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Master's Thesis

**Sustainability of Agriculture Land Use in Eastern Bhutan
In Relation to Climatic, Topographic and Social Factors**

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Submitted in September, 2011

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Approval

As principal supervisor, I hereby approve this thesis “**Sustainability of Agriculture Land Use in Eastern Bhutan in Relation to Climatic, Topographic and Social Factors**” is prepared and submitted by Loday Phuntsho in partial fulfillment of the requirements for the Master’s degree in Sustainability Science.

Professor Takashi Oguchi

Date.....

Declaration

I hereby declare that this Master's Thesis contains presentation of my original work. However, wherever contributions of others are involved, every effort is made to indicate or acknowledge them either through citations, references to literature or acknowledgements. I declare that the thesis has not been submitted to any other institution for the award of any academic degree, diploma or certificate.

Loday Phuntsho

Date.....

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Abstract

Agriculture provides livelihood to about 70% of the people in Bhutan. Therefore development of agriculture is a central policy of the nation. In recent years agriculture land in Bhutan and elsewhere has often been abandoned or changed to other forms. Worldwide it is recognized as a result of complex interactions among climatic, topographic and socio-economic factors although findings differ according to the place, scale and land use. Hence, this study examines the impact of these factors on three common types of agriculture land use in Eastern Bhutan: dry land, mixed land and wet land.

Vector land use data for 1994 and 2005 were arranged into those with the same categories, and their change in area between the two periods was analyzed. It was observed that all the three types of agricultural land use had decreased; with mixed land fastest and wet land slowest. For detailed analyses, the land use data for 2005 were converted into raster data. Then climatological data (temperature, rainfall and the moisture index), topographic data (elevation, slope, aspect, and distance to river), soil data and social data (distance to town, distance to road and rural population) were extracted in raster. All these operations were conducted using ArcGIS 9.3.1, a GIS software package. Then a binary logistic regression was used to build a predictive model of the probability of land use occurrence in each sampled grid cell using the climatic, topographic, soil and social data as predictor variables. Finally to study the potential impact of climate change, the probability of agriculture land use in the year 2050 was predicted using the projected climate data.

This study shows that agriculture land use is affected by the combination of climatic, topographic and social factors indicating the need for a holistic approach for its sustainability. The climate variables including temperature and rainfall play a greater role in determining land use, pointing to the vulnerability of agriculture to climate change. The three types of land use were affected differently: wet land was found to be the most sensitive to climate, while dry land the least. It was also observed that changes in temperature and rainfall tended to differ by locations. Thus understanding of both global and local physiographic conditions is useful for adaptation to future climatic change. The knowledge about land use and its controlling factors is

essential for the sustainable use of land resources. Hence, this study has provided useful inputs to the policy makers and land managers in Bhutan.

Keywords: Agriculture land use, Eastern Bhutan, Climate variables, Food security, Sustainability

List of Acronyms

AD:	Agriculture Dry Land
AEZ:	Agro-Ecological Zone
AM:	Agriculture Mixed Land
AUC:	Area Under Curve
AW:	Agriculture Wet Land
BO:	Bhutan Observer
CIAT:	Centro International de Agricultura Tropical
DA:	Discriminant Analysis
DANIDA:	Danish International Development Agency
DEM:	Digital Elevation Model
DRUK DIF:	Druk (Bhutan) Dynamic Information Framework
FAO:	Food and Agriculture Organization
GDP:	Gross Domestic Product
GIS:	Geographical Information System
IPCC:	Inter-governmental Panel on Climate Change
LUPP:	Land Use and Planning Project
MoA:	Ministry of Agriculture
MW:	Megawatt
NSB:	National Statistical Bureau
NSSC:	National Soil Services Centre
PPD:	Policy and Planning Division of the Ministry of Agriculture
RC:	Research Centre
RMSE:	Root Mean Square Error
RNR:	Renewable Natural Resources
ROC:	Receiver Operating Characteristics
SPOT:	Satellite Pour l'observation de la Terre (French Satellite)
SRES:	Special Report on Emission Scenarios
UNESCO:	United Nations Educational, Scientific and Cultural Organization
WFP:	World Food Program

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1. Introduction

1.1 Background

Reliable food production on sustainable agricultural land is highly important to feed the world's population. Agriculture, however, often has a negative impact when practiced without regard for environmental conditions (Chang, 2007). Today 49% of the world's population lives in urban areas. By 2050, it will reach 70% which could pose a serious problem of food supply (FAO, 2009). We live in a world with growing human population but possibly shrinking land resources. Since the dawn of the 21st century, the global communities have recognized and understood the enormous challenges of feeding the increasing global population using limited land resources (Lal, 2001). Demand for food will further increase in the 21st century (Ewert et al., 2005) which can only be met through increase in agricultural production area or production per unit area (productivity). Researchers argue that the scenario is even more difficult for the developing world as there is higher population pressure on land resources due to smaller landholding size and deteriorating quality of land (Paudel and Thapa, 2004). Further, many developing countries have limited capacities in terms of infrastructures and financial resources to cope with such situations.

The long held view that land is an infinite resource is no more valid. Today land resource is under threat both in terms of quality and quantity. The protection of agriculture land from the scourge of urbanization, degradation and climate change has never been felt more important than today. However, land resources are finite and often scarce, and there may be growing competition among various land uses. World's population is increasing rapidly but essential natural resources such as land and water are declining both in quantity and quality (Patel, 2005). For example Rounsevell et al. (2003) observed that in Europe agricultural land use has already declined by 13% over the last four decades. Asia also has limited availability of new arable land to feed the growing population. In Africa climatic conditions, poor infrastructures and limited capacity restrict the expansion of arable land.

Although countries across the world seek for industrialization, the role of agriculture as an engine of growth cannot be ignored. For example Datt and Ravallion (1996) observed that in India improved agriculture had led to poverty reduction both in rural and urban areas. Tiffin and Irz (2006) have found agriculture as an important cause of economic growth, and concluded that economic growth cannot be sustained without improving agricultural productivity. Tsakok and Gardner (2007) used a Popperian approach to study the impact of agriculture on growth in both developed and developing countries. Their study showed that in England and China industrialization depended on agricultural development, whereas in the US and South Korea although no direct causal relationship was observed, even there industrialization did benefit from agriculture development. Gollin (2009) also observed the important role of agriculture on growth in Africa, particularly in land locked countries with less potential of importing agricultural products. Economic development will be difficult if large sections of the society live in the risk of food insecurity. In the 21st century, agriculture continues to be fundamental for sustainable development and poverty reduction (World Bank, 2008).

The sustainability of agricultural production system is becoming a major concern of researchers and policy makers in both developed and developing countries (Medugu, 2006). O'Callaghan (1995) states that understanding relationships between land use types and their determinants contributes to sustainable land-use planning. Knowledge about current land use is needed also for the sustainable use of resources (Janetos and Townshend, 2005).

At global level, diverse literature discusses the role of social, cultural, economic and ecological factors that influence agricultural land use but they differ as per the context, scale and nature of land-use types. The determinants of agriculture land use include access to road and/or markets (Turner et al., 1994), availability of rural population for labor (Walsh et al., 2001), fertility of soil (Sanchez, 1976) and terrain characteristics (Schreier et al., 1994). Ballayan (2007) adds that land use is generally determined by socio-economic market forces and climate and topographic constraints. Xie et al. (2005) has argued that no single set of factors can explain land-use changes in different places subject to different driving forces. Skole and Tucker (1993) also indicated that various factors including human activities, soil characteristics, climate, topography and vegetation affect the spatial pattern and change of land use. There is also growing realization that

rapid land use change results from political and economic influences as well as changes in the physical environment such as climate (Rounsevell et al., 1997). A study conducted by 26 researchers representing various disciplines have argued that global scale assessment on land use may conflict with findings from micro- or meso-scale data sets specific to particular time and place (Lambin et al., 2001).

Because of the above-noted complexity, conventional multiple regression models have often been used to examine relationships between land use and socio-economic/physical factors; for example, in Costa Rica (Veldkamp and Fresco, 1997), Ecuador (de Koning et al., 1999) and China (Verburg et al., 1997). The studies have indicated that the results differ by region, spatial scale and the nature of the agriculture land use. Such differences may be enhanced in mountainous systems with ecological, economical and cultural diversity under the extreme topographic and climatic conditions that make the systems highly instable, fragile and sensitive (Alewell et al., 2008).

This study deals with the sustainability of agriculture land use in Bhutan, because the country presents a good opportunity to study and discuss the sustainability of agriculture land use and its controlling factors, but has few detailed studies on the topic. A sustainable agriculture land use is one that is less vulnerable to shocks and stresses and assures farmers' production with dynamic efficiency. In the country about 70% of population engages in agriculture and in recent years, pressure to abandon agricultural land or change it into other forms has been a big challenge. It has huge implication on not only food security and livelihood but also the future development of the nation. Serious challenges for the sustainability of agriculture land use include drought and disease related to climate variability, rural-urban migration and remoteness from commercial areas. In many fields, Bhutan is still in an initial phase of development with modernization started only since late 1960s, and in many respect it is yet to experience the challenges some other countries had already been through. In addition, one of the main policies of the government is making rural livelihood productive and sustainable.

1.2 Literature review on challenges of agriculture in Bhutan

The governmental policy of Bhutan recognizes that the agriculture sector is the mainstay of economy and will continue to remain so in the near future (MoA, 2009). However, there are relevant challenges such as urbanization, land degradation, pest and diseases, wildlife predation, labor shortage (MoA, 2009), climatic change (Thapa, 2008) and land fallowing (RC Wengkar, 2008). In Bhutan, extension of arable land may not be feasible because of the steep terrain and the constitution that requires the government to maintain 60% forest cover. This affects the food security and income of a large section of the society. About one-third of the Bhutanese population suffers from food insecurity. They depend on imports for 34% of cereal needs, which include 51% of rice imported from India (Dema, 2009).

In 2005, Bhutan was losing about 404.9 ha of paddy fields annually for development activities, natural disasters and regeneration of forests (Dema, 2009). Loss of agriculture land at this rate will have serious implications on the governmental plan to achieve 70% food sufficiency and increase national food production (BO, 2011). In Eastern Bhutan, for example, out of about 3,600 ha of wetland, 483 ha were left fallow in the past decade and if this trend continues, Bhutan may not have wetland in about seven decades. Limitations in accessibility, irrigation, technical and economic policies and environment conditions are mentioned as possible reasons (RC Wengkar, 2008; Wangdi, 2009). Also agriculture in Bhutan is heavily dependent on monsoon rainfall because 70% of agricultural land is rain-fed (Wangdi, 2011).

The existing literature, however, is mainly qualitative without strong scientific evidence. Several existing studies based on realistic empirical approaches focus mainly on land degradation. For instance, Turkelboom et al. (2001) and Norbu et al. (2003) studied about land degradation and its impact; Myint and Thinley (2006) mapped land degradation potential with respect to topographic and geologic factors; Gyeltshen (2010) studied the role of socio-economic changes on land degradation in two rural communities of eastern Bhutan and (Yeshey, 2010) about comparative assessment of two types of land management approaches. However, agriculture land use is affected by many factors besides land degradation. Only Gosai (2009) studied relationships between land use change and relevant factors in the vicinity of capital city Thimphu. However, the study focused mainly on change in forest cover in relation to political, cultural and economic

frameworks as the city developed over the years. However, in the case of agriculture land use, climate and topography also play an important role. Hence, the existing studies have either focused solely on land degradation or considered only limited factors. Moreover, these studies studied land as a whole, not categories of agriculture land use. Therefore, it is necessary to conduct a detailed study taking into account many factors and modeling the dynamics of agriculture land use change for future sustainability. Such a study will contribute to future sustainability of agriculture in Bhutan, which is vital for livelihood of rural people as well as the development of the country.

Within Bhutan, the eastern region is one of the major agricultural zones where in recent years drought, disease, land fallowing and resultant decline in agriculture land use have been reported, although detailed studies about them are lacking. Therefore, this study takes eastern Bhutan as a case study area.

1.3 Research objectives

Many studies cited in the literature reviews above indicate that land use change is a result of complex interactions among a number of climatic, topographic and social factors. These studies have also revealed that the results could differ by location, spatial scale of the study area and nature of the agriculture land use. Studies in mountainous regions have been limited, although they are unique in their ecology, economy and cultural diversity because of the topographic and climatic conditions of the ecosystem. Paudel and Thapa (2004) state that ecological conditions of the mountain areas vary significantly even within short distances. Therefore, in mountainous eastern Bhutan, the potential impact of climatic, topographic and social factors on agriculture land use needs to be investigated in detail.

This study is based on the hypothesis that:

- Climatic, topographic and social factors can explain the distribution and change of agriculture land use with statistical significance, and understanding its mechanism will contribute to the sustainability of agriculture land use.

Therefore, the objectives of this study are:

- To study how climatic, topographic and social factors affect different types of agriculture land use, and
- To identify influential factors and predict potential future scenarios.

2. Study area

2.1 Country profile

Bhutan is a small country in the Eastern Himalayas with a total geographical area of 38,394 km² and population of 683,407 (NSB, 2009). The country is bordered by India to the East, South and West, and the Tibet Autonomous Region of China to the North and North West. Bhutan's terrain is almost entirely mountainous. Within a short distance of 170 km from South to North, elevation rises from about 88 m to above 7,500 m above sea level (a.s.l). Of the total geographical area, 38.4% of the area lies between 2,400 to 4,200 m a.s.l, 35.8% between 600 and



Figure 1: Location of Bhutan

2,400 m and only 5.3% below 600 m a.s.l. The Southern Foothills consist of narrow belts of flat land bordering India; the Inner Himalayas mainly consist of river valleys and steep mountains; and snow-clad mountains and alpine meadows make up the Higher Himalayas. The southwestern monsoon from the Bay of Bengal accounts for 60% to 90% of the annual precipitation. The monsoon usually starts from June and lasts until early September. Mean annual rainfall varies from approximately 2,500 to 5,500 mm in the Southern Foothills, 1,000 to 2,500 mm in the Inner Himalayas, and 500 to 1,000 mm in the Higher Himalayas.

Bhutan is principally based on an agrarian economy. It mainly concerns three key components of the Renewable Natural Resources (RNR) sector which comprises of agriculture, livestock and forestry. In Bhutan, the installed hydropower with a capacity of 1,488 MW accounted for 25.8%

of the GDP in 2007. The contribution of RNR sector to the GDP in the same year was 17.1% and it has been decreasing mainly due to the growth of hydro-power industry. However, the hydro-power sector generates less than 5% of the total employment in the country whereas the RNR sector accounts for more than 60%. Therefore, the RNR sector is crucial for the sustainability of the labor and society.

