, 2016

*Notes: * Weighted mean is calculated based on total score point divided by total frequency ** Total score point is calculated based on individual scale points multiplied by corresponding frequencies *** Scale point is the corresponding score of individual scale*

The above table shows that according to perception of farmers, 20.71 per cent farmers strongly agree and 79.29 per cent farmers agree with the meaning of land suitability. The weighted mean is 4.2 out of 5-point scale. Therefore, perception about land suitability meaning is good and this is necessary for agricultural development.

Following the procedure described in table 8.8 and frequency and percentage mentioned in table 8.7, the weighted mean of farmers' perception against 19 statements are calculated and presented below.

Table 8.9. Farmers' Perception (Knowledge) about Land Suitability and Sustainable Agriculture

Statements	Weighted Mean
Land suitability is cultivation of proper crops according to soil, irrigation water, climate, topography, floodability, and accessibility attributes	4.20
Crops selection depending on acid soil and alkaline soil will increase production	2.41
Crop selection depending on soil organic matter leads to optimum yield	3.78
Balance of macronutrients in soil leads to potential yield	4.03
Balance of micronutrients in soil leads to optimum yield	3.85
Selection of crop based on land type is necessary for potential yield	4.51
For maximum production, crop should be selected based on soil texture	4.66
To select proper crop to get maximum yield soil test at times is imperative	4.01
Crop selection depending on water quality can give good production	4.01
Crop should be selected which require less water in *rabi* season	3.87
Temperature of irrigated water in summer and winter season has impact on potential yield	3.96
To select proper crop for getting maximum yield water test at times is imperative	3.98
Cultivation of summer and winter critical temperature tolerant crop can increase yield	2.10
Selection of crop based on monthly total rainfall is necessary	2.12
Farmers have deficiency of knowledge to cultivate land as per land suitability	3.17
Use of chemical fertilizer is necessary for crop production in the present soil condition	4.20
Use of chemical fertilizer instead of organic fertilizer is not too much harmful to crops*	1.79
Extensive use of insecticide is harmful to sustainable agriculture	4.09
Crop diversification and cropping pattern changes according to land suitability is necessary for sustainable agriculture	3.70
Mean of Weighted Mean	**3.60**

Source: Field Data, 2016

*Note: *Reverse Statement*

Weighted value means average score points of 381 farmers against each statement in 1 to 5 point Likert scale. The above table shows the farmers perception about land suitability and agriculture development which are described below.

Perception Regarding Land Suitability Meaning: The above result shows that weighted mean of farmers' perception about land suitability meaning is found 4.20, which is considered farmers quite good perception. Agriculture development requires good perception of farmers about land suitability and farmers have that.

Perception about Soil and Land Type: Regarding 'crops selection depending on acid soil and alkaline soil', farmers perception is very poor (2.41). Pertaining 'crops selection depending on soil organic matter', 'balance of macronutrients in soil' and 'balance of micronutrients in soil', farmers' perceptions are found good (3.78, 4.03 and 3.85 respectively). Relating to selection of crops based on land type, crops should be selected based on soil texture and to select proper crops soil test at times is imperative, the weighted means are 4.51, 4.66 and 4.01 which say that farmers' perception to these issues are very good.

Except crops selection and acid soil and alkaline soil, farmers' perceptions in other cases of soil and land type are good which are necessary and encouraging for agricultural development. With respect to acid soil and alkaline soil, farmers have lack of proper knowledge and it needs to be corrected.

Perception Regarding Irrigation Water: Farmers perception levels are found from 3.87 to 4.01 with regard to 4 statements of irrigation water which mean that their perceptions are good. In spite of no problem in water quality in the study area, farmers' perception is good which would be helpful for encouraging farmers to cultivate land according to land suitability.

Perception Concerning Climate: The weighted mean found regarding two attributes of climate are 2.10 and 2.1 respectively which mean that farmers perception in this regard are very low. In view of above, it is presumed that farmers lack of proper perception regarding climate attributes and agriculture. Climate is an important element of agriculture development and farmers' perception need to be elevated through perception developing steps.

Perception Regarding Knowledge Deficiency about Land Suitability, Chemical and Organic Fertilizer and Insecticide: In case of farmer's deficiency of knowledge to cultivate lands as per land suitability, the weighted mean is 3.17, which indicates that farmers have deficiency of knowledge. Regarding 'use of chemical fertilizer is necessary for crops production' and 'extensive use of insecticide is harmful', farmers' perception levels are 4.20 and 4.09 respectively. On the other hand, the perception level of farmers is very poor (1.79) against 'use of chemical fertilizer instead of organic fertilizer is not too much harmful'.

In view of above, it is said that farmers failed to properly understand the consequences of chemical and organic fertilizer and insecticide use which are destroying soil in particular and agriculture in general. On the other hand, they understand their knowledge deficiency. Against this backdrop, it is necessary to develop farmers knowledge regarding long term adverse effects of chemical and organic fertilizer and insecticide use and ways and means of agriculture development.

Perception With Respect to Crop Diversification and Cropping Pattern Changes: The perception of farmers regarding crop diversification and cropping pattern changes is moderately good (weighted mean 3.70). However, crop diversification and cropping pattern changes are considered good solution for sustainable agriculture and higher economic returns from agriculture sector in the study area. Hence, farmers' perception level must be elevated in this regard.

Mean of Weighted Mean: The mean of weighted mean is found 3.60 that indicates the medium level of perception of farmers in the study area regarding land suitability and agriculture development. Farmers perception level is found medium and their education level is poor. However, these two factors are very important for implementing any steps for the development of agriculture. Hence, improvement measures of farmers' perception level as well as education level are necessary and vital. As success of any effective measures for the long term development of agriculture depends on perception and education level, these two should be taken into consideration before taking any measures of agriculture development.

8.10 Farmers Perception Level

Nineteen statements were used to measure farmers' perception which are mentioned in table 8.7. Against the mentioned 19 statements, individual 381 farmer's responses' total score, mean, and standard deviation of perception were measured. Based on interval of mean from standard deviation, classification of farmers according to their perception level (perceived knowledge or knowledge level) towards land suitability and sustainable agriculture are presented below.

