LAND USE CHANGE MODELLING IN BARAK VALLEY OF NORTHEAST INDIA

Thesis submitted in partial fulfilment of the
requirements for the degree of

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by

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CERTIFICATE

It is certified that the work contained in this thesis, titled “Land use change modelling in Barak valley of Northeast India” by Jyoti Misra, has been carried out under my supervision and is not submitted elsewhere for a degree.

Date | Adviser: Dr. K. S. Rajan

To my family,
For always standing by my side

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I would like to express my sincere gratitude to my advisor Dr K S Rajan for being constant source of knowledge and guidance throughout the research. Constant discussions with him helped me gain new perspectives. His constant encouragement has been a motivation for me throughout the journey which taught me a great deal about patience, hard-work and dedication.

I would like to thank NESAC for the data provided and their continued help during the course of this research.

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Abstract

Barak valley is an area in the north-eastern part of India where traditionally the practice of shifting cultivation has been more prevalent than sedentary agriculture. In the recent past, population growth coupled with the geographic isolation of the area has further aggravated the decline of forest land cover in the area. The region that encompasses the Barak valley, shows varied land covers and has diverse population densities. While some land use and land cover changes are gradual and slow, some can be rapid and fast. Also, many of these changes are dependent on the biophysical and socio-economic drivers of change, including policy inputs. So, there is a need to understand these interactions and how these changes will be affected by the different factors in the near future.

This thesis focuses on modelling land use changes in the Kathakal basin of Barak valley, primarily changes in the shifting cultivation patterns, over a period of 1988 to 2005 using an agent-based model after understanding changes in the recent past. Each district is modelled as an agent of change in the agent-based model,

1. to capture the interactions between the various drivers like population changes, infrastructure development and land use practices and
2. to decide on the land resource allocation across the district at the land parcel level including allotment of shifting cultivation regions.

The model accounts for both socio-economic as well as geographic factors, like access to infrastructure while making the land use decision on a year-on-year basis. The model considers the need for shifting cultivation land area for both a staple crop – paddy (rice) and a non-staple crop based on the demand against the supply estimated from irrigated and rain-fed cropping regions.

While the model has been fine-tuned based on the data till 1997, the simulated model outcome of 2005 is validated against an existing remote sensing derived land use map of the region. The model shows an accuracy of 98% for the test period till 1997 and achieves an overall accuracy of about 94% for 2005 predicted land use pattern. While the aggregated results across the region show good concurrence, the randomness inherent in the choice of the shifting cultivation land limits the ability to predict the precise locations. Further, the thesis will discuss the challenges of different land use conditions prevailing in the two districts and how the model is able to adapt to those in providing a good estimate of the land use changes in a region as diverse as Barak Valley.

Based on the model and its applicability to the Barak valley region, the research further explores the impact of various policies on the choice of land use over a period of 30 years, i.e., the land use patterns between 2005 and 2035. Four different scenarios, including a business-as-usual (BAU) scenario were modelled, to highlight how either ecological or economic considerations affects the choice of land use in the two diverse existing land use conditions of the districts of Hailakandi and Mamit.

The results show that depending on whether the district is largely rural or urban, has sparse or dense population, and has access to irrigation infrastructure, the land use responses are different. The BAU scenario shows that without intervention of any kind, it is difficult to stop the spread of shifting cultivation due to the land pressures from population growth and the need for increased economic returns from the land. The model shows that infrastructure development and incentivising settled forms of agriculture can have a positive impact on reducing shifting cultivation, though the rate of this change is dependent on both socio-economic and bio-physical conditions of the region.

Contents

List of Figures

Figures

List of Tables

Tables

Chapter 1 - Introduction

1.1 Land Use Studies

Understanding land use change is important from environmental, ecological, and hydrological perspectives. Land use which has been usually considered a local environmental issue, is becoming an issue with global importance. There have been worldwide changes to forests and farmlands due to the need to provide food and shelter to 7.9 billion people. To provide for these needs, there has been an increase in farmed lands and urban areas as well as a huge increase in energy, water consumption. This has undoubtedly resulted in losses of biodiversity. [2] While maps that are obtained through remote sensing do present us with the past and current scenarios, it is important to understand how land use might change in the future. Land-use change is driven by resource scarcity which causes an increased pressure of production on the existing resources. Other factors like changes in social organization and attitudes, outside policy intervention and changing opportunities created by markets also lead to land use changes.[3] These land use changes enable humans to use up an ever-increasing share of earth's resources but they decrease the capacity of ecosystems to sustain food production, control climate and air quality and maintain forest resources. Humans through changes in land use like urbanization and agriculture, have influenced climate by emission of greenhouse gases.[4] We need to manage the trade-off between maintaining the biosphere's capacity to encourage life forms in the long term and meeting immediate human food and lifestyle needs.