2.2 Study area

Eastern Bhutan consists of six districts and is mostly characterized by rugged terrain and remoteness. Its elevation ranges from 88 m a.s.l in the south to more than 6,000 m a.s.l in the north within a distance of about 140 km. Eastern Bhutan accounts for about 40% of the country's population and most of them are engaged in farming. Maize, rice and potatoes are three main crops there and subsistence farming without using chemical fertilizers is common although the situation is slowly changing due to developmental activities by the government. The majority of agricultural land (57.3%) is located at 1200–2100 m a.s.l followed by 33.7% at ≤ 1200 m. In terms of slope, agriculture is concentrated between 20-33 degrees (41.3%), and 28% between 10–20 degrees. Only 15% of agricultural land is below 10 degrees although in other places it is often considered most suitable for farming. Therefore, settlements in Bhutan are often scattered in remote mountainous terrains, which is huge challenge for development (Wangchuk, 2008).

Over the years, agriculture in Eastern Bhutan has been challenged by various problems such as drought, flash floods, pests and diseases that were never observed before (Wangdi, 2009; Namgyal, 2010). For irrigation farmers depend heavily on monsoon rains. Rice production in Radhi which is often referred to as the rice bowl of Eastern Bhutan, decreased by more than 30% in 2009 because of late rainfall. Farmers said they have lost rice production due to dry spells every two years (Wangdi, 2011).

A study observed that 51% of the total rice consumption in 50 of the 69 blocks in the six eastern districts of Bhutan is imported. The study also mentions that 482.6 out of about 3600 ha of wetland in six districts have been laid fallow in the past ten years (RC Wengkhar, 2008). Chettri (2010) states that malnutrition, low food availability and poverty are concentrated in the eastern and southern rural parts of the country. Another study shows that five out of the six eastern

districts fall within the 10 districts most vulnerable to food insecurity in the country. Food security and income generation, two crucial elements of poverty are mainly dependent on agriculture (MoA/WFP, 2005).

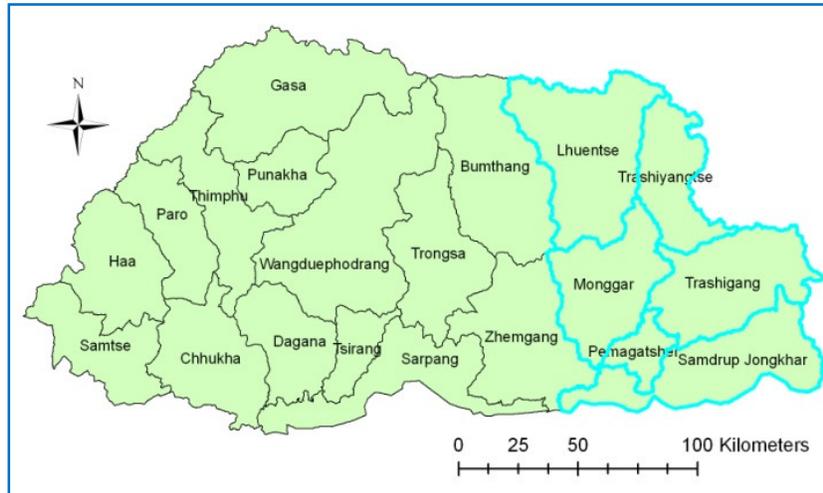


Figure 2: Administrative map of Bhutan highlighting the study area

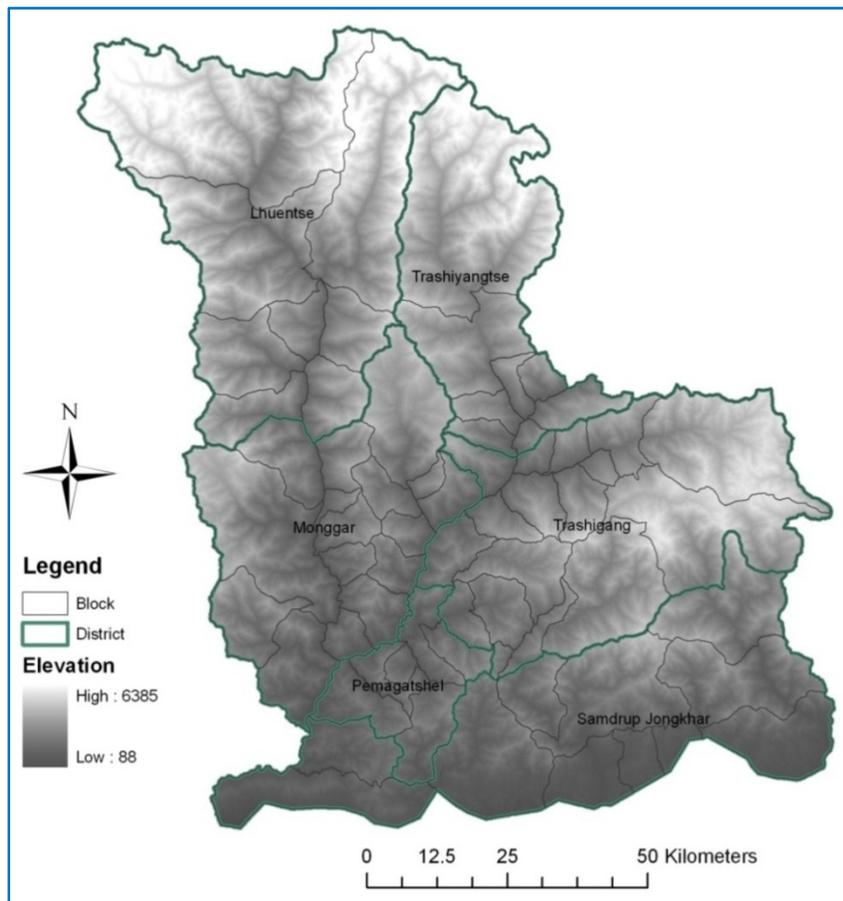


Figure 3: Study area: Eastern Bhutan

3. Data and methods

3.1 Data

Most data used in this research were obtained from governmental institutes in Bhutan. The rest were from open access data sources. Three types of data are used: land use, physical and social data.

3.1.1 Land use

In this study land use data for years 1994 and 2005 are used. The data were obtained from the GIS section, RNR Research Centre, Wengkhar in Eastern Bhutan, Ministry of Agriculture and Forests. For this study three types of agriculture land use are used: 1) dry land dominated by maize and sometimes wheat; 2) mixed land with combination of maize, vegetables, and some other crops; and 3) wet land with rice cultivation. The 1994 land use data were developed by the Land Use and Planning Project (LUPP) of the Ministry of Agriculture with financial support from DANIDA using SPOT satellite images. The 2005 land use data were also developed from SPOT images with additional field verifications. The land use data for both years are in 30 m resolution. The projection system used for these data is shown in Table 1:

Table 1: Parameters of the map projection system used for the land use data

Projection system	Polyconic Projection
Unit	Meter
Datum	Everest 1956 Spheroid
Central meridian	90
Latitude of origin	26
False Easting	2743196.5 m
False Northing	914398.8 m

Source: Myint and Thinley (2006)

3.1.2 Climate

The climate data consist of temperature and rainfall. The data were recorded at 24 weather stations located across eastern Bhutan, and obtained from the Watershed Division of the Ministry of Agriculture and the Forests, and Hydromet Division of the Ministry of Economic Affairs. The temperature data include daily minimum and maximum temperatures. The rainfall data consist of daily rainfall. All these data were recorded manually using thermometers and rain gauges. Although most data used for this study are for 1985 to 2005, some are available only from the 1990s. In addition, the moisture index was computed from the given temperature and rainfall data using the method of Wu and Huffer (1997).

3.1.3 Predicted climate

In order to study the likely impact of climate changes in the future, the predicted climate data for the year 2050 were obtained from the website of the Centro Internacional de Agricultura Tropical/International Centre for Tropical Agriculture (<http://ccafs-climate.org>). The data were originally developed using the CLIMGEN model developed by researchers at the University of East Anglia (CIAT, 2011). The data used reflect the A1B SRES scenario of the IPCC which assumes balanced use of all energy sources.

3.1.4 Soil

The soil data were obtained from the DRUK DIF (<http://www.drukdif.ocean.washington.edu>) of Washington University, extracted from the Global FAO/UNESCO database 1995. However, the soil data are generic and lack details.

3.1.5 Topography

The topographic data analyzed include elevation, aspect, slope and distance from the river. The first three data were derived from the ASTER GDEM provided by the Earth Remote Sensing Data Analysis Centre (<http://www.gdem.aster.ersdac.or.jp>). All these data are of 30 m resolution. The distance from the river data were obtained from the ArcIMS Server of the National Statistical Bureau of Bhutan (<http://www.nsb.gov.bt/index.php?id=9>).

3.1.6 Social data

Social data comprise of distance to road, distance to town, rural population and legal/political framework. Distance to road, distance to town and rural population were derived from the ArcIMS Server of NSB. These data are available only for the year 2005. The legal/political framework data include the Land Act, Forest and Nature Conservation Act, Biodiversity Act, Urban Act and Decentralization Policy. These were obtained from various sources and official websites of the government.

3.2 Methodology

Change in agriculture land use is considered as a function of climate, social, soil and topographic factors. However, choice of explanatory/predictor variables is important for statistical analysis. In this study ten explanatory variables are used to model the land use change. In order to select these variables, existing literature was reviewed. Views of the agriculture personnel working in the study area were also sought. Existing reports and newsletters by various agencies and offices dealing with the study area also provided useful information. Reading various newspapers to understand problems farmers are facing was also very useful for identifying the possible explanatory variables. In addition, a number of similar studies conducted by researchers in other countries were also helpful in identifying and selecting the variables. Hence, the selected variables are annual rainfall, annual temperature, moisture index, elevation, slope, aspect, distance to road, distance to town, distance to river and rural population. The soil data were arranged but were not used for final analysis because the data are generic and they showed collinearity when statistical analysis was performed. The legal/political framework was also not used because its conversion into effective spatial data was difficult.

The binary logistic regression method is used to model how these factors can explain changes in the three types of agriculture land use in Eastern Bhutan. ArcGIS 9.3.1 was used for extracting and processing the explanatory/dependent factors, and the Stata software was used to perform logistic regression. Fig. 4 is the flow chart of the methodology of this study.

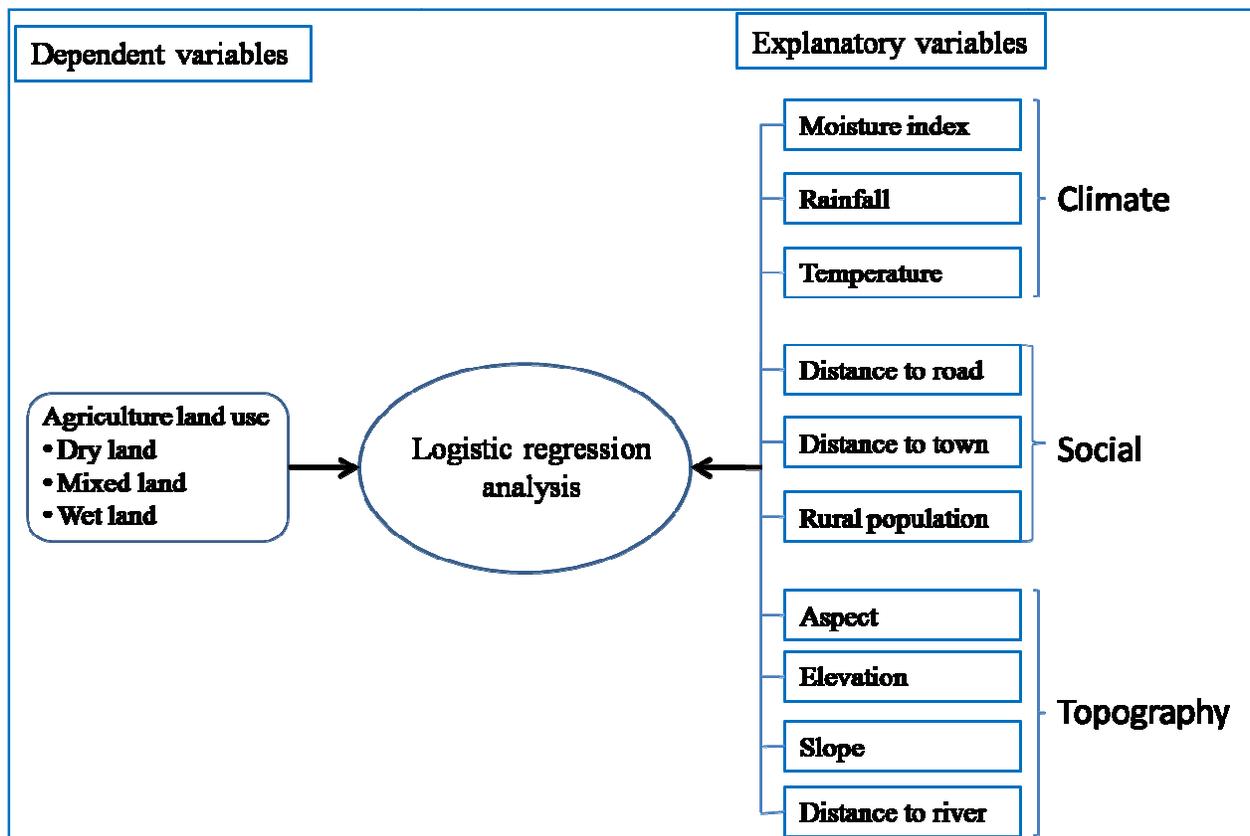


Figure 4: Methodological flow chart

3.2.1 Data processing

Land use data for 1994 and 2005 were in vector format. Some of the categories used in the data for 1994 and 2005 were not the same. For example the 1994 data have more detailed land use types about crops than the 2005 data. Hence, the detailed land use types were grouped into dry land, mixed land and wet land. Figs. 5 and 6 below show the agriculture land use data for 1994 and 2005 respectively. The area of each land type was calculated for both years so as to analyze temporal change in land use extent. For further analysis, these land use data were rasterized with the cell size of 30 m.