Table 8.10. Farmers Perception Level about Land Suitability and Agriculture Development

Farmers Level of Perception	Frequency	Percentage	Cumulative Percentage
Very low (VL)	49	12.90	12.90
Low (L)	130	34.10	47.00
Medium (M)	158	41.50	88.50
High (H)	44	11.50	100.00
Total	381	100.00	-

Source: Field Data, 2016

The results of the study presented in above table show that majority (41.50 per cent) of farmers in the study area have medium level of perception regarding land suitability and sustainable agriculture followed by low (34.10 per cent) and very low level (12.90 per cent). On the other hand, only 11.50 per cent farmers have high level of perception. This result clearly tells that farmers in the study area do not have high level of knowledge regarding land suitability and sustainable agriculture rather they have medium and low level of knowledge.

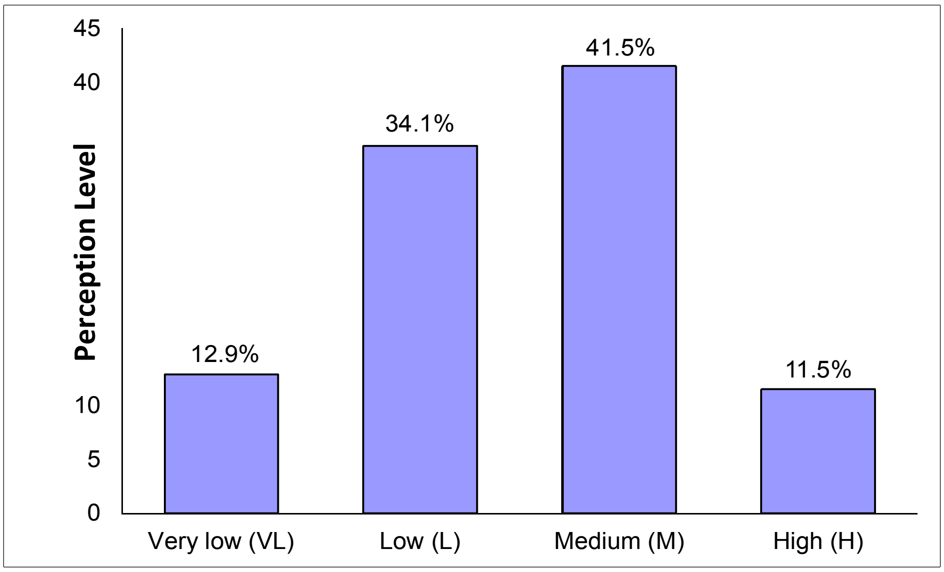

Figure 8.4. Perception Level of Farmers in the Study Area

Hence, the present perception level found through KAP study is not conducive for agriculture development in the study area. Therefore, it is imperative to elevate the perception level of main stakeholder farmers through perception developing measures such as education, training, motivation, mobile/smartphone/tab apps, focusing on comparative advantages etc.

8.11 Coefficient of Variation (CV) of 19 Statements Used for Perception Study

The coefficient of variation (CV) is a relative measure of dispersion that represents the spread of distribution relative to the mean of the same distribution. The coefficient of variation of 19 statements that used for measuring farmers' perception regarding land suitability and agriculture development and ranking are presented below.

Table 8.11. Coefficient of Variation and Ranking of Statements

Statements	Mean	SD	CV	Rank
To select proper crops for getting maximum yield water test at times is imperative	3.99	0.355	8.90	1
Land suitability is cultivation of proper crops for optimum yield according to soil, irrigation water, climate, topography, floodability, and accessibility attributes	4.21	0.406	9.64	2
Crops selection depending on water quality can give good production	3.98	0.447	11.23	3
Temperature of irrigated water has impact on potential yield of cultivated crops	3.90	0.574	14.72	4
Crops should be selected which require less water in *rabi* season	3.87	0.595	15.37	5
For maximum production, crops should be selected based on soil texture-sandy soils, clayey soils, and loamy soils	4.58	0.866	18.91	6
Selection of crops based on monthly total rainfall is necessary	2.86	0.570	19.93	7
To select proper crops to get maximum yield soil test at times is imperative	3.90	0.781	20.03	8
Use of chemical fertilizer is necessary for crops production in present soil condition	4.23	0.897	21.21	9
Crops diversification and cropping pattern changes according to land suitability is necessary for sustainable agriculture	3.69	0.829	22.47	10
Crops selection depending on acid soil and alkaline soil will increase production	2.97	0.678	22.83	11
Cultivation of summer and winter critical temperature tolerant crops can increase yield	2.76	0.687	24.89	12
Balance of macronutrients in soil leads to potential yield	3.81	1.047	27.48	13
Selection of crops based on land type- high land, medium high land, medium low land, low land, and very low land is necessary for potential yield	4.31	1.216	28.21	14
Farmers have deficiency of knowledge to cultivate lands as per land suitability	3.42	0.969	28.33	15
Use of chemical fertilizer instead of organic fertilizer is not too much harmful to crops *	3.15	0.987	31.33	16
Balance of micronutrients in soil leads to optimum yield	3.39	1.213	35.78	17
Extensive use of insecticide is harmful to sustainable agriculture	3.86	1.414	36.63	18
Crops selection depending on soil organic matter leads to optimum yield	3.24	1.395	43.06	19

Source: Calculated from Field Data, 2016

*Notes: *Reverse Statement, CV (Coefficient of Variation) = Standard Deviation/Mean=CV is expressed as Percentage*

The above table shows that coefficient of variation is found the least amongst the all statements in case of ‘to select proper crops water test at times is imperative’ followed by ‘land suitability is cultivation of proper crops according to soil, irrigation water, climate, topography, floodability, and accessibility attributes’ and ‘crops selection depending on water quality can give good production’ respectively. On the other hand, coefficient of variation is found highest in ‘crops selection depending on soil organic matter leads to optimum yield’ followed by ‘extensive use of insecticide is harmful to sustainable agriculture’ and ‘balance of micronutrients in soil leads to optimum yield’ respectively.

8.12 Correlation and Regression Analysis

Correlation and regression analysis are the most commonly used techniques for investigating the relationship between two quantitative variables. The technique of correlation is used to test the statistical significance of the association. In regression analysis, the problem of interest is the nature of relationship itself between the response (dependent) variable and the predictor (independent) variable. Response variables are related to knowledge means 19 statements regarding land suitability and agriculture development. In this study, we have calculated total score of response variable (perception) by adding 19 statements regarding land suitability and agriculture development of 381 respondents. On the other hand, predictor variables are age, education level, and agriculture training of farmers. Knowledge levels are dependent on predictor variables means age, education, and agriculture training.