For predicting land use changes, we need to model land use change processes. We need to understand what the changes are and what factors drive them. Localized research on land use/land cover changes requires a combination of the agent-based systems and narrative perspectives of understanding.

Shifting cultivation term is used for defining any agricultural system in which fields are cleared by burning and are cropped discontinuously. This system of cultivation has periods of fallowing which are longer than periods of cropping on average. Shifting cultivation is often held to be the principal driving force for deforestation in tropical Asia.[6]

In shifting cultivation, crop production depends on the natural fertility of the soil. Depletion of fertility during cultivation is the reason for land abandonment. During the fallow period which follows a shifting cultivation cycle, fertility levels tend to improve, and the land may be available for further cultivation cycles. Several studies observe that eight to 10 years of fallow period are needed to raise the fertility level of the site to its original uncultivated state.[7] Fallow lands create secondary forests which cover a large amount of area in the humid tropics and have great economic as well as ecological benefits.

Fallow length depends on the crop type, the field size as well as the access to labour and forest patches available for shifting cultivation. A household having access to lesser land holdings will have significantly shorter fallows than a household with more land holdings. The land under fallow period is called fallow holding. For various households in an area, there exists a considerable difference in the area, number and age of fallow land holdings over time. Households with better access to land and labour have more fallow holdings and longer fallow periods.[8] As forest areas available for shifting cultivation decline, households increase the number of fallow holdings while decreasing the fallow period length.

The conditions that historically ensured the sustainability of shifting cultivation in countries of south and east Asia have vanished to a great extent. With rapid population growth and declaration of wildlands as protected areas, there is an ever growing need to evolve to more settled forms of agriculture. [9]

1.2 Modelling land use changes

Modelling is the context of geographic information systems (GIS) is an attempt to understand and replicate the processes in the real world, either over a time period or at a particular point in time. In an agent-based model, a system’s dynamic behaviour is represented through rules governing the actions of a number of autonomous agents. Land use changes are modelled in many different ways. Modelling agricultural changes can even be purely statistical. In our area of interest, we are looking at changes that can be driven by shifting cultivation as well as other agricultural practices in the given landscape.

There have been efforts made to modify cellular automata which was previously used for modelling of urban land-use dynamics and make it suitable for modelling shifting cultivation. The model thus created accounts for the changes in soil fertility when a plot is cleared for cultivation and captures the changes in soil fertility during the fallow period. It captures the increasing land pressure through the long cultivation period coupled with the shortened fallow periods. [13]

Another modelling effort was made in Nghe-An province of Vietnam's northern mountain region using spatially explicit agent-based modelling. The level of clustering in agricultural fields was observed around a study village. This was reproduced based on the empirical data from fieldwork and observations for parameterization of variables. In this model, agents acted to maximize labour productivity which was defined using on potential yield and the labour costs while honouring physical constraints. Comparing the results of the simulation with the land cover data attained through remote sensing showed a high degree of similarity to the land cover data but also a need for further adjustment of model variables and controls.[10]

Modelling land-use/cover change using multi agent systems work by combining a cellular landscape model with agent-based representations of decision making and integrating the two components through specification of interdependencies and feedbacks between agents and their environment. It has been established that multi agent system models of land-use/land cover changes are particularly good for modelling complex spatial interactions as well as decentralized, autonomous decision making. [11]

1.3 Research motivation

Shifting cultivation is a widespread practice in South and Southeast Asian countries which affects forest cover as well as land productivity. The present-day problems with shifting cultivation are caused by the changes due to shortening of cycle to 5 years or less. Shifting cultivation is considered as a major driver of deforestation globally. In India, the states of Manipur, Meghalaya, Mizoram and Nagaland have seen a decrease in the shifting cultivation cycles by 20 years, thus not leaving enough time for the land fertility to be restored. The practice in this region is more diverse than any other part of the world due to diverse sociocultural, socio-economic and socio-religious practices of over a hundred tribes in the north-eastern region. We need to understand the dynamics of shifting cultivation (jhum) practice and the zones of high concentration where the practice exists in the Barak basin.