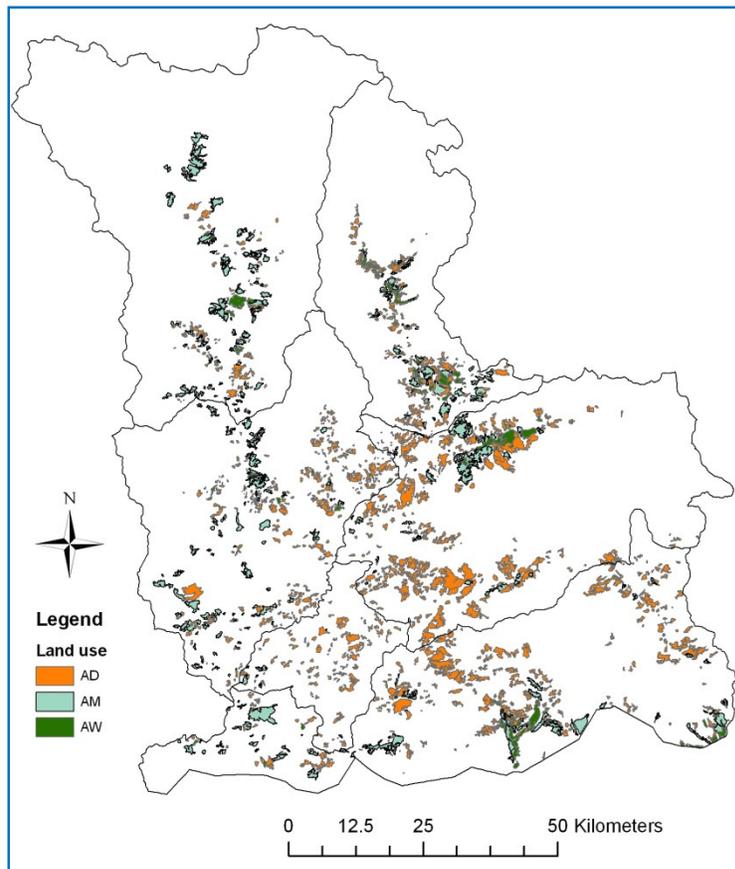


Figure 5: Agriculture land use in 1994

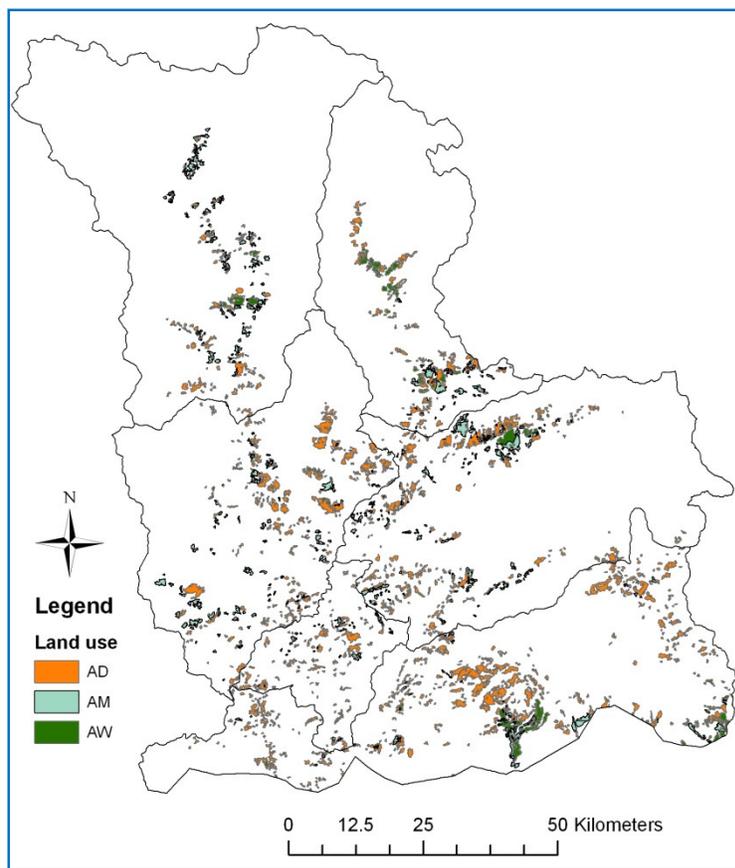


Figure 6: Agriculture land use in 2005

Mean annual and seasonal (spring, summer, autumn and winter) temperatures for 24 weather stations were calculated from the minimum and maximum temperature data. Similarly mean annual and seasonal rainfall values were estimated. In order to map weather stations and interpolate the temperature and rainfall data, latitude and longitude information for the stations were used (Fig.7).

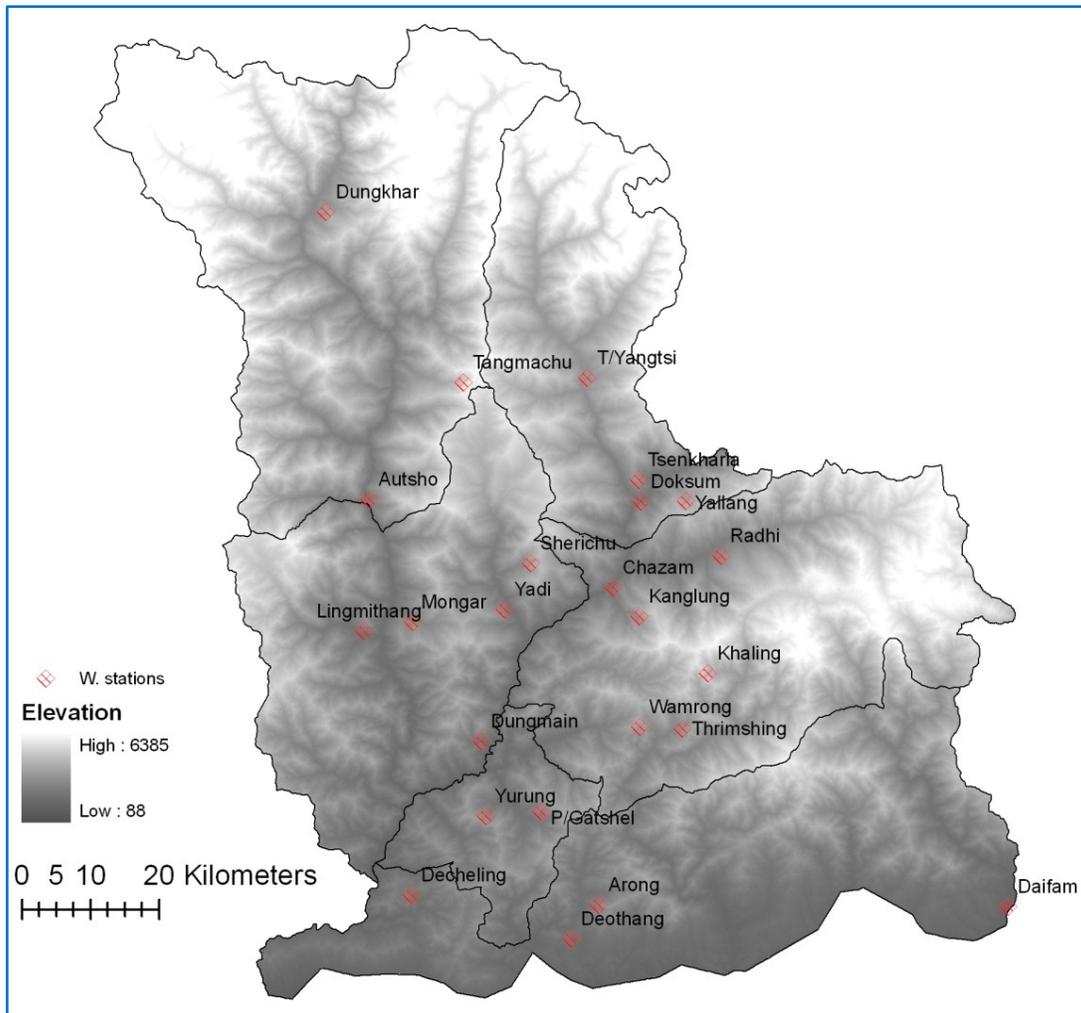


Figure 7: Location of 24 weather stations in the study area

To provide maps of climate for the whole study area, the data was interpolated. Different methods of interpolations including inverse distance weighting, ordinary kriging, co-kriging with altitude, co-kriging with altitude and aspect, and elevationally detrended kriging were performed and their RMSE (root mean square error) and standardized RMSE were compared. Among the

five methods, elevationally detrended kriging had the smallest RMSE (1.534) and standardized RMSE (0.927) for the interpolation of temperature data because it is strongly dependent on elevation. This confirms results of Li et al. (2003). Hence, this method was used for the interpolation of temperature data as follows:

1. The linear regression relationship between the observed temperature and elevation was obtained.
2. The obtained elevation trend was removed by subtracting values from the observed temperature. In other words residuals were calculated.
3. The residuals were interpolated by using the ordinary kriging module in the Geostatistical Analyst extension of ArcGIS
4. The DEM and the regression relationship were used to get linear regression relationship at all locations
5. Finally temperature data for the whole study area were obtained by adding the results of 3) and 4).

In the case of rainfall data, the simple kriging method was used for interpolation instead of the elevationally detrended kriging because the correlation coefficient between rainfall and elevation was only 0.49, and Goovaerts (2000) suggested that for precipitation data the simple kriging gives the better result when the correlation coefficient is less than 0.75.

The interpolated temperature and rainfall data were used to calculate the moisture index (*MI*) using the formula of Wu and Huffer (1997):

$$MI = PRCP / 58.93TAV \dots\dots\dots (1)$$

where *TAV* = mean annual temperature in degrees Celsius, and *PRCP*= mean total annual precipitation in mm. The value of $58.93TAV$ corresponds to the mean annual potential evapotranspiration estimated by the Holdridge method.

The files of ASTER GDEM were mosaicked into a single raster dataset for the study area and the projection of the data was converted into polyconic system using the parameters shown in Table 1. Other secondary data like aspect and slope were derived from the DEM using surface analysis function of the ArcMap.

The river data used are in vector format. First line buffers were created around the rivers. Then distance from the sample points to the river was calculated using ArcMap and results were saved in raster.

Social data including roads, towns and rural population are all in vector. In the case of roads and towns, buffers were created around the roads and towns and then distance to road and that to town from sampling points were calculated using ArcGIS and saved as raster data. The rural population data were also converted into raster data.

Once the data were processed, sampling points for logistic regression were selected using two ArcGIS extensions: “Grid Extract Tool” freely downloadable from the Precision Agriculture Software and Resources (http://www.cse.csiro.au/client_serv/paresources.htm) and the “Hawth’s Analysis Tools” from (<http://www.spatial ecology.com/htools/tool desc.php>). In order to avoid spatial autocorrelation, the points were randomly selected. In the case of dry land, 1499 points inside dry land and 1499 points outside of it were selected; for mixed land 998 points inside and also outside; and for wet land 800 inside and also outside. The sample numbers for the three types of land use are different depending on the extent of each type.

The attribute tables of the climate, topographic, soil and social data corresponding to the sampled points were converted into the Excel format for analysis in the Stata software.

3.2.2 Logistic regression model

Logistic regression is a variation of standard regression. It can be binary, ordinal or multivariate. Logistic regression is very useful when the dependent variable is dichotomous (1 or 0; yes or no; and occurrence or non-occurrence). In such a case, standard regression and discriminant analysis (DA) are less effective due to strict assumptions such as linearity, normality and continuity for the former and multivariate normality for the latter. Logistic regression has been widely used for analyzing binary variables (Hosmer et al., 1997). Independent explanatory variables can be continuous, categorical or both.

Logistic regression is expressed in terms of probability. For example in the present study, it gives the probability of land use occurrence as a function of explanatory variables. The dependent variable (Y) in logistic regression is the logarithm of the odds of the probability (p) of occurrence ($Y=1$) to that of non-occurrence ($Y= 0$) which is normally called logit.

$$\text{Odds (probability) of occurrence} = p / (1 - p) \dots\dots\dots (2)$$

$$\text{logit} = \ln(p/(1-p)) = a + bX_1 + cX_2 \dots\dots\dots (3)$$

where $X_1, X_2 \dots$ are dependent variables and $a, b \dots$ are constants.

Finally to get the probability equation, logs are taken out from both sides of Equation (3) and then converted odds to simple probability as given below:

$$p/(1-p) = e^{a+bX} \dots\dots\dots (4)$$

$$p = e^{a+bX} / (1 + e^{a+bX}) =$$

$$p = 1 / (1 + e^{-(a+bX)}) \dots\dots\dots (5)$$

where e is the natural logarithm (= ca.2.72).

Unlike the normal regression method, the relation between p and X is nonlinear. Thus coefficient b does not have a straightforward interpretation. For easier interpretation, the coefficient has to be converted to odds ratio which is an exponential function of the given coefficient:

$$\text{odds ratio} = e^b \dots\dots\dots (6)$$

In normal regression, R^2 indicates how powerful the model is in predicting the variable. For logistic regression, however, a log likelihood ratio test is useful to indicate the power of the model. Therefore, a chi-square test between the null model and the model including explanatory or predictor variables is conducted.

In this study logistic model was used because it can 1) analyze the binary presence or absence of land use (e.g., Gobin et al., 2002), 2) handle categorical data like aspect (N, NE, etc.) and slope classes (<10; 10-20, etc.), and 3) work without the assumptions of normality (Xie et al., 2005). Non-parametric statistical methods that capture non-linear relationships and expose interactions among predictor variables have been developed (D'eath and Fabricus, 2000; Kelly and Meentemeyer, 2002), which can be used with logistic regression.

The drawbacks of the method include: 1) the interpretation of coefficient is not straightforward and they need to be converted to the odds ratio for meaningful interpretation and 2) it needs large sample size to obtain stable results.

3.2.3 Data analyses

Data were imported into the Stata software and were divided into two equal sub-samples: one as a training sample and the other as a test sample for cross-validation. Stata can randomly divide samples into two, which is useful for this study. Then logistic regression analysis was performed by regressing the logit of agriculture land use for 2005 against the explanatory variables, and the odds ratio was obtained to evaluate the effect of each explanatory variable. In addition, a number of post diagnostic analyses were performed to determine the model fitness. Correlation and Receiver Operating Characteristics (ROC) graphs were also generated to explain the results. Finally the probability equation obtained by logistic regression analysis was used to develop probability maps of dry, mixed and wet land use. In order to predict likely future scenarios, temperature, rainfall and the moisture index for 2050 was used to develop future probability maps as mentioned earlier and compared them with the current situation. All these operations were performed using raster calculator functions of ArcGIS.

4. Results and discussion

4.1 Agriculture land use

The land use data and the DEM revealed that in Eastern Bhutan, the majority of agriculture is practiced between 1,200 to 2,100 m a.s.l with 58% of dry land, 65% of mixed land and 49% of wet land falling in this region. In terms of slope, 47% of dry land, 45% of mixed land and 33% of wet land is practiced between 20 and 33 degrees. These observations indicate that agriculture

is practiced in relatively higher and steeper places. It is observed that over the years agricultural land use in Eastern Bhutan has decreased: from 1994 to 2005 the region has lost 58.27 km² of dry land; 106.2 km² of mixed land and 0.92 km² of wet land (Fig. 8). These are big losses since Bhutan has very limited arable land; the total agriculture

land is only 2.93% of the total area of Bhutan (NSSC/PPD, 2010). Fischer et al. (2005)

have predicted that Agro-Ecological Zone (AEZ) in Asia including Bhutan is likely to decrease by 20–70% by 2080 due to climate impact. This will directly affect the food security and livelihood of the rural people because farming is their main occupations. In Bhutan, rural areas account for 90% of the total poverty (MoA, 2009) and the Eastern Bhutan is considered one of the food insecure areas (MoA/WFP, 2005). Therefore, decline in agricultural land use deserves greater attention because it has serious implications.