8.12.1 Correlation Analysis

Correlation analysis is the statistical tool which is used to describe the degree to which one variable is related to another variable. The correlation among age, agriculture training, and education of farmers and farmers’ perception is presented below.

Table 8.12. Correlation Analysis

		Total Perception	Age	Agriculture Training	Education
Total Perception	Pearson Correlation	1			
	P-value				
Age	Pearson Correlation	.085	1		
	P-value	.099			
Agriculture Training	Pearson Correlation	-.129*	-.090	1	
	P-value	.011	.078		
Education	Pearson Correlation	.040	-.119*	-.391**	1
	P-value	.441	.021	.000	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

It is found in the above table 8.12 that there is significant correlation at the 0.05 level of significance between agriculture training (-.129*) and farmers' perception about land suitability and agriculture development. On the other hand, though there is relation but exists no significant correlation between age (.085) and education (.040) with farmers' perception. Department of Agriculture Extension (DAE) is providing different types of training in the study area for years on high value crops cultivation techniques depending on land type, drought tolerant crops production, proper timing of different crops cultivation, and good agriculture management etc. which are creating awareness among farmers to select proper crops according to land.

On the other hand, it is found from data that farmers of older ages have comparatively little education than young farmers. Besides, older farmers have tendency to stick to traditional farming practices and are reluctant to adopt newer things in farming practices. Land suitability is considered slightly an advance level issue. It is not a trite matter that farmers can gain and increase knowledge level about land suitability and agriculture development reading few more classes education. Farmers' education levels are found from class-one to class eleven. It is known from school and college that there is no curriculum in any classes up to HSC level about land suitability based crops cultivation. For this reason, farmers' education level is not favorable for elevating perception level of land suitability based cultivation. Therefore, it is very usual not to find any significant relation between age and perception and education and perception regarding land suitability and agriculture development.

8.12.2 Regression Analysis

Regression is the average of the linear relationship between two or more variables. The resulting equation is called regression equation. The normal distribution had a statistically pivotal role in the development of regression analysis. Before applying statistical methods that assume normality or not, it is necessary to perform a normality test on the data. To check the normality assumption of data, histogram and normal probability plotting (PP-plot) are used in this study which are presented below.

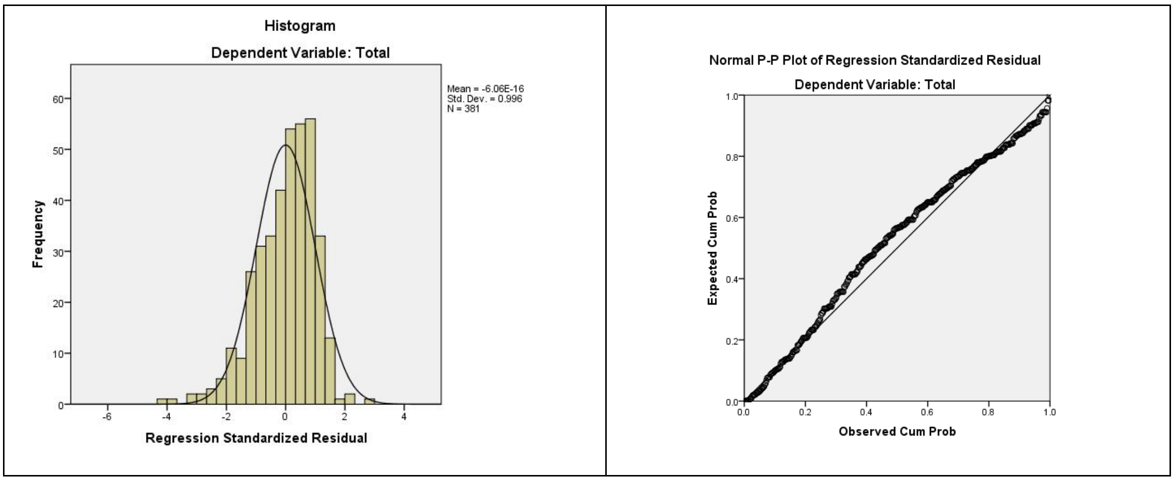

Figure 8.5. Normality Assumption of Data

It is found in figure 8.5 that data are approximately normally distributed. Analysis of variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures. ANOVA test is done to see the overall effects of regression coefficients. The ANOVA results of this study are presented below.

Table 8.13. Analysis of Variance (ANOVA)

Model	Sum of Squares	df	Mean Square	F	P-Value
Regression	376.844	3	125.615	2.841	.038
Residual	16666.972	377	44.209		
Total	17043.816	380			

It is found from above table 8.13 that the p-value (0.038) is less than 0.05. Thus, we may conclude that the test is significant. Therefore, we may say that the null hypothesis is rejected which means that there is a significant effect of predictor variables (age, agriculture training and education) on the response variable (total perception).

After being confirm the overall significant effect of independent variable on dependent variables now we have to know the effect on individual variable. To do this, regression equation is employed in this study to determine the dependency of perception on predictor variables; age, agriculture training, and education. Regression coefficients of response and predictor variables of perception are presented below.

Table 8.14. Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	p-value	95.0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
Constant	69.077	2.941		23.484	.000	63.293	74.861		
Age	.059	.041	.074	1.420	.156	-.023	.140	.964	1.037
Agriculture training	-2.051	.937	-.123	-2.190	.029	-3.892	-.209	.828	1.207
Education	.004	.449	.000	.008	.994	-.879	.886	.823	1.214

$R^2 = 0.022$

From the above Table 8.14 we see that regression coefficient (RC) of agriculture training is -2.051. Therefore, if we increase 1 unit of agriculture training, then perception of 2.051 units changes. We also see that p-value is 0.029 which is less than 0.05. This means that test is significant i.e., agriculture training has a significant effect on perception of farmers. On the other hand, age and education are found having effects but not significant effects on perception of farmers in the study area. It is also found that there is no multicollinearity problem in the data as VIF (Variance Inflation Factor) is less than 5 (VIF<5).