1.4 Research objective

Looking at previous work done to model shifting cultivation, we can observe the use of modelling to try and understand the processes behind the need for shifting cultivation. Spatial distribution of crop cultivation is often determined by the relationship between demand and supply of crops in an area. The simulation results are compared with land cover data obtained from remote sensing to determine the accuracy of predictions.

The region of Barak valley has widespread shifting cultivation practices. This coupled with the rampant economic changes in the region have made the area an interesting study to observe how various socio-economic change factors are affecting shifting cultivation in the region.

The objective of this research is to model shifting cultivation in two regions of south Barak valley and come to an understanding of the factors that affect shifting cultivation in the region. We also seek to understand the interplay of these factors in affecting land use patterns. As agriculture practices get deeply affected by social and political factors, we would also like to understand how changes in policies and social practices would affect the agricultural practices in the region. As the region under study is largely homogeneous, all data is used at a resolution of 500m.

1.5 Scope

The scope of this research is limited to two regions in south Barak valley in north-east India: the region under district of Hailakandi in Assam and extended Mamit region in Mizoram. We seek to model the agricultural practices of this region. The research takes into account the food demand and supply for the region and its effects on the need or continuance of shifting cultivation. Social factors like migration and economic factors like inflation are not taken into account for affecting agriculture practices explicitly. We would also be looking into how policy and social changes might affect the cropping patterns of the region in the near future.

1.6 Problem statement

We seek to modify an existing agent-based land use model [1] to make it applicable for the social economic scenario of Barak valley regions under consideration. To accurately create the model, we would need to understand the shifting cultivation pattern in the region and identify the causes that affect land use changes in the area. We also intend to understand how the land use changes over time in Barak valley and how different policies affect shifting cultivation practices. The changes are studied over a period of about 50 years (1988-2035). This time period helps us observe the behaviour of land use changes over a larger period of time and helps negate any changes that might be caused due to local factors.

1.7 Thesis organization

- Chapter 2 presents an overview of the work done in modelling land use in general and shifting cultivation in particular
- Chapter 3 presents details about the Barak Valley region in India and analyses the suitability of this region for modelling shifting cultivation
- Chapter 4 details the different types of datasets used for generating this land use model.
- Chapter 5 details the design and development of the land use model and its architecture.
- Chapter 6 explains the scenario building with the help of the generated land use model.
- Chapter 7 concludes the thesis with a summary of the work done.

Chapter 2 - Literature review and related work

2.1 General land use models

Land-use change models are useful tools to explain and understand the cause and effects of land use dynamics. Land use change modelling is an important technique for projection of future scenarios through experiments that test the understanding of the processes involved in land use changes. These models represent the complexity of land use system and factors that influence land use change. With these models we can test how land use patterns change with changes in the factors influencing them. Through scenario building, we have a possibility of testing the stability of social and ecological systems linked to the land use changes.

Through combination of tools and knowledge from socio-economic and biophysical sciences, spatially explicit agent-based models have been developed that focus on patterns of change and the underlying decision processes that cause it. Such developments enable determining the environmental impact with the use of land use change models. The affect of changing land use on the environmental conditions and vice-versa can be included to land use models. The current models unfortunately do not incorporate this feedback model and it poses an interesting challenge for land use model development.

Spatially explicit land-use/land-cover models involve modelling drivers of land-use change as well as modelling the scale dependency of drivers of land use change. It is of utmost importance for land use models to incorporate biophysical feedbacks in order to model the location and the quantity of land use change.