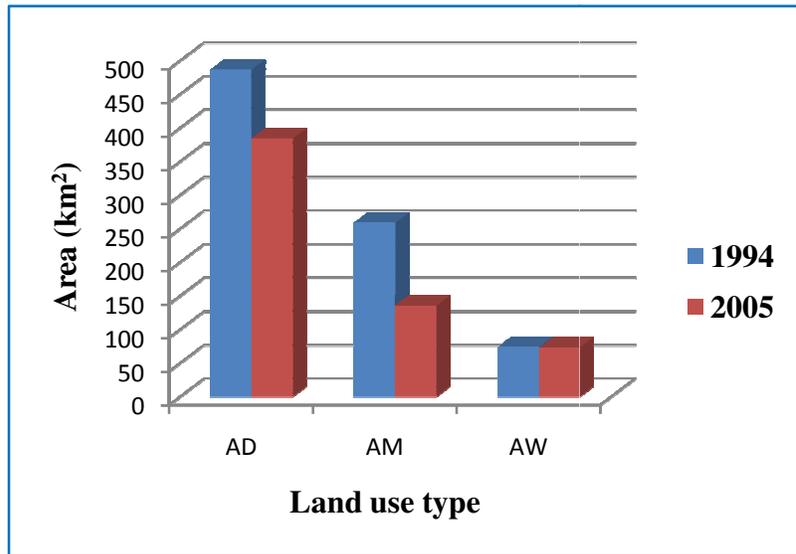


Figure 8: Comparison of the extent of agriculture land use between 1994 and 2005

4.2 Climate

The climate data for 1985 to 2005 indicate that over the years temperature has increased by about 0.7°C. This is comparable to an earlier study that indicates an increase of 0.5°C for Bhutan from 1985 to 2002 (Tse-ring et al., 2010). In contrast, rainfall in the study area tended to decrease. Although both temperature and rainfall indicate general trends, their local patterns differ from one location to another. For example at 280 m a.s.l both temperature and rainfall show decreasing trends (Figs. 9 and 10) while at 1930 m a.s.l both temperature and rainfall tended to increase (Figs. 11 and 12). As mentioned by Solomon et al. (2007), it could reflect the complex local topography. Therefore, understanding both global and local agro-ecological characteristics is useful to deal with future climate changes in relation to agriculture.

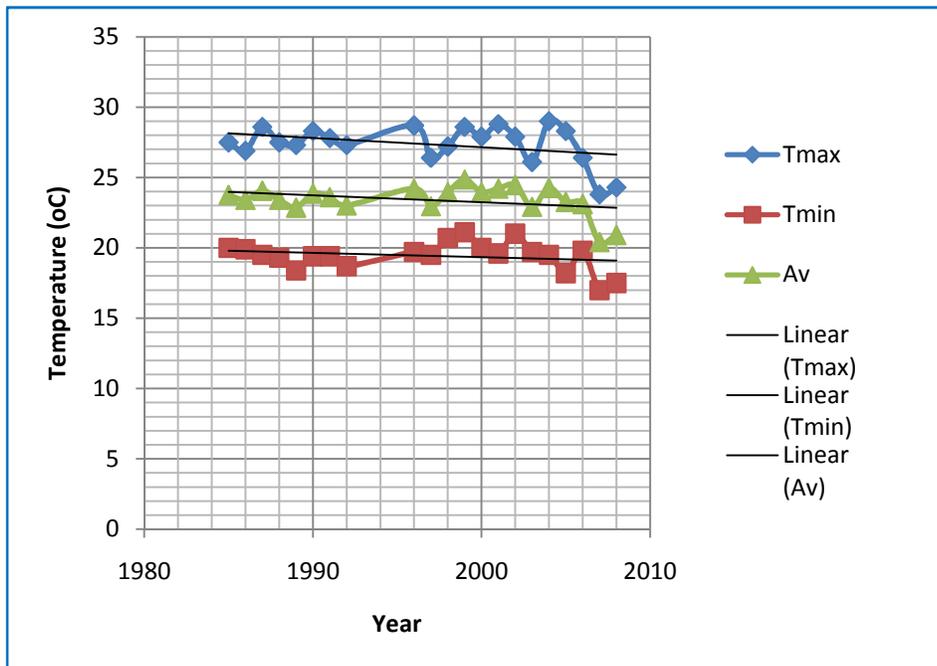


Figure 9: Temperature trend at 280 m a.s.l

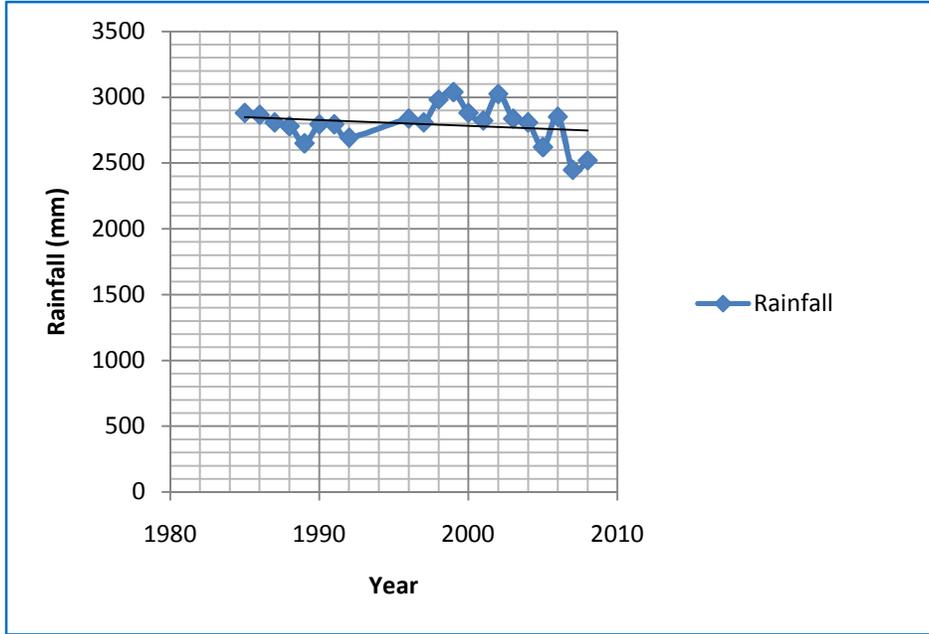


Figure 10: Rainfall trend at 280 m a.s.l

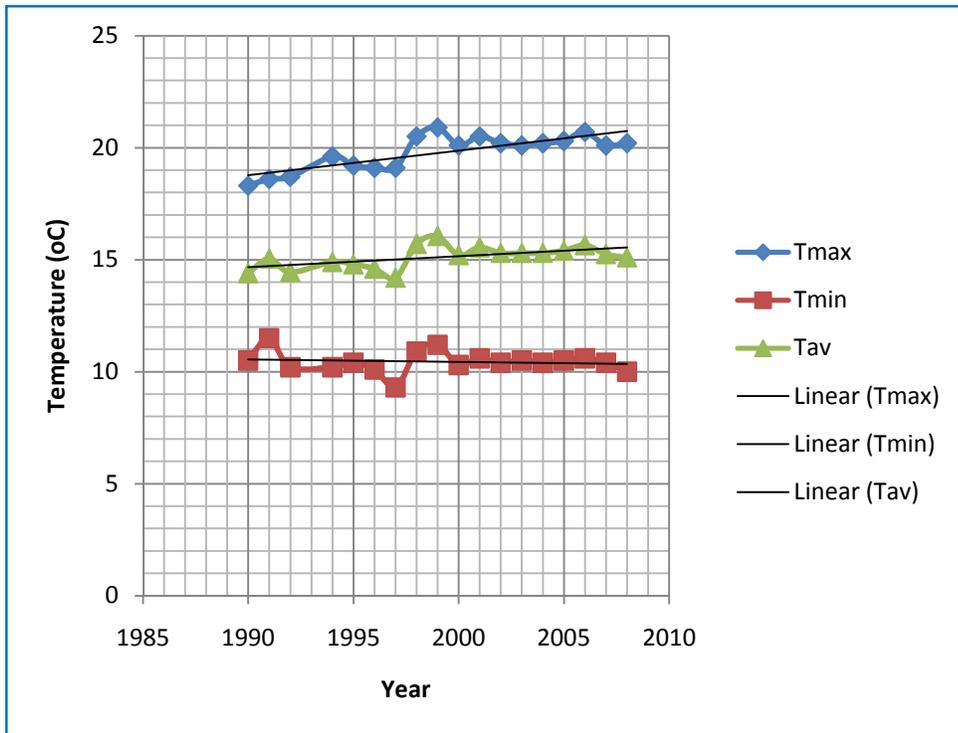


Figure 11: Temperature trend at 1930 m a.s.l

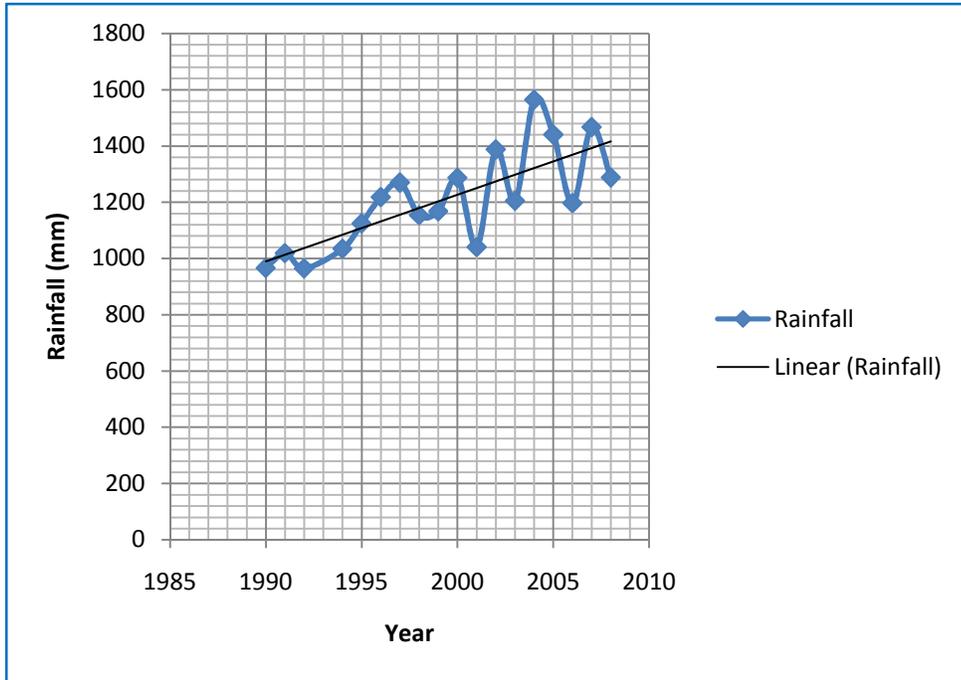


Figure 12: Rainfall trend at 1930 m a.s.l

4.3 Logistic modeling of agriculture land use

4.3.1 Agriculture dry land

Table 2 shows the value of the logit coefficient, standard error, beta and p (probability). Out of the ten explanatory variables, three (annual precipitation, elevation and rural population) are significant since the p value for these variables are less than 0.05. Asterisk (*) indicates the significance of a particular variable.

Table 2: Logit coefficient for dry land

Explanatory variables	Coefficient	Std. Error	Beta	P value
Annual precipitation	-0.001012	.00020	-0.291	0.001*
Annual temperature	-0.346021	.21082	-0.684	0.101
Moisture index	-0.069949	.05299	-0.183	0.187
Elevation	-0.003107	.00020	-1.393	0.002*
Slope	-0.011303	.00582	-0.050	0.052
Aspect	-0.091564	.06041	-0.037	0.130
Distance from river	-0.000019	.00002	-0.021	0.447
Distance from town	-0.000088	.00002	-0.036	0.580
Distance from road	0.000005	.00002	0.019	0.785
Rural population	0.000212	.00006	0.102	0.001*
Constant	13.11655			

Table 3: Odds ratio for dry land

Explanatory variables	Odds ratio	Std. Error	Beta	P value
Annual precipitation	0.998989	.00020	-0.291	0.001*
Annual temperature	0.7074976	.14915	-0.684	0.101
Moisture index	0.9324417	.04941	-0.183	0.187
Elevation	0.9968972	.00020	-1.393	0.002*
Slope	0.9887605	.00575	-0.050	0.052
Aspect	0.9125024	.05512	-0.037	0.130
Distance from river	0.9999811	.00002	-0.021	0.447
Distance from town	0.9999912	.00002	-0.036	0.580
Distance from road	1.000005	.00002	0.019	0.785
Rural population	1.000212	.00006	0.102	0.001*

The odds ratio values (Table 3) show that the probability that dry land use occurs (=1) is 0.998 times likely for every 1 unit increase in precipitation; for elevation 0.996 times; and for rural population 1.0 times. The beta value in the table is a standardized coefficient indicating the relative effect of the explanatory variable. Among the three significant variables, beta for elevation has the largest absolute value, followed by annual precipitation and rural population indicating that elevation has the greatest influence. The graphs given below better explain the effect of these variables on dry land use.