8.13 Conclusion

Farmers, the main stakeholder of agriculture, have different level of perception regarding the land suitability and agriculture development in the study area. Majority of farmers have medium and low level of perception with poor education level. In the present situation, farmers' perception levels need to be elevated for the development of agriculture in the study area. Perceptions are generated based on farmers understanding and an in-depth knowledge regarding the entire gamut of agriculture for long time. There is a strong need for an in-depth understanding of farmers' perception to determine the sustainable options for agricultural development in the research area. Therefore, their perceptions are valuable and decisions and policy formulations about agriculture development are to be formulated taking into account farmers' perception.

Chapter Nine
Conclusion

9.1 Introduction

Land suitability based crop cultivation is the source of affluence of the country and it is decisive in determining production, net return, economic status, social standing, cultural and political setting and strength as well as socio-economic development and food security of Bangladesh. The purposes of this study were to analyze the land suitability of major agriculture crops for sustainable agricultural development including economic viability of major crops and cropping patterns, land use changing pattern and farmers' perception regarding land suitability and agriculture development of the study area. Data of soil, irrigation water, climate, topography, floodability, accessibility, questionnaire survey for economic viability and farmers perception, expert and agriculture officials opinion, case study, satellite images etc. were collected and analyzed through GIS, MCE, Benefit-Cost Analysis (BCE), statistical techniques etc. Analyzed data were used for the analysis of land characteristics, land suitability of major agricultural crops, economic viability of crops and cropping patterns, land use changing pattern and farmers' perception etc. Through these processes, the major findings found are presented below.

9.2 Major Findings

1. Land Characteristics and Variables

i. **Soil:** Clay loam and loam dominate the texture of soil. Both clay loam and loam texture are found in 45 per cent sample areas. Loam soil is good for agriculture and clay and clay loam texture are not suitable for potential yield. Low moisture is found in about 90 per cent area but pH status is almost good in the whole study area. Organic matter, nitrogen, phosphorus, potassium, sulfur, and zinc contents are low in most areas.

ii. **Irrigation Water:** pH, EC, and temperature of irrigation water are within normal range for irrigation around the year. These three parameters of irrigation water in the study area are no problem for crop production and agriculture development.

iii. Climate: Aggregate average normal temperature in Rajshahi is almost similar to that of Bangladesh except few days in the summer and winter season and temperature is no problem for producing different crops in the study area. Rainfall of Rajshahi is very low and average (1975-2014) yearly rainfall is 1456 mm as against 2401 mm rainfall of Bangladesh. Scanty rainfall is a problem for crops production and agriculture is not possible in *boro* and *kharif* 1 season without irrigation.

iv. Topography: The study locale is predominantly high land area. About 74 per cent land in the study area are highland and 17 per cent medium high land. High land area requires huge irrigation for crop production in *boro* and *kharif* 1 seasons.

v. **Floodability:** Flood is no problem in the study area as the region is high land area. In case of depth of flooding, about 50 per cent area are above normal flooding and insignificant area are flooded mainly along the river area. On the other hand, duration of flooding is only few days (2-15 days) in about 80 per cent area and these areas are flood free.

vi. Accessibility: Union wise mean distance from highway is 4.937 km and 5.106 km from local market. Basudevpur union is close to highway (1.58 km) and Pakri (7.77 km) and Gogram (6.297 km) union have higher distance. Basudevpur union (3.02 km) has low distance from local market and Char Ashariadaha (7.89 km) and Mohanpur union (6.99 km) have higher distance.

2. Land Suitability Analysis

i. Land Suitability Components: In case of soil suitability, about 72 per cent area are found moderate suitable and 28 per cent land are low suitable in the study area. Hundred percent area are found suitable for irrigation water. Irrigation water quality is good and suitable for potential yield. Climate is moderately suitable for agriculture in the study locale. Temperature is suitable for different crops but rainfall is low. The research area is mainly highland and most of the areas are found low suitable in terms of topography suitability. Suitable and moderate suitable class of floodability dominate the study region. Moderate suitable and suitable class of accessibility are found in most areas though it is found very low in Char Ashariadaha union because this union is separated by mighty river the Padma.

ii. Overall Land Suitability: The whole study area is found moderately suitable for general agriculture.

iii. Land Suitability of Major Crops: All unions are found moderately suitable for rice, wheat, maize, potato, and chili crops cultivation. Lentil, mustard, and onion crop are found moderately suitable in Basudevpur, Deopara, Gogram, Matikata, Rishikul, Godagari, Mohanpur, and Pakri union which constitute 92.34 per cent area. On the other hand, only Char Ashariadaha union is found marginally suitable for lentil, mustard, and onion cultivation which covers only 7.66 per cent area. Rice is the dominant crop and it is cultivated in 79.06 per cent area. Wheat is cultivated in about 2.56 per cent area, pulses occupy 4.93 per cent area, maize occupies 2.90 per cent, and oil seeds 2.59 per cent land of the study area.

3. Economic Viability

i. **Economic Viability of Presently Cultivated Major Crops:** Net returns from onion seeds and cauliflower cultivation per 33 decimal are about BDT 97,573 and 26,090 respectively which are very profitable and much more than rice. The next economically viable five crops are onion, brinjal, tomato, maize, and potato respectively on the basis of net return. On the other hand, rice (*aus*; 805 BDT, *aman*:1426.80 BDT and *boro*;1855.56 BDT) is economically the least viable crop which is cultivated in 79.06 per cent land in the study area and 78.52 per cent land in Bangladesh. Economically least viable five crops next to rice are mustard, wheat, lentil, chili, and pulses respectively. Economically least viable 6 crops constitute about 90 per cent land in the study area which is not desirable and economically not viable and need to switch. Besides, yield of almost all crops in the study are low than Northern Bangladesh.

ii. **Economic Viability of Present Cropping Patterns:** In presently followed different cropping patterns in the study area, highest net return comes from *boro*+*aus*+tomato cropping pattern which is about BDT 15858. The next highest net return earning cropping patterns are fallow+*aus*+tomato. maize+*aus*+*aman*, vegetables (potato)+*aus*+fallow, *boro*+*aus*+pulses(lentil), `pulses(lentil) +*aus*+*aman*, wheat+*aus*+*aman,* and *boro*+*aus*+*aman*. In case of three rice based cropping patterns, *boro*+*aus*+*aman* cropping pattern brings slightly higher returns than *boro*+fallow+*aman,* and fallow+*aus*+*aman*. The lowest net returns come from fallow+*aus*+*aman* cropping pattern which is BDT 2232. It is clear from above picture that rice based cropping patterns are economically least viable and non-rice based cropping patterns are highly viable.