Land use models are used for the analysis of system properties, along with the socio-economic and biophysical context, at many different scales. Satellite data through remote sensing, geographic information systems and stochastic modelling are some of the techniques that have been used to investigate land use change modelling. To effectively analyse the spatial pattern, rate and direction of land use change combining satellite remote sensing and GIS have been used. Additionally, Markov modelling has been used to integrate these two technologies which has been beneficial in describing and analysing land use change process.[17]

While doing an analysis of the triggers and effects of land use dynamics, land use change models are used. By using the land use change models, scenario analyses can be carried out which would help with land use planning. Currently there exist numerous land use models that have been developed from various disciplinary backgrounds.

There has been work done on developing a Land Transformation Model (LTM) [18], which uses a combination of artificial neural networks and geographic information systems (GIS) to predict land use changes. The model takes into account a variety of social, political, and environmental factors to predict land use change. The model investigates the influence of transport facilities like roads, highways and residential streets, rivers as well as quality of views on urbanization patterns. The model uses neural network to learn the patterns in which development takes place in the region and predict the future changes, while GIS is used to develop the spatial predictors that affect the land use changes and perform spatial analysis on the results.

Conversion of Land Use and its Effects (CLUE) [19] is a dynamic model which is used to simulate land use. The model is not developed for any specific region. CLUE simulates land use conversion and predicts the changes in the area over time by considering the interaction of biophysical and human drivers. If biophysical and human demands cannot be met by the existing land use, CLUE considers the region for a land use change. CLUE first carries out a regional assessment of land use needs and then arrives on the final land use on a local grid level. It considers biophysical drivers like land use history, spatial distribution of infrastructure and land use, and the occurrence of pests and diseases as well as human factors such as population size and density, access to technology, affluence of the region, economic conditions etc.

Building on CLUE, the CLUE-S model [20] was developed for land use analysis done in small regions at a finer resolution. The model is based on systems theory and integrates analysis of land-use changes with socio-economic and biophysical factors. The model takes into consideration the hierarchical organization of land use systems and spatial connectivity between locations.

There are still many aspects of land use modelling that are not met by the current land use models like addressing the multi-scale characteristics of the land use system, incorporating neighbourhood effects and integration between models studying rural and urban land use changes. This gives rise to the need for a new generation of land use change models that will support the land use dynamics analysis better and help in land use policy formulation.

2.2 Types of models

Models are defined variously. They can be considered as the formal representation of some theory of a system of interest. More broadly, models can be considered as abstractions of complex real-world relations to the point that they are understandable and analytically manageable. The representation of reality is expressed through the use of symbols. Mathematical techniques are applied for the manipulation of the relationships among the entities represented by these symbols. Hence, the term symbolic (or operational or empirical) model is used to distinguish it from other types of representation (e.g., conceptual models).

There exists a wide variety of land use change models wherein land use is the direct object of the modelling exercise. There are descriptive, explanatory, prescriptive, predictive and impact assessment models based on the purpose for which the model was built. There are local, regional, interregional, national and global level models based on the spatial scale of the data used. Models can be classified as geo-referenced, fully spatially explicit models and non-geo-referenced or incompletely spatially explicit models. Models can be urban, agricultural and forest sector models that take into account the deforestation, urbanization and other factors of the land under consideration. There are static, quasi-static or quasi-dynamic and dynamic models depending on the temporal conditions considered in the model. Models can also be classified as statistical, programming, gravity-type, simulation and integrated models based on the solution techniques used in building the model.

2.3 Modelling specific land use

Cellular automata has been used extensively to carry out urban land use modelling. Usually cell states represent land uses, and transition rules indicate the likelihood of a change from one state to another as a function of existing land use and the suitability of the cell for the land use. Sensitivity analysis of these models show that the predictions of the model are relatively accurate and reproducible, thus suggesting that cellular-automata-based models is useful for carrying out planning activities.

Another model was developed to predict the environmental stress connected with urban development and the associated changes in land use and human behaviour under various different economic, policy and environmental scenarios [23]. This model was built on UrbanSim, an existing urban simulation model developed by

Waddell. Businesses, developers, households and governments are the primary actors in this model. These actors decide on the land development and the location of activities. To represent the land use cover interactions at a regional scale and replicate the ecosystem processes, a spatially explicit process based landscape modelling approach was used.