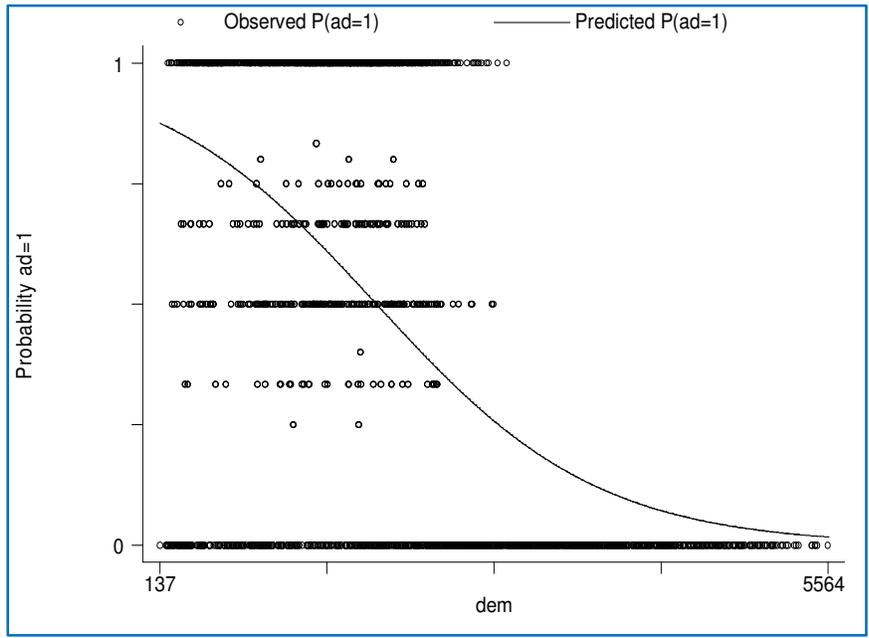


Figure 13: Partial effect of elevation on agriculture dry land

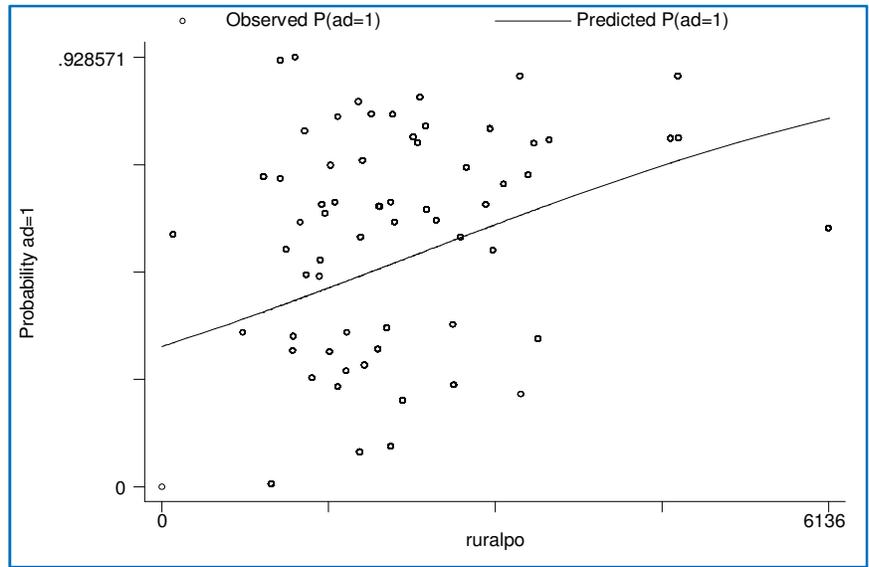


Figure 14: Partial effect of rural population on agriculture dry land

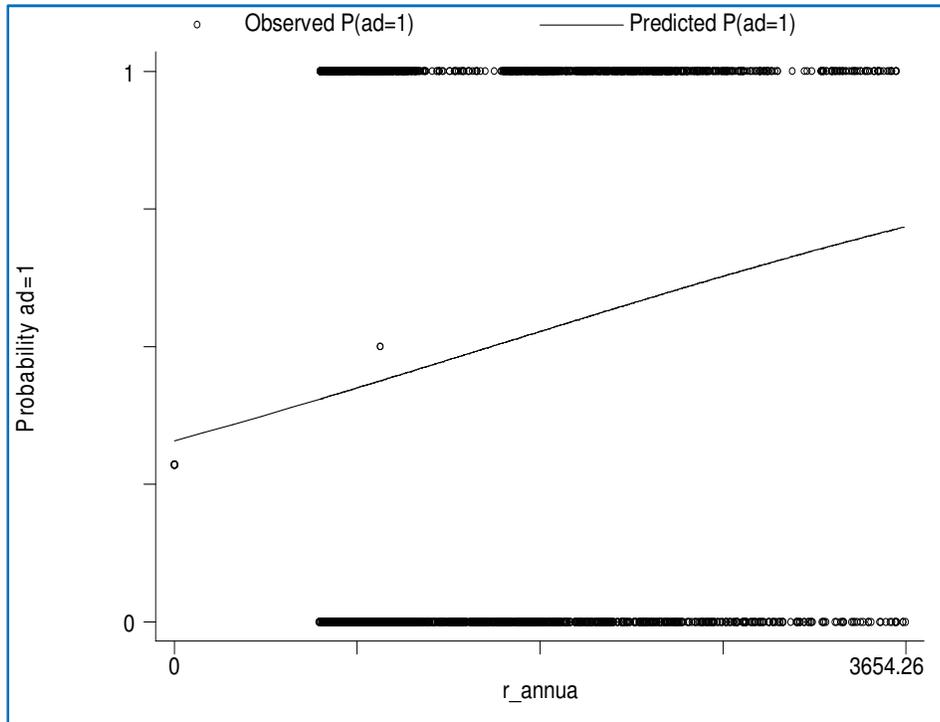


Figure 15: Partial effect of annual precipitation on agriculture dry land

Fig.13 indicates that as the elevation increases, the probability of practicing dry land agriculture decreases. This is natural because the climate of higher lands is less suitable for cultivation. Temperature and precipitation play crucial roles in the growth and development of crops. Fig.14 indicates that rural population has a positive effect on the cultivation of dry land. This may reflect topography in Eastern Bhutan characterized by steep slopes and narrow mountains valleys, where mechanization of agriculture farming is difficult and manual labor plays an important role in the agriculture practices. Thakur et al. (2009) also mentioned that the labor shortage is one of the reasons for abandoning agriculture fields in Bhutan. Fig.15 shows that annual precipitation has a positive impact on dry land, which is true in Bhutan where about 70% of farming depends on rain-fed irrigation.

Dry land cultivation has been one of most important agricultural activity in eastern Bhutan for ages. Rugged terrain and remoteness of the region have been limiting factors for dry land cultivation although the situation has been changing with the use of some technology. Eastern Bhutan is known for *kharang*, grounded maize eaten as staple food for local people. Therefore, decrease in agricultural dry land (Fig. 8) directly affects the food security of rural people. This

study shows that rainfall and rural population are two dynamic factors affecting dry land cultivation. Thus, decreasing rainfall and increasing out-migration (NSB, 2009) in Eastern Bhutan, pose serious challenges on the sustainability of dry land farming. Also steep terrains there restrict mechanization and rural population is needed for land cultivation. In addition, Gyeltshen (2010) reports that if maize is available, Bhutan is self-sufficient and rice import from India maybe unnecessary. A policy that encourages diversification of dry land crops may be important because logistic regression indicates that dry land is affected by least number of factors. The diversification of crops also has the potential to reduce the risk of livelihood failure by spreading it across more than one source of crops rather than depending on a single crop like rice.

4.3.2 Agriculture mixed land

Tables 4 and 5 show that in the case of mixed land, five explanatory variables (annual precipitation, annual temperature, slope, distance from river and that from town) are significant. Among these, annual temperature has the greatest influence since its beta value is the largest followed by distance from town, slope, distance from river and precipitation.

Table 4: Logit coefficient for mixed land

Explanatory variables	Coefficient	Beta	P value
Annual precipitation	-0.0010567	0.1003	0.001*
Annual temperature	0.2085820	0.3564	0.037*
Moisture index	-0.0718575	-0.0729	0.270
Elevation	-0.0007472	-0.2852	0.107
Slope	-0.0537367	-0.2105	0.001*
Aspect	0.1266492	0.0511	0.077
Distance from river	-0.0001084	-0.1021	0.002*
Distance from town	-0.0000675	-0.2401	0.003*
Distance from road	0.0000375	0.1379	0.130
Rural population	-0.0001271	-0.0454	0.177
Constant	1.7228680		

Table 5: Odds ratio for mixed land

Explanatory variables	Odds ratio	Beta	P value
Annual precipitation	0.99894	0.1003	0.001*
Annual temperature	1.23193	0.3564	0.037*
Moisture index	0.93066	-0.0729	0.270
Elevation	0.99925	-0.2852	0.107
Slope	0.94768	-0.2105	0.001*
Aspect	1.13501	0.0511	0.077
Distance from river	0.99989	-0.1021	0.002*
Distance from town	0.99993	-0.2401	0.003*
Distance from road	1.00003	0.1379	0.130
Rural population	0.99987	-0.0454	0.177