iii. **Economic Viability of Land Suitability Based Cropping Patterns:** Among the land suitability based proposed cropping patterns, the highest net return is assumed about BDT 1 lac in onion seed+ *aus*+ *aman* cropping pattern which is only BDT 4088 for present *boro*+ *aus*+ *aman* cropping pattern. The second and third highest net return generating cropping pattern are Thai guava+ Thai guava+ Thai guava and cauliflower+ a*us*+ tomato respectively. On the other hand, three lowest net return cropping patterns are mustard+ a*us*+ *aman*, wheat+ *aus*+ *aman*, and lentil+ a*us* + *aman* which are rice dominated. Non-rice based cropping patterns are found highly profitable also in land suitability based cropping patterns. Cultivation of high economic value crops can change the agriculture sector and socio-economic condition of farmers in the study area.

iv. **Net Return Changes through Land Suitability Based Cropping Patterns:** The net return increase could be possible in huge amount following land suitability based cropping patterns. The increase in net return about BDT 511.74, 2398.54, 9512.49, and 97930.14 crores are possible for the study area Godagari upazila, Rajshahi district, Rajshahi division, and Bangladesh respectively practicing land suitability based high return and economically viable cropping patterns. BDT 97930.14 crores are about 56 per cent of total export (173783.11 crores in 2013-2014) of Bangladesh. Therefore, agriculture sector alone can contribute a lot to develop Bangladesh if land suitability based cropping patters are followed which are very encouraging.

4. **Land Use Changing Pattern**

i. **Soil Properties:** In case of soil properties change, pH, organic matter, and zinc level have been increased in 2015 from 1991 but organic matter is still much lower than required level. Nitrogen, phosphorus, sulfur, and boron have decreased significantly which are alarming for sustainable agriculture as they are now considered vital for good yield.

ii. **Crop Cultivation Areas:** HYV *aus*, HYV *boro,* and hybrid *boro* cultivation area have significantly increased. Jute, potato, fruit, spices, oil seeds, vegetables, and maize cultivation area are also increasing. HYV *aman*, sugarcane, pulses, and wheat cultivation area are decreasing. Rice is very low profitable crop which has significantly increased.

iii. **Agriculture Land:** About 8407 acres agricultural land, 1200 acres area for both moderate vegetation and sand bar area have been increased from 1977 to 2016 in the study area. On the other hand, about 7206 acres' barren land, about 4804 acres' sparse vegetation area have been decreased in the study area.

iv. **Cultural Changes:** Cultural changes in used seed varieties, chemical fertilizer and insecticide use, food culture, health risks, farm working culture, costumes, and foods of farm workers, and household working cultures in farming system in the study area have been occurred significantly. These changes are considered reactive to indigenous culture of rural Bangladesh and rural Bangladesh constitutes about 94 per cent area.

5. **Farmers Perception:** Weighted mean of farmers' perception regarding land suitability and agriculture development were found from 1.79 to 4.66 in 1 to 5 point scale and mean of weighted mean is 3.60. Majority of farmers have medium (41.5 per cent farmers) and low level (34.1 per cent farmers) of perception in the study area regarding land suitability and sustainable agriculture and it is necessary to elevate their perception level for the development of agriculture through various perception development measures.

6. **Potentialities:** The study area has boundless potentialities of agriculture. Thai guavas, *bablah*, moringa, flowers, mango, aonla, ber, golden apple etc. have immense potentialities. Goose and ram cultivation raising are considered profitable along with crops under integrated agriculture. There are also potentialities of fish cultivation in 1162 ha low land areas of which about 500 ha are very low land.

9.3 Policy Suggestions

One of the goals of the present research work is to put forward some policies aiming at practicing cultivation of land for agriculture development based on land suitability. In the light of the facts and findings of the present study, the important policy suggestions are as follows:

1. Land Suitability Based Crop Cultivation: Land is cultivated now in the study area without any suitability analysis and following parental practices which are not appropriate and economically profitable. Therefore, land could be cultivated selecting crops based on land suitability. To cultivate crops following land suitability should be mandatory for all farm holdings and prescription of agriculture officials are supreme in this regard. 'National Agriculture Policy 1999' and 'National Land Use Policy 2001' should be amended and make land cultivation legally binding as per land suitability and empower the agriculture officials to enforce these systems.

2. **Crop Diversification and Cropping Pattern Changes:** Crop diversification and cropping pattern changes according to land suitability are very important and required for sustainable agriculture. Cropping pattern changes based on land suitability and selection of higher value crops are pivotal and these can develop the agriculture sector significantly.

3. **Emphasis on Profitable Non-Traditional Crops:** High economic value crops suitable to specific pieces of land are required to produce and farmers should be motivated to cultivate those crops for the development of agriculture as well as socio-economy of the study area.

4. Application of GIS and RS for Identification of Land Suitability: GIS in conjunction with RS could be applied to identify suitable land for specific crops. It is expected that land suitability analysis model developed in this study is useful to identify suitable areas for sustainable agricultural development.

5. Use of Organic and Green Manure Fertilizer instead of Chemical Fertilizer: Organic and green manure fertilizers are essential for sustainable agriculture. On the other hand, chemical fertilizer, and insecticides are not conducive for sustainable agriculture in the end and they are destroying soil fertility in particular and agriculture in general.

Hence, use of organic and green manure fertilizer should be required and chemical fertilizer, and insecticide use should be strictly regulated.

6. Low Land Uses for Fish Cultivation and Other Practices: About 1162 ha areas are very low land out of 47563 ha in the study area, which are not suitable for crop cultivation mainly in the *kharif* 2 season. Therefore, these areas could be used for fish cultivation excavating ponds and canals and horticulture in the rounding, which are profitable that are kept fallow mainly in the rainy season.

7. Integrated Water Resource Management for Irrigation: The study area is highland area and irrigation is a major problem for sustainable agriculture. Without irrigation, farmers could not produce crops in *rabi* and *kharif* 1 season. The ground water level is going down and down in the study area due to over exploitation of ground water for irrigation. Augment surface water in rivers, creeks, canals, ponds, and lowlying areas by constructing water control structures could be stored and used for irrigation in the *rabi* and *kharif* 1 season. Judicious use of surface, rainwater and ground water in an integrated water resource management approach is important and crop diversification for efficient water utilization is helpful.