MUSSA is another land use model developed to interact with the Santiago four-stage transport model called ESTRAUS [21]. It is a practical application of the BID-CHOICE theory of urban land market, where land rents are dependent on land availability and developers' behaviour. It interacts with the transport model ESTRAUS which represents economic access. MUSSA in turn provides the locations of households and firms. Total activity volumes and population forecasts are externally provided by a region input-output model. The whole system interacts through a central data base of geographic information system. MUSSA has been able to forecast location choices of 65 household clusters into 264 zones and six dwelling types plus five firm types allocated to lot sizes; residents and firms compete for the available land.

There exist several weaknesses in the present urban simulation models which reduce their ability to be used as planning support tools. However, models that use multi-agent systems coupled with cellular automata are beginning to find practical applications. Based on simulation techniques that have origins in artificial intelligence, they have a very practical application as potential for planning support tools, with the ability to simulate individual households in a dynamic and realistic manner.

2.4 Modelling Shifting Cultivation

Using the remote sensing data of Fouta Djallon mountains in the Republic of Guinea, West Africa a dynamic spatial model was developed that captured the land use change and deforestation in the region. The model was developed to simulate patterns of forest clearing for shifting cultivation and farmers' selection behaviour for new fields. The model took into account the topography of the area and proximity to villages. The projected outputs of the model were compared to the land use data collected in 1989. However, the model was unsuccessful in simulating the farmers' behaviour for selection of village proximity and topography accurately. [25]

Based on some of the fundamental mechanisms of shifting cultivation, another simple model was formulated, focusing on the flow of nutrients, and in particular the use of fallow vegetation for collecting and storing nutrients as well as the allocation of labour with the purpose of satisfying subsistence needs and maximizing labour productivity, and the management of agricultural land, in particular the opening of new fields and abandonment of old ones. A 'decision rule' was formulated, expressing how farmers select between a number of options in order to obtain the goals of satisfying food needs and maximizing labour requirements.

Both these models determined that site productivity as determined by the length of fallow is a critical variable for selection of the site for shifting cultivation. Based on a test, it was demonstrated that increase in population density would cause shortened cultivation-fallow cycle and so lead to a decrease in labour productivity.[26]

The existing shifting cultivation models take a top-down approach to land use distribution wherein estimates are made for a larger area of land and distributed locally. The interaction of different crop types is not taken into consideration in these models. In this thesis, we look to create a land use model that evaluates each land cover separately and understand the role played by them in affecting shifting cultivation. We want to understand and implement the dynamics of the different agricultural practices through which paddy crop is grown like irrigated cultivation, seasonal cultivation and shifting cultivation.