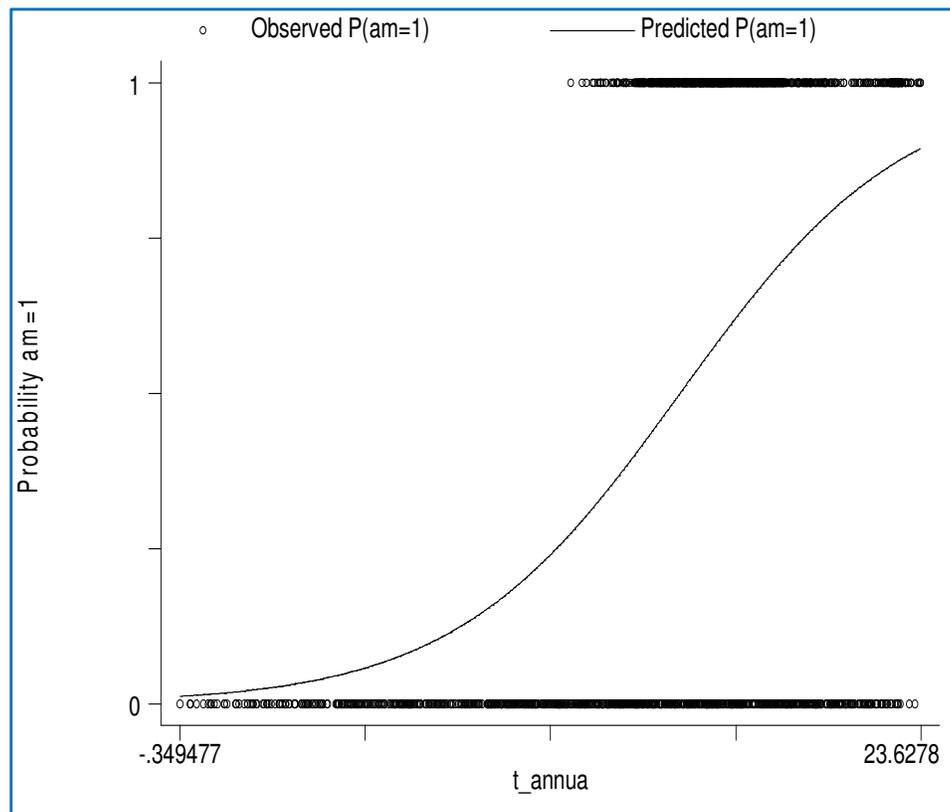


Figure 16: Partial effect of annual temperature on agriculture mixed land

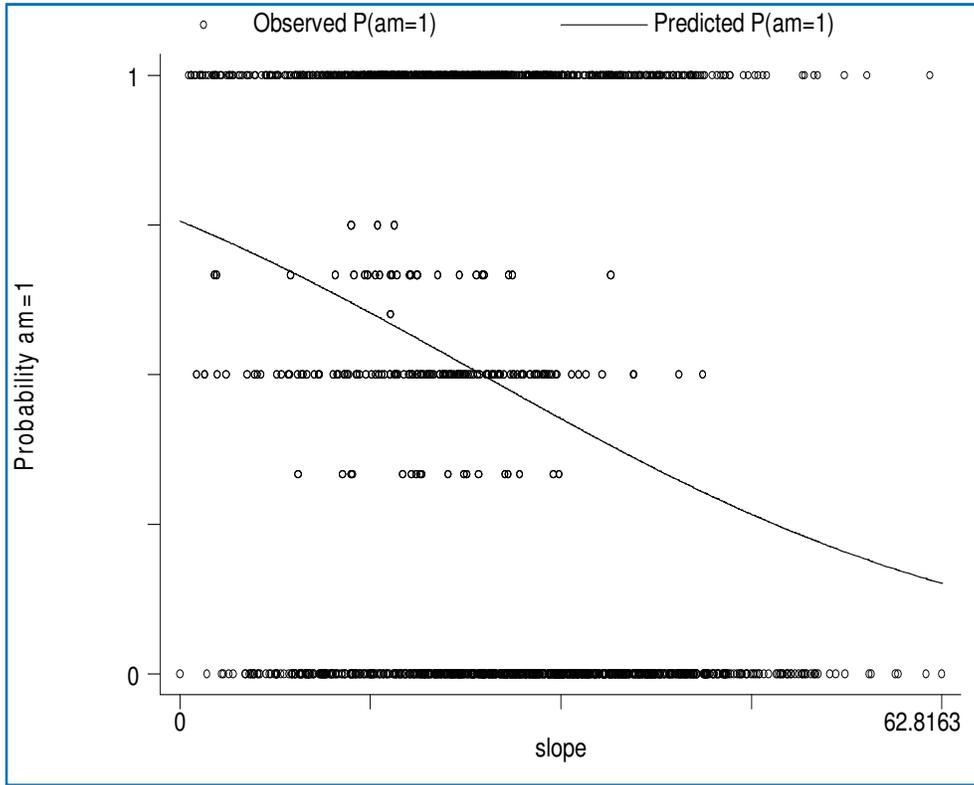


Figure 17: Partial effect of slope on agriculture mixed land

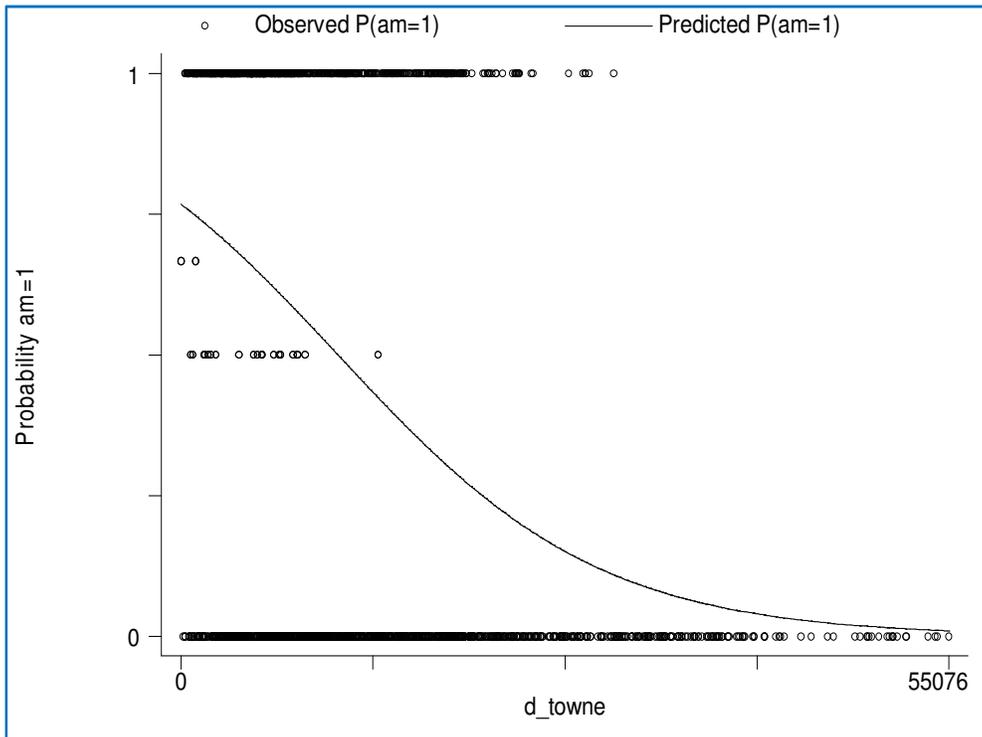


Figure 18: Partial effect of distance from town on agriculture mixed land

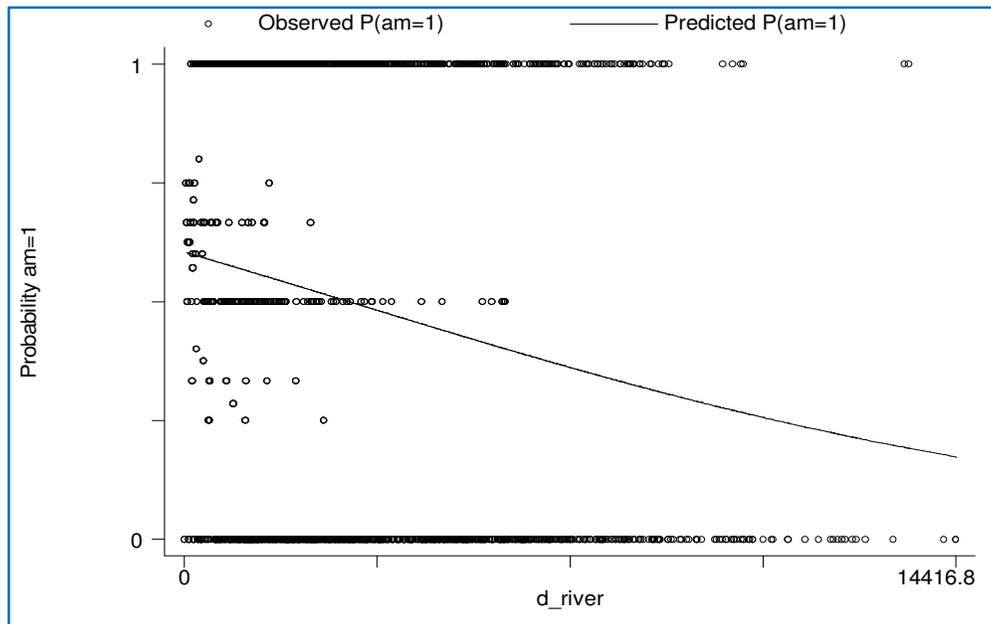


Figure 19: Partial effect of distance from river on agriculture mixed land

In mixed land, temperature and precipitation positively affect the land use, while slope, distance from town and that from river affect negatively. The former two reflect the direct dependence of agriculture on climate. As expected if slope is large agriculture practices become less feasible. Also if land is located far from a town, selling vegetables and other commercial crops in a market becomes difficult. Also if land is distant from a river, irrigation is more difficult.

The decrease of mixed land from 1994 to 2005 was the biggest among the three types of land use. Mixed land is more sensitive to environmental changes than dry land because it is significantly affected by five factors compared to three for dry land. Changes in both climate and developmental activities in and around the human community may have led to the rapid decrease in mixed land.

4.3.3 Agriculture wet land

Logistic regression shows that six explanatory variables have significant impacts on wet land use. Compared to dry or mixed land, wet land is affected by a greater number of factors indicating that it is more sensitive or vulnerable to environmental conditions. All three climatic parameters including the moisture index as well as elevation, slope and distance from river are significant. The beta values indicate that elevation has the greatest impact, followed by temperature, precipitation, the moisture index, slope, and distance from river. Temperature and precipitation have positive impacts on wet land use because rice grows in wet and warm environment. Elevation has a negative impact since higher elevation means lower temperature and precipitation. Similarly steeper slope and longer distance from the river restrict rice cultivation in an irrigated wet field with ponded water.

Table 6: Logit coefficient for wet land

Explanatory variables	Coefficient	Beta	P value
Annual precipitation	0.003156	0.2708	0.016*
Annual temperature	-1.285140	-0.6841	0.004*
Moisture index	-5.043386	-0.1616	0.049*
Elevation	-0.005937	-0.7116	0.004*
Slope	-0.035360	-0.0472	0.001*
Aspect	0.083918	0.0096	0.349
Distance from river	-0.000151	-0.0443	0.001*
Distance from town	-0.000037	-0.0376	0.114
Distance from road	0.000005	0.0047	0.870
Rural population	-0.000125	-0.0141	0.228
Constant	35.77537		

Table 7: Odds ratio for wet land

Explanatory variables	Odds ratio	Beta	P value
Annual precipitation	1.00316	0.2708	0.016*
Annual temperature	0.27661	-0.6841	0.004*
Moisture index	0.00645	-0.1616	0.049*
Elevation	0.99408	-0.7116	0.004*
Slope	0.96525	-0.0472	0.001*
Aspect	1.08754	0.0096	0.349
Distance from river	0.99984	-0.0443	0.001*
Distance from town	0.99996	-0.0376	0.114
Distance from road	1.00000	0.0047	0.870
Rural population	0.99987	-0.0141	0.228

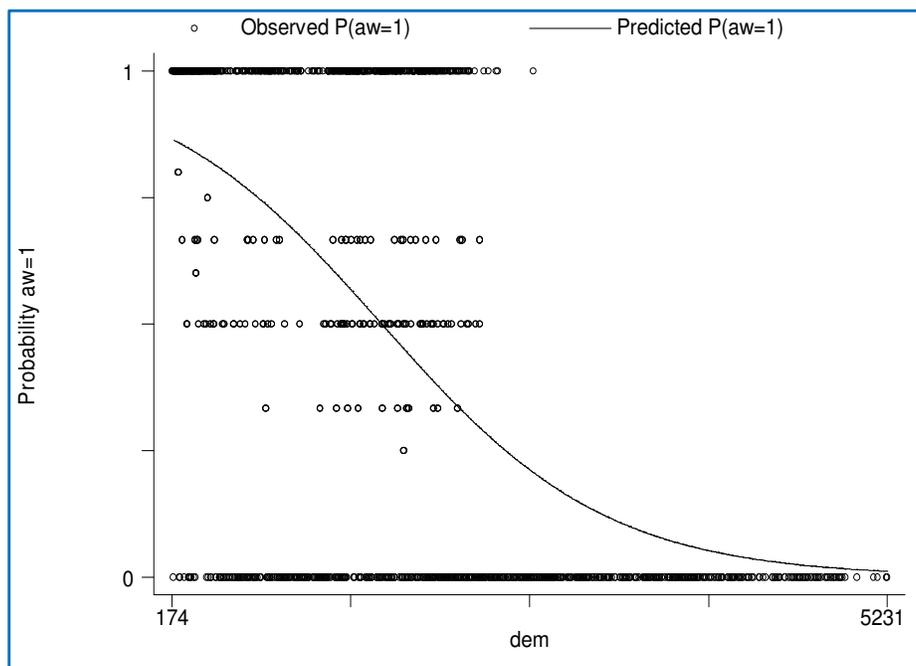


Figure 20: Partial effect of elevation on agriculture wet land

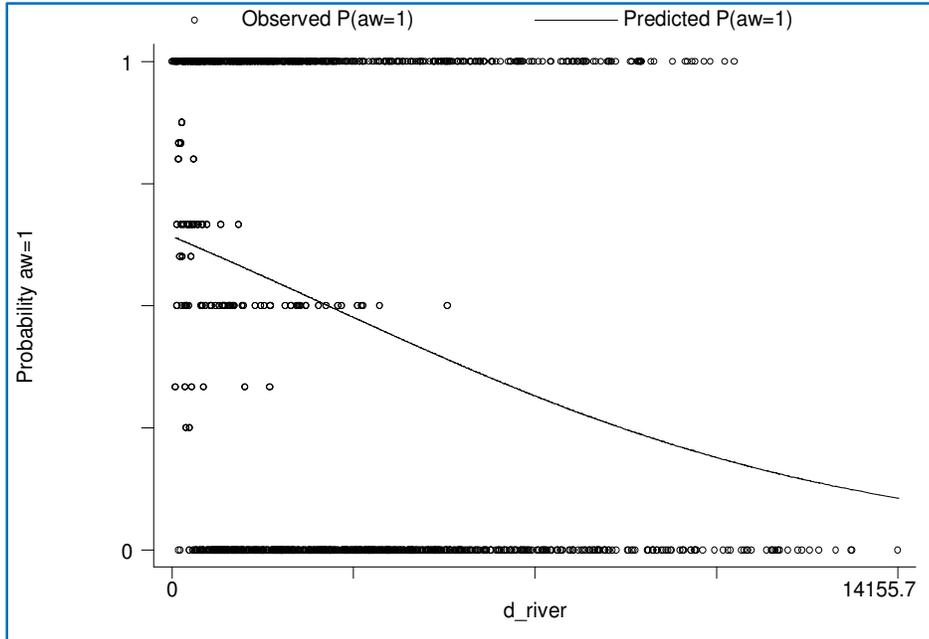


Figure 21: Partial effect of distance from river on agriculture wet land

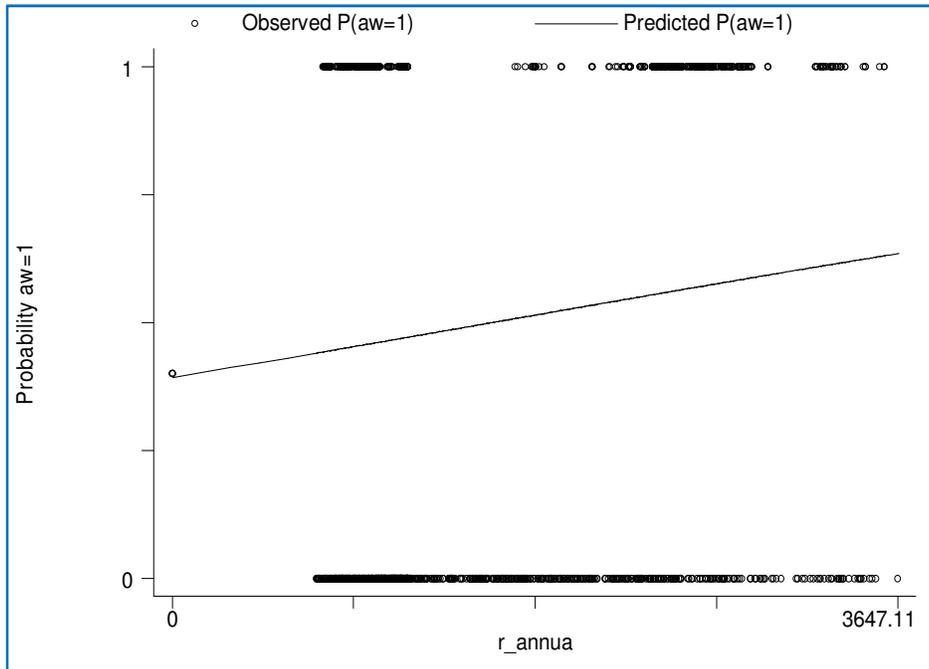


Figure 22: Partial effect of annual precipitation on agriculture wetland

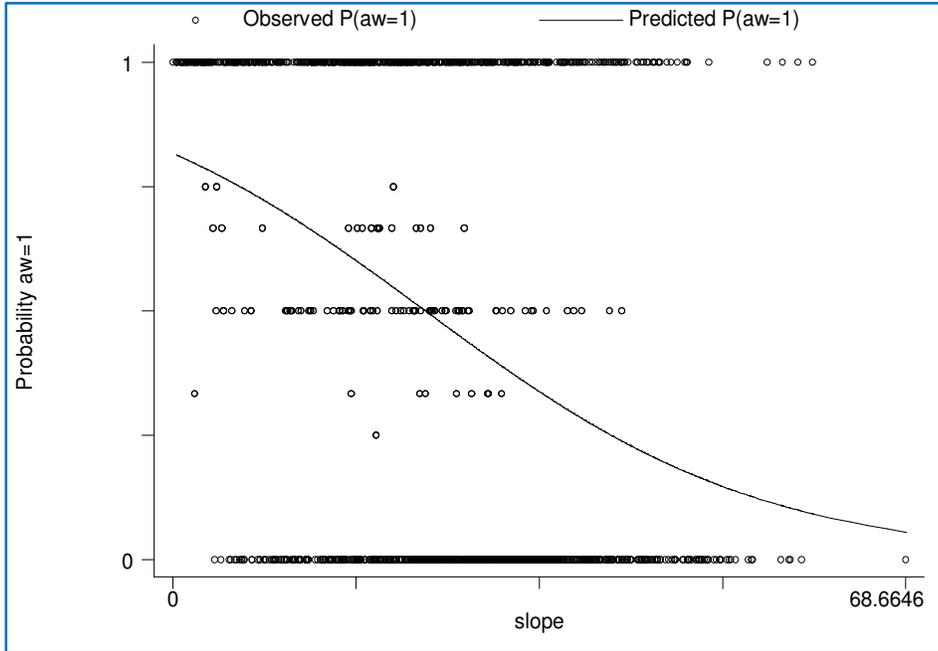


Figure 23: Partial effect of slope on agriculture wetland

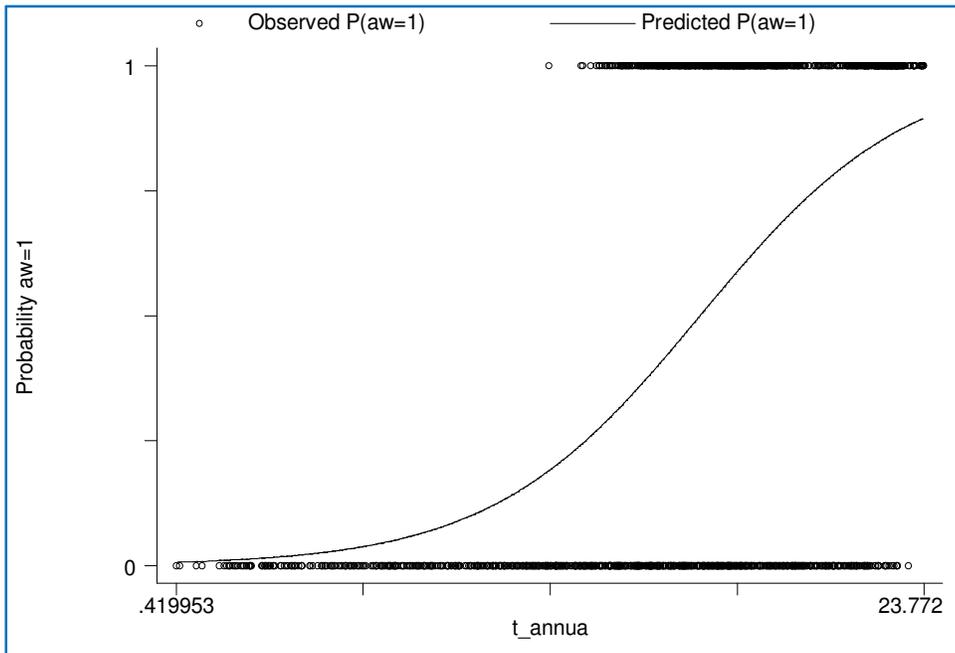


Figure 24: Partial effect of annual temperature on agriculture wet land

From 1994 to 2005 wet land decreased only by 0.92 km² although it is found to be the most sensitive in terms of the number of significant factors. This may be due to land act that restricts conversion to other forms. However, lots of wet land in the study area is now left as fallow. For instance, in Samkhar Village, which is about 18 km from Trashigang Town, about 1 ha of wetland became fallow because of water shortage. Most of 134 ha of registered wetland in the Pemagatshel district have become fallow for the same reason. Rice production in Radhi decreased by more than 30% in 2009 because of the late rainfall (Namgyel, 2010; Wangdi, 2011). These are a few of many examples of wet land being left fallow. Future climatic changes may further affect wet land use, and development of irrigation infrastructures, use of water saving technology and knowledge on climate, agro-ecological characteristics and crop management are important to deal with the situation. For example, adjusting the sowing season of crops and use of new varieties can be useful for adaptation.