8. E-Agriculture: E-agriculture is necessary for agriculture development in Bangladesh applying all available tools in a holistic way. E-agriculture includes land suitability based crop cultivation, soil and irrigation water, climate and weather, sowing and harvesting time of crops, seed, fertilizer, insecticide and pest management, credit and subsidy, marketing and price, agriculture mechanization, preservation and processing, extension activities, education and training, total agriculture management system etc.

Mode of e-agriculture could be tele-center, social community club, portal in Bangla, call, SMS, and other systems to mobile phone, radio broadcast through FM band, community radio, short wave, medium wave, and television programs through smart phone/tab, web television, and web radio, teleconference, and phone in program, audio documentary, video documentary, agriculture content digitalization etc.

9. Market Price Control: Market prices of agricultural crops are the determining factor of making the cultivation profitable or losing. If market prices are lower, no mechanism will work to make the farming money spinning. Therefore, emphasis should lay on controlling market prices of agricultural produces.

10. Necessary Credit: Most of the small and medium farmers are not becoming able to switch from rice and other low profitable crops to high value crops cultivation only because of capital that they do not have. Because vegetables and high value crops cultivation require huge investment which farmers are not becoming able to manage. As a corollary, they are cultivating rice and other low capital requiring crops in their farms and they are not getting profit and remain poor like vicious cycle of poverty. To bring out farmers from this problem necessary capital must be provided without or with minimum interest. In addition to that, all inputs must be made available at farm levels at lower prices giving subsidies.

11. **Establish Agriculture Market:** Local markets are open for two days a week in the study area. Therefore, farmers cannot sell their agricultural produces seven days but they need to sell their surpluses every day, as many products are perishable. For solution of this problem, two to three agriculture markets are needed to establish in the study area open for everyday and all day, which will be toll and middlemen free.

12. **Establish Cold Storages for Storing Surpluses:** There is no cold storage in the study area. They have to store perishable and rotten goods in neighboring upazila paba, 30-60 km distance from their farm, which is a major problem for storing surpluses and agriculture development. It is necessary to establish at least three cold storages in the study area for storing agriculture products.

13. Timely Cultivation of Crops: Many farmers do not cultivate crops timely. For example, farmers can cultivate wheat in November but they cultivate wheat in December. As a corollary, they get less time for *kharif* 1 season and they cannot cultivate many lands due to time congestion and have to keep land fallow. Motivation and knowledge about proper sowing and harvesting time are necessary.

14. Improvement of Accessibility: Char Ashariadaha union (7.66 per cent area) is disconnected from the rest areas by the mighty river Padma. There is no market in this union and purchasing agriculture inputs and selling productions are major problem. 'Border *haat*' between Bangladesh and India should be opened as soon as possible for buying inputs and selling products to solve the accessibility problem. Besides, road networks and access to markets should be developed across the study area.

15. Elevation of Farmers' Perception Level: Majority of farmers have medium and low level of perception regarding land suitability and sustainable agriculture which are not conducive for agriculture development. Therefore, it is imperative to elevate the perception level of farmers through education, training, motivation, mobile apps etc. and perception developing measures should be long term basis.

9.4 Limitations of the Present Study and Need for Further Study

Agriculture is the mainstay of the study area and development of this sector is very much important. However, the present study of land suitability analysis is done based on selected attributes and aspects. Hence, this study is by no way a comprehensive one covering the entire gamut of land suitability and sustainable agricultural development. Many things are left out in the present study and there remain many things of land suitability and sustainable agricultural development that are to be taken into consideration for further study pertaining to land suitability and agricultural development.

There is also need for further study on soil quality improvement, limiting climate uncertainties, potentialities in livestock, forestry, recreational use, housing, business, communication, infrastructure, land tenure and better management systems, farmers' attitude and practice and discrepancies among knowledge, attitude and practice regarding land suitability and agricultural development etc. Besides, taking into account the other attributes of soil, irrigation water, climate, topography, floodability, and accessibility many researches need to be done. Four crops- jute, cotton, sugar cane and different type of fruits are important for further studies which are left out in this study. It will require further multidisciplinary study by experts of various disciplines to find out the potential problems and development ways and means of agriculture sustainability.

9.5 Conclusion

Agriculture is the backbone of the study area and greatly contributes to livelihood, food security, socio-economy, political and cultural settings. As the land is the foundation of agricultural activities, the leading sector of the country, its judicious and optimum use based on land suitability will bring fruitful outcome for the most sectors of the whole country. Basic properties of a soil in the field are not subject to change in a short time.[1] Similarly, irrigation water, climate, topography, and floodability characteristics are not changeable in a short period. Hence, outcome of this research is useable for a long period and based on the findings policy suggestions are formulated for the use of the land for sustainable agricultural development and the best outputs and economic returns.

It is expected that this work will provide a basis for the study of land suitability analysis for sustainable agriculture development of the study area of Rajshahi district in a comprehensive way that will be a guideline to improve the agriculture sector for the whole sweet water areas of the country. Therefore, it is hoped that the areas investigated in this study regarding land suitability, economic viability and sustainable agriculture etc. will be of considerable interest to agriculture planners, agriculture extension officials, policy makers, academicians and future researchers. Despite limiting factors, lands have potentialities in the study area. So, exploring potentialities and implementation measures must be conveyed to the main stakeholders- farmers, agriculture officials and decision makers so that the outcome and real purposes of the present research work will be grasped and can bring tangible results in the agriculture sector of the study area as well as sweet water areas of Bangladesh.

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Appendices

Appendix 1. Union Wise Number by Type of Household

Sl.	Union Name	Area (ha)	No. of *Mauza*	Farm Holdings			
				Small	Medium	Large	Total
1	Basudevpur	1896	19	2121	659	117	2897
2	Char Ashariadaha	3646	09	2113	948	72	3133
3	Deopara	5234	35	3634	972	106	4712
4	Gogram	7026	63	3017	1085	142	4244
5	Matikata	3956	54	3881	823	58	4762
6	Rishikul	5933	36	2828	788	93	3709
7	Godagari	3830	53	1550	558	55	2163
8	Mohanpur	9647	83	2879	1193	179	4251
9	Pakri	6395	38	2470	1016	156	3642
Total	09	47563	390	24493	8042	978	33513

Sources: Census of Agriculture 2008, Zila Series: Rajshahi. pp. 311-320.