Chapter 3 - Area of study

3.1 Barak valley area

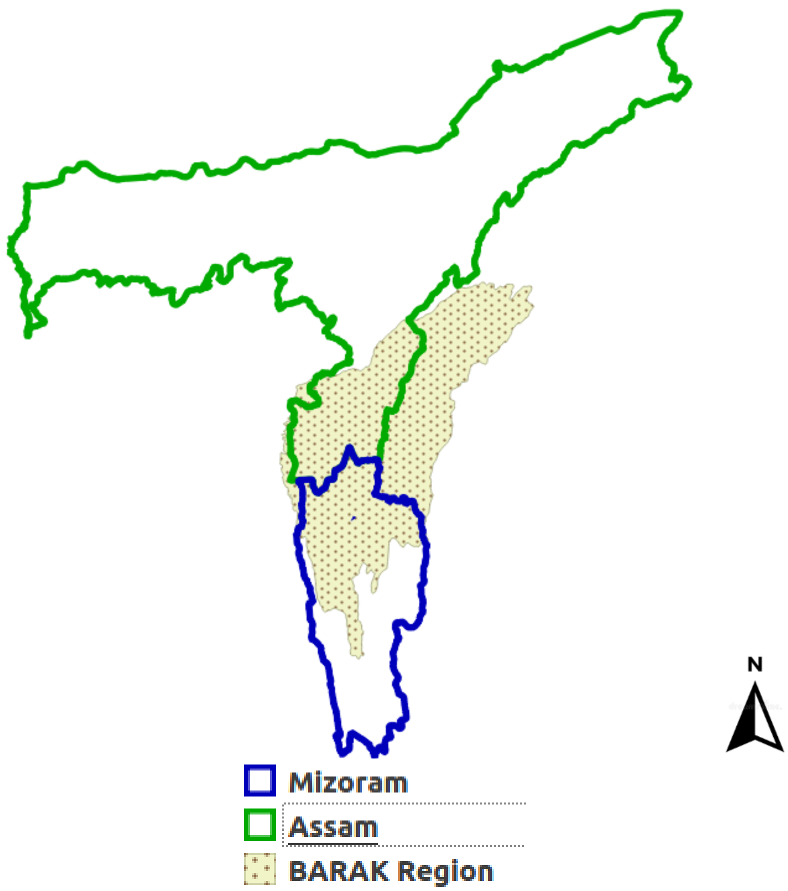


Figure 3.1: Location of Barak valley

Barak valley is a region in the northeast part of India that lies between longitude of 92°15’ and 93°15’ East and latitude of 24°8’ and 25°8’ North. It contains various districts over the two states of Assam and Mizoram. The area is largely forested and has not undergone much urbanization. The practice of shifting cultivation is widely followed in Barak along with the regular forms of cultivation. Under shifting cultivation, patches of forest land are used for temporary cultivation. Shifting cultivation is not very labour or resource intensive. Upon harvest, the shifting cultivation patches are cleared and moved to a different area of the forest. Rarely does cultivation happen in the same patch for consecutive seasons. Undoubtedly, this practice affects the forest cover negatively if increased beyond a sustainable limit.

3.2 Geographic description

In this thesis we are taking two regions of south Barak valley under consideration: the region under district of Hailakandi in Assam and extended Mamit region in Mizoram. The extended Mamit region consists of the Mamit district within the Kathakal basin as well as the contiguous forest patch which lies in parts of Kolasib and Aizwal districts. Aizwal district has 23% area in extended Mamit region and Kolasib district contributes 17%. The other 60% of extended Mamit region is taken up by area under Mamit district. Since Mamit is the primary district of this region, socio-economic data of Mamit, is used for modelling of the region.

Mamit is a district in Mizoram which is a state in the north-east region of India. The total Geographical area of the district is 3025 sq. km. The total forest cover of the district is 2741sq. km. Mamit is located 901 meter above sea level and the district gets an average rainfall of about 212 mm. The Geographical location of the Mamit District is between latitude $23^{o}17^{o}$N and $24^{o}15^{o}$N and longitude $92^{o}17^{o}$E and $92^{o}40^{o}$E. The district is surrounded on the north by the Hailakandi district of Assam, on the south by Lunglei district, on the east by Kolasib & Aizawl and on the west by the North Tripura district of Tripura. Mamit has a population of 86364 as per the 2011 census.

Hailakandi district in the southmost part of Assam. It is located between North Latitudes 24^{o} 08 and 24^{o} 53 and East Longitudes 92^{0} 25” and 92^{0} 46. The total geographical area of the district is 1327 sq.km. The district is located in the middle of Barak Valley and is surrounded by Cachar district in the north and east, Karimganj district in the west and Mizoram state in the south. The district has a varied topology with both plain and hilly areas. As per the 2011 census, Hailakandi has a population of 659,296. As per 2011 census, 92.70 % population of Hailakandi districts lives in rural areas of villages and 7.30 percent lives in urban regions of district.

3.3 Socio-economic description

Residents of Hailakandi districts are predominantly agriculturists. The total cultivated area is 44,670 hectares with rice being the major crop of the district, covering 36,500 hectares. Other crops like banana, pineapple, orange cover 1,700 hectares and beetle nut crops cover an area of 2,800 hectares. The area receives an annual rainfall of 2600mm and the total irrigated area in the region is 4,164 Hectares. The region has a temperate and humid climate.

Tea is the main organized sector industry of the district with 17 tea gardens covering 5,570.38 hectares. In the urban area, people are engaged in merchandise and other sundry activities.