Sustainability of the existing wet land is very important for Bhutan since more than 50% of the rice consumed in Eastern Bhutan is imported (Dema, 2009). With an increasing number of population consuming rice, fallowing of wet land is an important issue. Not only improving irrigation facilities but also leasing fallow land or inviting public private partnership needs to be explored. Incentives such as provision for high price, marketing loan and targeted subsidies may encourage cultivation of fallow land. Over-dependence on imported rice may not be sustainable as shown in 2008 when India stopped rice export during world food crisis.

4.4 Model validation

In any type of modeling, validation of model is important. In logistic regression, a number of methods exist to validate model. One efficient way to assess the goodness-of-fit of logistic regression is to cross tabulate prediction with observation and calculate the percentage of correctly predicted cases (Pereira and Itami, 1991; Xie et al., 2005; Zhang et al., 2009) and Pontius and Schneider (2001) have also suggested ROC as one of the effective methods of validation. These two methods are used in this study.

The classification method measures sensitivity and specificity. Sensitivity is a measure of actual positives (1 or occurrence) correctly classified whereas specificity measures the actual negatives (0 or non-occurrence) correctly classified.

The ROC method tests the null hypothesis that difference in area under the ROC curve (*AUC*) for the two samples is not significantly different. In addition, *AUC* value also indicates the predictive power of the model. The *AUC* value of 1 indicates an ideal model.

As explained in Section 3, the sample was randomly divided into two sub-samples with equal number using Stata and then analyzed to test the stability of their results.

4.4.1 Agriculture dry land

The result of the classification table method for dry land (Table 8) shows that both the training and test samples yield similar results, indicating the stability of the model. The overall correct classification (72.72%) is fairly good although not very high. The *AUC* values for the two samples (Table 8) are not significantly different since the chi-square test is more than 0.05, which further reaffirms the stability of the model. The *AUC* values around (0.76) also show that the model is fairly good.

Table 8: Classification and ROC results for dry land

Methods	Parameters	Training sample	Test sample
1. Classification table	Sensitivity	82.51%	80.67%
	Specificity	65.60%	64.75%
	Over all correctly classified	74.05%	72.72%
2. ROC	Area under ROC (<i>AUC</i>)	0.7645	0.7693
	Chi ² probability	0.1145 (not significant)	

4.4.2 Agriculture mixed land

In Table 9 for mixed land, the two samples (training and test) yield almost the same results and the overall correctness is little better than the case of dry land. Also the difference in *AUC* values is not significant while the values themselves (ca.83) are high enough, indicating the goodness of fit of the model.

Table 9: Classification and ROC results for mixed land

Methods	Parameters	Training sample	Test sample
1. Classification table	Sensitivity	83.40%	84.13%
	Specificity	72.82%	71.05%
	Over all correctly classified	78.06%	77.66%
2. ROC	Area under ROC (<i>AUC</i>)	0.8361	0.8309
	Chi ² probability	0.0502 (not significant)	

4.4.3 Agriculture wet land

Like the case of dry and mixed land, two samples of training and test for wet land give similar results both in terms of sensitivity and specificity (Table 10). The overall correctness of classification (79.63%) is even higher than the earlier cases. In wet land, usually only rice is grown whereas in other cases various crops are grown. The distribution of single crop seems to be easier to predict compared to the other more complex cases. The values of *AUC* (ca. 0.84) higher than the others also confirm the better predictive power of the model.

Table 10: Classification and ROC results for wet land

Methods	Parameters	Training sample	Test sample
1. Classification table	Sensitivity	85.47%	84.52%
	Specificity	73.60%	74.88%
	Over all correctly classified	79.63%	79.63%
2. ROC	Area under ROC (<i>AUC</i>)	0.84238	0.84788
	Chi ² probability	0.1497 (not significant)	

4.5 Mapping potential impacts on agriculture land use

For all three types of land use, temperature and precipitation were found to have significant effects. Indeed, agriculture is a climate dependent economic activity (Solomon et al., 2007; Thapa, 2008). Hence, to study the likely impact of climate change on agriculture, predicted probability maps of agriculture land use for the years 2005 and 2050 were developed and the overlay function was employed to detect potential changes or impacts.

4.5.1 Predicted probability maps

Predicted probability maps of dry land, mixed land and wet land for 2005 were developed in ArcMap by substituting logit coefficients values, obtained in logistic regression (Tables 2, 4 and 6) respectively, into the Equation (5). In order to develop a probability map for the year 2050, only the temperature, precipitation and moisture values in Equation (5) were replaced by those of the 2050 prediction to focus on the impact of climate change. Once the maps were developed, raster cells with probability value less than 0.01 were classified as less suitable; 0.01 to 0.49 as suitable and 0.5 to 1 as highly suitable (Figs. 25 to 30).