Land and Soil Resources Utilization Guide: Godagari Thana. pp. 81-93.

Appendix 2. Land suitability model outputs and observed field data of overall land suitability, rice, wheat, maize, potato, lentil, mustard, onion, and chili crops cultivation

Sl	Union	Latitude	Longitude	OLS		Rice		Wheat		Maize		Potato		Lentil		Mustard		Onion		Chili	
				ML	OF	ML	OF	ML	OF	ML	OF	ML	OF	ML	OF	ML	OF	ML	OF	ML	OF
1	Basudebpur	24.53183300	88.32213900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS
2	Basudebpur	24.52319400	88.32791700	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS
3	Basudebpur	24.53961100	88.31455600	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
4	C. Ashariad	24.39063900	88.34586100	MS	SU	MS	SO	MS	MS	MS	SU	MS	MS	MRS	SU	MRS	SU	MRS	SU	MS	SU
5	Deopara	24.42175000	88.51638900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
6	Deopara	24.44861100	88.52200000	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS
7	Deopara	24.38611100	88.47694400	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
8	Deopara	24.39000000	88.44638900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
9	Deopara	24.42636100	88.46319400	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
10	Godagari	24.49166700	88.32166700	MS	MS	MS	SO	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
11	Godagari	24.50361100	88.32833300	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	SO
12	Godagari	24.48333300	88.33927800	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS
13	Godagari	24.50005600	88.34069400	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO
14	Godagari	24.49036100	88.36652800	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS
15	Godagari	24.45913900	88.35852800	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
16	Godagari	24.45957628	88.33600759	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
17	Godagari	24.47880232	88.38397753	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
18	Gogram	24.44836100	88.43452800	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
19	Gogram	24.45283300	88.43855600	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
20	Gogram	24.47833300	88.42658300	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
21	Gogram	24.43952800	88.45311100	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS
22	Gogram	24.43569400	88.43122200	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
23	Gogram	24.44138900	88.43552800	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
24	Gogram	24.46450000	88.43147200	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
25	Gogram	24.41602800	88.42647200	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS
26	Gogram	24.45786100	88.43875000	MS	MS	MS	MS	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS
27	Matikata	24.44922200	88.34988900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
28	Matikata	24.43636100	88.38036100	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
29	Matikata	24.42783300	88.40002800	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
30	Matikata	24.45177800	88.37830600	MS	MS	MS	SU	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
31	Matikata	24.40361100	88.40063900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
32	Matikata	24.43197200	88.37952800	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
33	Matikata	24.45342356	88.39983619	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
34	Matikata	24.41801718	88.38936656	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO

35	Mohanpur	24.51850000	88.37030600	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
36	Mohanpur	24.54144400	88.38811100	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
37	Mohanpur	24.55586100	88.33141700	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
38	Mohanpur	24.56136100	88.35708300	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO
39	Mohanpur	24.55263900	88.38075000	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
40	Mohanpur	24.54822200	88.37036100	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS
41	Mohanpur	24.54836100	88.39016700	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
42	Mohanpur	24.57533300	88.42255600	MS	MS	MS	MS	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS
43	Mohanpur	24.58661100	88.43700000	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO
44	Mohanpur	24.56255600	88.40550000	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
45	Mohanpur	24.55463900	88.40433300	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
46	Mohanpur	24.59941700	88.38388900	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
47	Pakri	24.55658300	88.47125000	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS
48	Pakri	24.57566700	88.45283300	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
49	Pakri	24.52672200	88.44700000	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS
50	Pakri	24.54127800	88.43566700	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SU	MS	MS
51	Pakri	24.56427800	88.43575000	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS
52	Rishikul	24.50936100	88.48788900	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO
53	Rishikul	24.48686100	88.45377800	MS	MS	MS	MS	MS	SO	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
54	Rishikul	24.47213900	88.46691700	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
55	Rishikul	24.48466700	88.50472200	MS	SU	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SO	MS	MS
56	Rishikul	24.52388900	88.50611100	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	SU	MS	MS	MS	MS
Inaccurate number					4		5		5		4		6		5		6		6		7

Sources: ArcGIS 10.1 model land suitability outputs and observed field data

Notes: OLS = Overall land suitability ML = Model land suitability output OF =Observed field data MS = Moderate suitable MRS = Marginally suitable SO = Slightly overestimated SU = Slightly underestimated LS = Land suitability

Appendix 3. Classified Image Data and Field Data Cross Tabulation

		Field Data							Total
		AL	BL	MV	MW	SB	SV	SW	
Image Data	AL	24	0	0	0	1	0	0	24
	BL	0	2	0	0	0	0	1	3
	MV	0	0	5	0	0	0	0	5
	MW	0	0	0	2	0	0	1	3
	SB	0	0	0	0	5	0	1	6
	SV	0	0	0	0	0	8	0	8
	SW	0	1	0	1	0	0	4	7
Total		24	3	5	3	6	8	7	56

Notes: AL= Agricultural Land SB=Sand Bar BL=Barren Land SV=Sparse Vegetation MV=Moderate Vegetation SW=Swallow Water MW=Medium Water

Appendix 4. Comparison of Classified Image Data and Observed Field Data

Sl.	Union	Image Classification Data	Field Data
1	Basudevpur	SB	SB
2	Basudevpur	AL	AL
3	Basudevpur	AL	AL
4	Char Ashariadaha	AL	SB
5	Deopara	AL	AL
6	Deopara	BL	BL
7	Deopara	MV	MV
8	Deopara	AL	AL
9	Deopara	SV	SV
10	Gogram	MW	MW
11	Gogram	BL	SW
12	Gogram	SW	SW
13	Gogram	SV	SV
14	Gogram	SW	BL
15	Gogram	AL	AL
16	Gogram	AL	AL
17	Gogram	SV	SV
18	Gogram	AL	AL
19	Matikata	AL	AL
20	Matikata	AL	AL
21	Matikata	SV	SV

22	Matikata	AL	AL
23	Matikata	MW	SW
24	Matikata	SW	MW
25	Matikata	SV	SV
26	Matikata	BL	BL
27	Rishikul	AL	AL
28	Rishikul	SB	SB
29	Rishikul	SB	SB
30	Rishikul	SB	SB
31	Rishikul	SB	SB
32	Godagari	SW	SB
33	Godagari	MV	MV
34	Godagari	AL	AL
35	Godagari	MV	MV
36	Godagari	AL	AL
37	Godagari	SW	SW
38	Godagari	MV	MV
39	Godagari	AL	AL
40	Mohanpur	AL	AL
41	Mohanpur	MW	MW
42	Mohanpur	SV	MV
43	Mohanpur	AL	AL
44	Mohanpur	SW	SW
45	Mohanpur	AL	AL
46	Mohanpur	AL	AL
47	Mohanpur	SV	SV
48	Mohanpur	AL	AL
49	Mohanpur	SV	SV
50	Mohanpur	AL	AL
51	Mohanpur	AL	AL
52	Pakri	AL	AL
53	Pakri	SB	SB
54	Pakri	SW	SW
55	Pakri	AL	AL
56	Pakri	MV	MV

Notes: AL= Agricultural Land SB=Sand Bar BL=Barren Land SV=Sparse Vegetation MV=Moderate Vegetation SW=Swallow Water MW=Medium Water

Appendix 5. Symmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Ordinal by Ordinal	Kendall's tau-b	.758	.090	7.314	.000
Measure of Agreement	Kappa	.809	.069	9.440	.000
N of Valid Cases		56			
a. Not assuming the null hypothesis.					
b. Using the asymptotic standard error assuming the null hypothesis.					

Appendix 6. Interpretation of Kappa- Statistic Measure of Agreement

Kappa Statistic	Strength of Agreement
Below 0.0	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost Perfect

Source: Landis and Koch, 1977 (P. 165)

Appendix 7. Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	285.430[a]	36	.000
Likelihood Ratio	103.255	36	.000
N of Valid Cases	56		
a. 45 cells (91.8%) have expected count less than 5. The minimum expected count is .02.			

Appendix 8. Questionnaire

Code No:

Questionnaire Survey for "Land Suitability Analysis for Sustainable Agricultural Development in Rajshahi District of Bangladesh"

(Data of questionnaire will be used only for PhD research)

(Bangla version of questionnaire has been used during data collection)

Section A. Basic Information

Information of the Interviewer		Information of the Respondent				
Name:		Name:		Educ Qualification:		
Identity:		Father's Name:		Mauza :		
Session:		Age:		Union:		
Institution:		Gender:		Farm Size:	0.05-2.49/2.50-7.49/7.50 acre & above	
Date:		Cell No.		Agric Training	Yes/No	(If Yes)……days

Section B. Appraisal of Economic Viability

1. Per 33 decimals production, prices and total revenue of the crops that you produced in the last year (*rabi* Season: 16 October, 2014 – *kharif* 2: 15 October, 2015)

Sl	Name of Crops	Per 33 Decimals Production(40 kg)	Prices of Per 40 kg	Total Price	By-Products	Quantity (bundle/kg)	Prices of By-Products	Total Revenue
1	*T. Aus*							
2	*T. Aman*							
3	*Boro*							
4								
5								
6								
7								
8								

2. Per 33 decimals production costs of the crops that you produced in the last year.

Sl	Costs	*T.Aus*	*T.Aman*	*Boro*							
1	Land Preparation(Tillage, Leveling, Ridging) Costs										
2	Seedling Costs										
3	Planting Costs										
4	Fertilization Costs										
5	Pest management Costs										
6	Weeds Control Costs										
7	Irrigation Costs										
8	Harvesting, Drying, Transportation, Threshing Costs										
9	Transport and Labor Costs for Sale										
10	Land Rent/Lease Cost										
11	Other Costs										
Total Costs											

Section C. Perception (Knowledge) Study

1. Are you acquainted with land suitability?

yes ☐ no ☐

2. If yes, to you land suitability is—

well known ☐ Moderately known ☐ Neutral ☐ little known ☐ Very little known ☐

3. Land suitability is cultivation of proper crop for optimum yield according to soil, irrigation water, climate, topography, floodability, and accessibility attributes.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

4. You know that soil is of acid soil and alkaline soil.

yes ☐ no ☐

5. Crops selection depending on acid soil and alkaline soil will increase production.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

6. Crop selection depending on soil organic matter leads to optimum yield.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ don't know ☐

7. You know about the macronutrients of soils—

yes ☐ no ☐

8. Balance of macronutrients (nitrogen, phosphorus, potassium, and sulfur) in soil leads to potential yield.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

9. Balance of micronutrients (zinc, and boron) in soil leads to optimum yield.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

10. Selection of crop based on land type- high land, medium high land, medium low land, low land, and very low land is necessary for potential yield.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

11. For maximum production, crop should be selected based on soil texture-sandy soils, clayey soils, and loamy soils.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

12. To select proper crop to get maximum yield soil test at times is imperative.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

13. Crop selection depending on water quality can give good production.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

14. Crop should be selected which require less water in *rabi* season.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

15. Very high and very low temperature of irrigated water in summer and winter season has impact on potential yield of cultivated crop.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

16. To select proper crop for getting maximum yield water test at times is imperative.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ neutral ☐

17. Cultivation of crop suitable to monthly average temperature, suitable to winter critical temperature (<18 c), and summer critical temperature (>35 c) can increase potential yield.

well known ☐ known ☐ moderately known ☐ Little known ☐ neutral ☐

18. Selection of crop based on monthly total rainfall is necessary.

well known ☐ known ☐ moderately known ☐ Little known ☐ neutral ☐

19. Farmers have deficiency of knowledge to cultivate lands as per land suitability.

Very much ☐ Moderate ☐ little ☐ very little ☐ neutral ☐

20. Use of chemical fertilizer is necessary for crop production in the present soil condition.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ Neutral ☐

21. Use of chemical fertilizer instead of organic fertilizer is not too much harmful to crops.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ Neutral ☐

22. Extensive use of insecticide is harmful to sustainable agriculture.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ Neutral ☐

23. Crop diversification and cropping pattern changes according to land suitability is necessary for sustainable agriculture.

strongly agree ☐ agree ☐ disagree ☐ strongly disagree ☐ Neutral ☐

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Thanks for your kind cooperation.

Appendix 9. Photos

1. Model Output Verification

2. Classified Image Verification (later)

3. Rice Field

4. Agriculture Transformation: From Rice to Ber

5. Agriculture Transformation: From Rice to Thai Guava

6. Agriculture Transformation: From Rice to Tree (Mahogany) Plantation

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