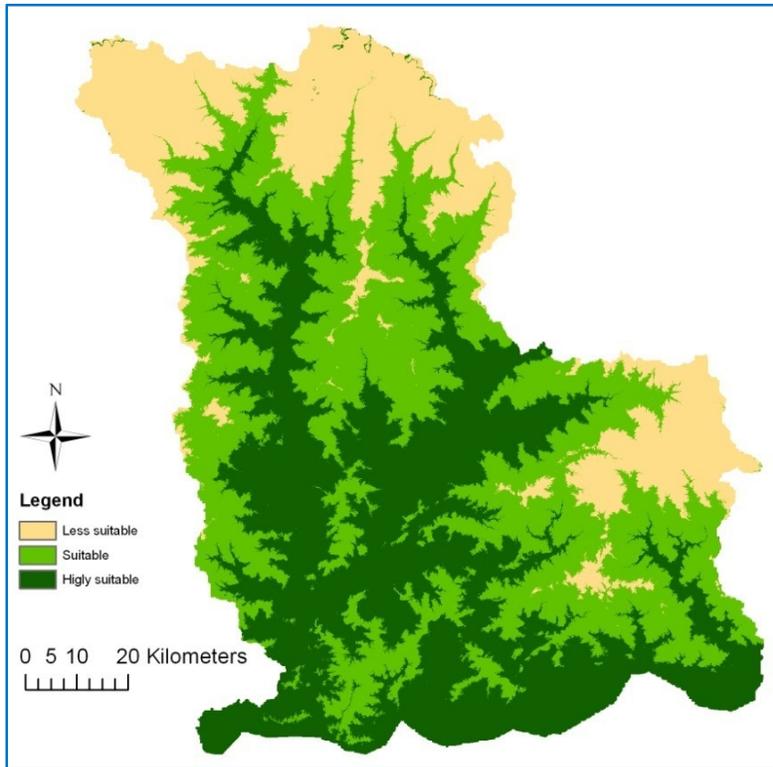


Figure 25: Probability map of agriculture dry land in 2005

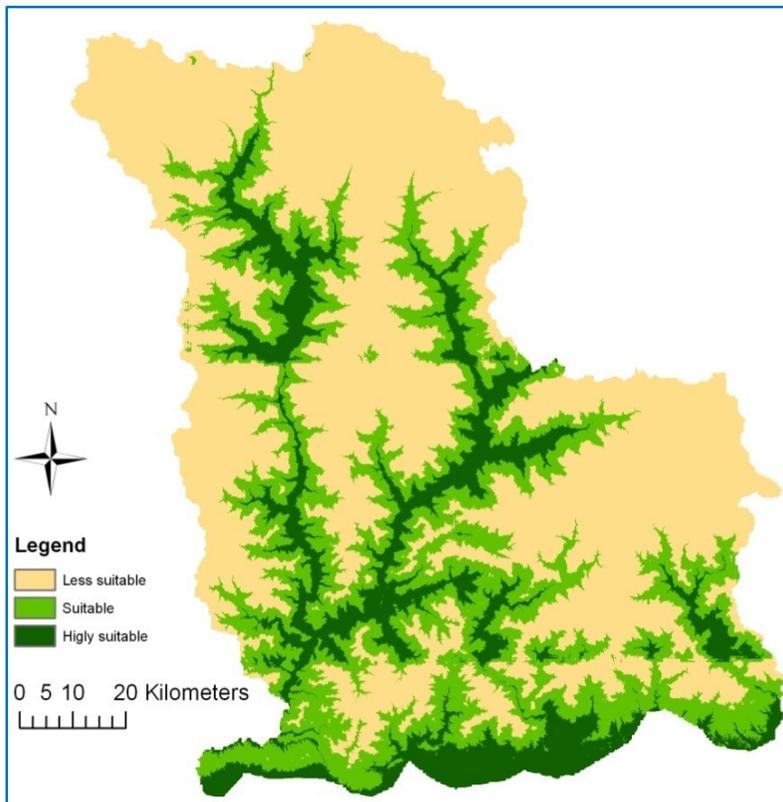


Figure 26: Probability map of agriculture dry land in 2050

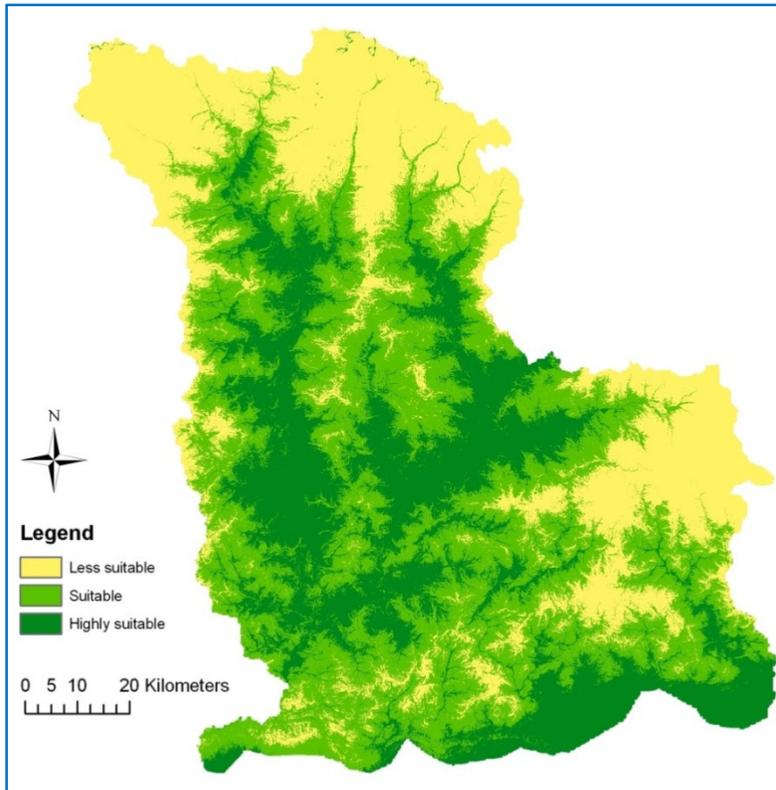


Figure 27: Probability map of agriculture mixed land in 2005

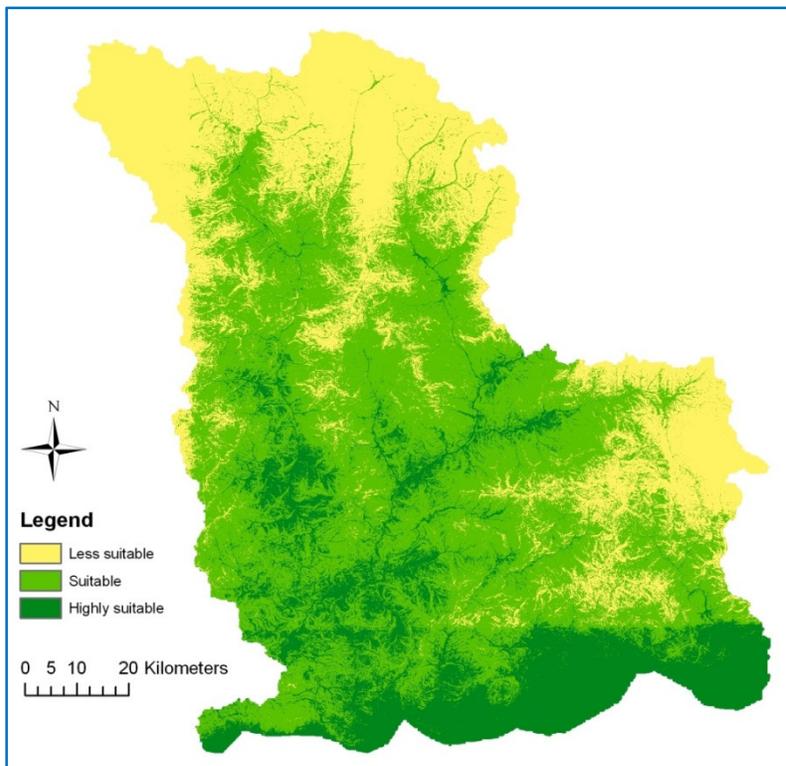


Figure 28: Probability map of agriculture mixed land in 2050

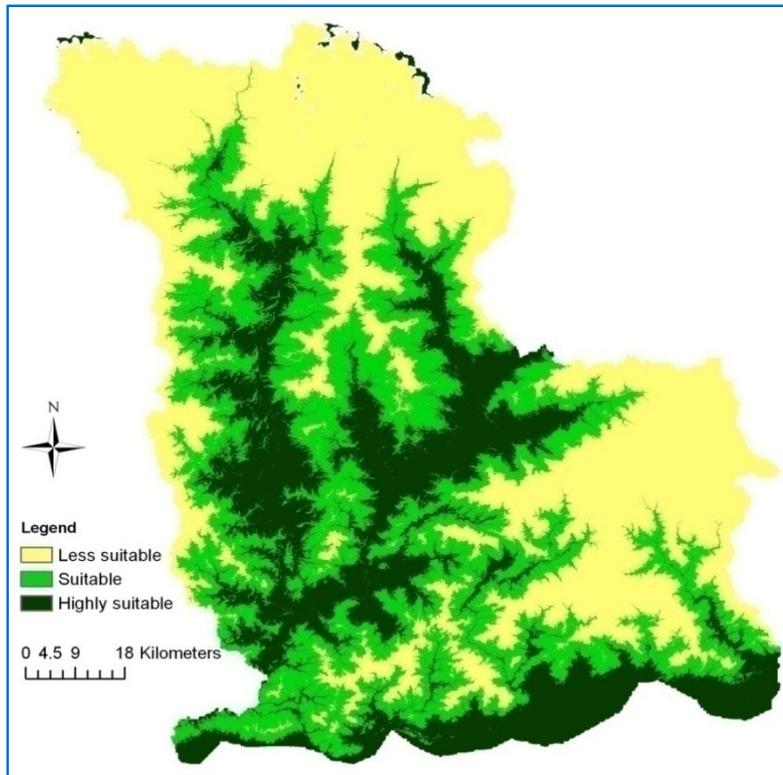


Figure 29: Probability map of agriculture wet land in 2005

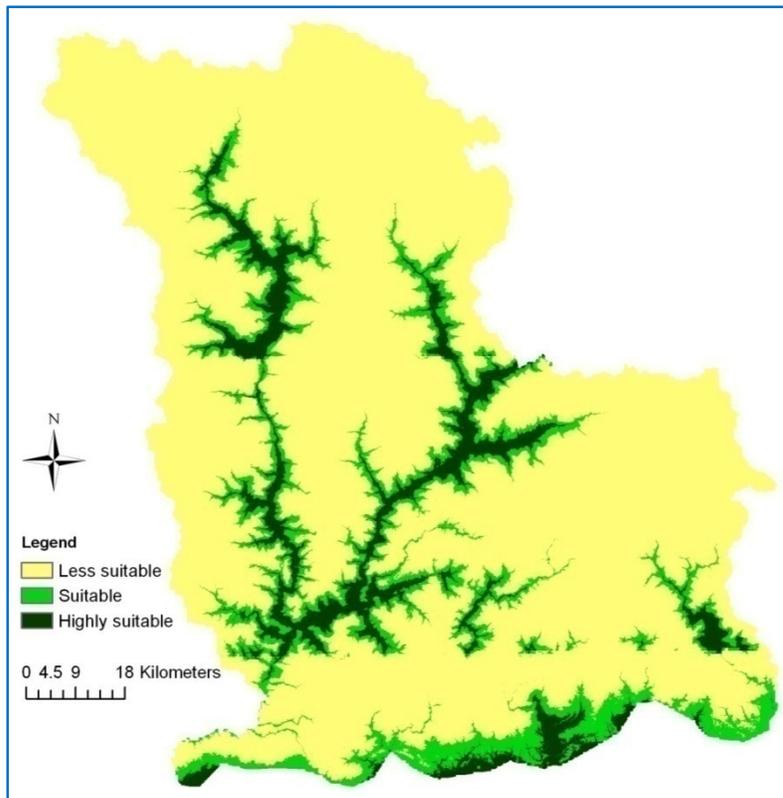


Figure 30: Probability map of agriculture wet land in 2050

4.5.2 Potential impacts due to change in climate variables

In order to detect potential change in agriculture land use in future (2050), the predicted probability maps for the current (2005) scenario and future (2050) scenario were overlaid in ArcGIS. Then raster cell values less than 0.5 in the predicted probability maps were classified as 0, and those greater than or equal to 0.5 as 1. When the current-scenario raster map is subtracted from the future map, four types of outcomes are possible (Table 11).

Table 11: Possible outcomes of future and current potential overlay

Situation	Future potential in 2050 (Raster value)	Current potential for 2005 (Raster value)	Result after subtraction (Raster value)
High impact	0	1	-1
Remains less suitable	0	0	0
Remains suitable	1	1	0
New potential	1	0	1

The resultant raster value 0 represents two situations: 1) remains less suitable and 2) remains suitable as before. In order to correct this, in the future case, cell values of probability greater than or equal to 0.5 are classified as 2 instead of 1. This technique was adapted from biodiversity species distribution study using DIVA-GIS (Schelderman and Zonnevel, 2011). Table 12 shows the new outcome.

Table 12: Modified possible outcomes of future and current potential overlay

Situation	Future potential in 2050 (Raster value)	Current potential for 2005 (Raster value)	Result after subtraction (Raster value)
High impact	0	1	-1
Remains less suitable	0	0	0
Remains suitable	2	1	1
New potential	2	0	2

In the table, the raster value -1 is considered as high impact since areas suitable in the current situation becomes unsuitable in the future; 0 represents remains less suitable situation; 1 means remains as suitable area as before; and 2 represents new potential since those areas currently not suitable become suitable in the future.

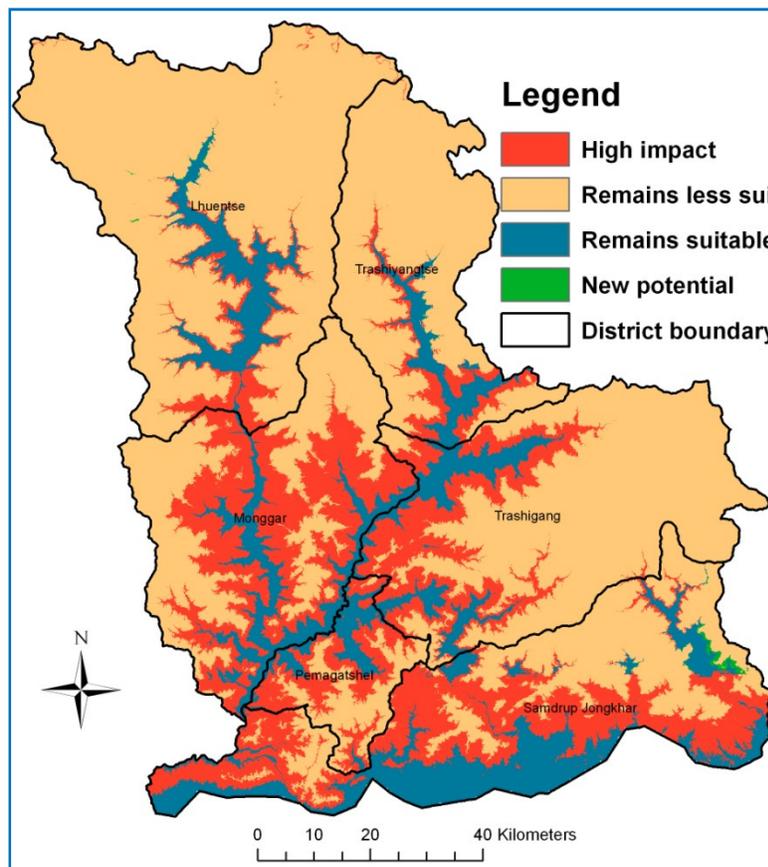


Figure 31: Potential impact on agriculture dry land in 2050

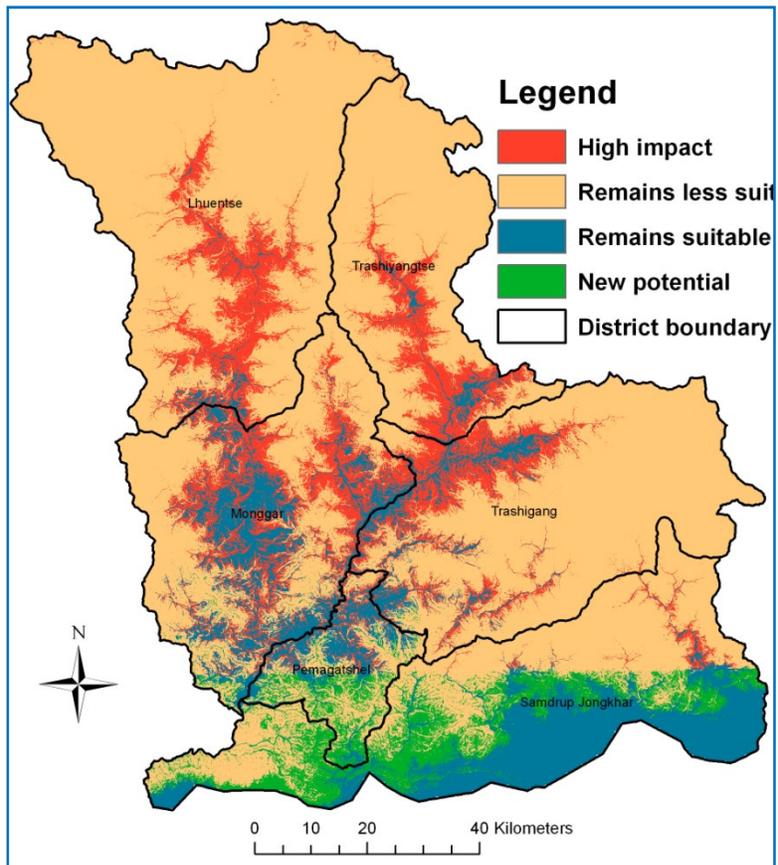


Figure 32: Potential impact on agriculture mixed land in 2050

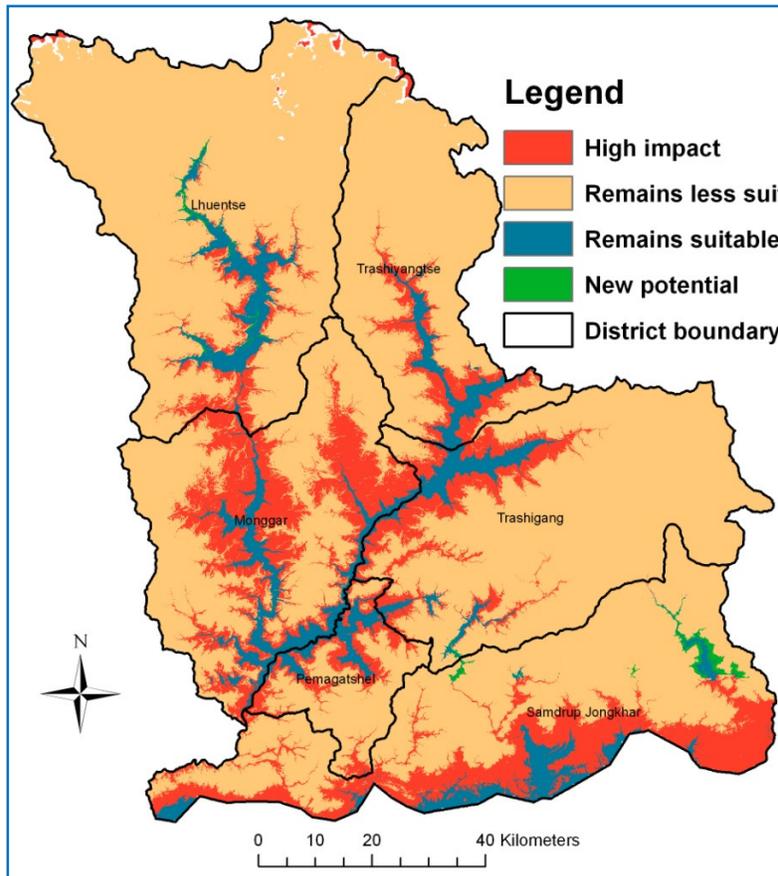


Figure 33: Potential impact on agriculture wet land in 2050

Fig. 31 shows that in the case of dry land, high impact is predicted mainly in the Mongar, Samdrup Jongkhar and Trashigang districts. In contrast, the Pemagatshel and Tashiyangtse districts are likely to have little impact because their majority is predicted to remain the same or will have little impact.

Fig. 32 shows that high impact on mixed land is predicted mainly in the Lhuentse and Tashiyangtse districts but only a bit in the Trashigang and Mongar districts. In some areas of Samdrup Jongkhar, new potential is predicted. The prediction for the majority of the area is to remain the same or have a low impact.

Fig. 33 indicates that high impact on wet land is predicted in the Samdrup Jongkhar, Mongar, and Trashigang districts, while the Tashiyangtse and Lhuentse districts will have little impact. Most places are predicted to have little or no impact.

It must be noted that above predictions reflect the effects of future climatic change and other factors such as social, soil and policy frameworks are assumed to be the same as in 2005. Agriculture particularly recent one is often affected by human activities. Consequently, the future may look rather different if human activities significantly alter the style of agriculture.

5. Summary and conclusions

Eastern Bhutan represents about 40% of the country's population. Majority of the people are engaged in agriculture. In recent years, agriculture there has been challenged by some issues which led to decline of agricultural land use. Although climatic, topographic and socio-economic factors may be responsible, detailed studies on this issue have been limited. This study has analyzed the distribution and temporal change of agriculture land use in eastern Bhutan and inferred their controlling factors using GIS. Over the period 1994 and 2005, agriculture land use in Eastern Bhutan decreased in general although the amount of decrease differed by land use type. It was also noticed that different land use types were affected by the combination of different factors, with climate variables being featured in almost all cases. Dry land was affected by the least number of factors while wet land by the largest number. The study has revealed how agriculture land use is affected by a combination of climatic, social and topographic factors. It has provided useful information for sustainable planning for the future. Temperature in the study area tended to increase from 1985 to 2005 and precipitation tended to slightly decrease, but their trends differ according to elevation/locations. These findings should also be taken into account for planning.

Based on the above results, some implications and inferences have been obtained:

- The ongoing reduction in agricultural land use affects not only food security but also livelihood because agriculture is the main source of livelihood for people in the study area.
- No single factor can explain the changes in agriculture land use. Hence, a holistic approach is needed to deal with issues related to agriculture land use.
- The effect of elevation/locations on the time series of temperature and precipitation suggests that understanding of both global and local physiographic conditions is useful for the adaptation of agriculture with future climatic changes.
- Among the three types of agriculture land use, dry land seems to be the most stable because it is affected by the least number of factors, whereas wet land affected by the largest number seems to be most sensitive. However, wet land underwent the least reduction, which could be due to the land act for the conversion of wet land. At the same

time, wet land tended to become fallow, which needs special attention because more than 50% of rice consumed in Bhutan is imported.

- The fact that temperature and precipitation affect all types of land use confirms previous studies which regard agriculture as being highly vulnerable to climate change. In Bhutan, steep terrain limits land use and management, and under such a situation, a small change in climate could have bigger impact. Also agriculture in Bhutan is basically dependent on monsoon rain, and erratic weather pattern often affect land use and management. In many areas agriculture is still practiced at subsistence level with limited resources. This may also make the impact of climate change stressful. It is important to acquire more knowledge and information on climate, crops and management aspects.
- The inferred effect of rural population on land use change could reflect increasing urban migration and resultant labor shortage as well as difficulties in mechanization under the steep topography.
- Logistic regression has been found to be effective to analyze the effects of climatic, social and topographic factors on the three types of land use, although it provided better prediction for wet land where single crop is grown. Therefore, future studies on the effect of crop types may provide useful information.

6. References

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