District Name	Area in sq. km	Population in 2011	Rural Population	Urban population
Hailakandi	1,327	659,296	611,156	48,140
Mamit	3,025.75	86,364	71,465	14,899

Table 3.1: Population data for Mamit and Hailakandi as per 2011 census

Mamit's economy is primarily agriculture based as well with paddy as the major crop of the region. The staple food of the district's population is rice. Shifting cultivation (jhum cultivation) is the prominent form of cultivation in the region and produces the majority of agricultural products. The region majorly produces paddy which is cultivated in the Kharif season. During the Rabi season, other crops like potato, pulses, mustard, radish, tomato and cabbage are grown. The soil of the region is fertile. The vegetation of the region comprises of multiple species like bamboo, cane, fuel wood and timber species. In addition to agriculture, the secondary economic activity of the region is animal husbandry.

Figure 3.2: Effect of income change on land use patterns

Changing population and livelihood drives changes in land use patterns. As in Figure 3.2, With a rise in income, people tend towards more consumption. Access to disposable income increases the demand of society. As society's consumption increases, production systems need to keep up with the increased demands. To accommodate the increase in production, land use patterns get modified.

Looking at changing lifestyles, changing income patterns and the changing production systems, we can say that the Barak valley area is undergoing changes in agricultural system and economic lifestyles. These changes might cause changes in the land use patterns and influence shifting cultivation decreasing or being sustainable as people might gravitate towards more settled forms of agriculture.

Since pre-independence, there have been efforts made by the state forest departments to stop shifting cultivation through afforestation programs. Forest department personnel tried reducing shifting cultivation by increasing the forest cover. Schemes like Social Forestry and Nation Afforestation Programme were implemented for tree plantation on land under shifting cultivation. During these plantation drives, timber and fuel wood species were planted. National Bamboo Mission promoted the plantation of bamboo and other medicinal plants were planted under projects of Medicinal Plant Board. However, these plantation drives failed to address the food demands of the shifting cultivation farmers. Consequently, the farmers continued practicing shifting cultivation to meet their food demands. Most of the plantation schemes had an implementation period of 3 to 5 years. There were no mechanisms in place to monitor the outcomes after the scheme period was over. Thus, most of the afforested lands reverted to shifting cultivation post the plantation scheme end.

Conversion of shifting cultivation to settled agriculture was promoted by the departments of agriculture, horticulture and rural development. They introduced use of high yielding varieties, irrigation and the use of fertilizers which did not suit the available manpower, skillset, food preferences and topography of the region. Cashew nuts, tea, coffee, floriculture were introduced as alternatives to shifting cultivation but were successful only in areas connected to the market. Similarly, horticulture and sericulture were successful in areas where there was a demand for the produce.

The emphasis for most of the shifting cultivation rehabilitation schemes was afforestation with plantation crops and converting lands under shifting cultivation to settled agriculture. This conversion in itself led to a reduction of land available for shifting cultivation and consequently a reduction in the fallow periods. Presently, most areas in northeast India have a shifting cultivation cycle of as little as three to four years. With the reduced cycle period, the soil has insufficient time to regain its fertility or for the regeneration of secondary forests. This causes the productivity of shifting cultivation to drastically decrease as well as all the while encouraging forest degradation with a loss of biodiversity as well as increased soil erosion. Combined, all these factors have led to a marginalization of communities that practice shifting cultivation supported by the cycle of environmental degradation and poverty that encourage each other. The schemes that were aimed at reducing shifting cultivation through encouraging settled cultivation have generally failed in achieving their objectives as they have failed to provide food security and alternate livelihood options for the people in the region.

Post analyzing the schemes and projects implemented by the government and other agencies to encourage shifting cultivation reduction, we can concur that reduction of shifting cultivation is less driven by encouragement of cash crops, afforestation or modern agriculture and rather driven by more complex socio-economic development efforts [27]. While these studies have shown the importance of each or some of the factors, there is still a need to understand what happens when more than one factor influences the decision making in the region, especially broad policy directions that manifest as either environmental and/or economic stimulus and how the land use choices are made in response.

Chapter 4 - Data Used

4.1 Data needed by the model

Datasets needed by the model include both spatial datasets like land use data as well as non-spatial data like crop yield data across the years of study and modelling. The spatial data helps us understand the geographical characteristics of the region. Datasets like elevation and slope influence the type of crop that can be grown at a location. The non-spatial data helps us with understanding the economic and social fabric of the region. Information about parameters like population growth are provided by these datasets. These datasets help us to consider the socioeconomic parameters and how it affects the land use decisions.

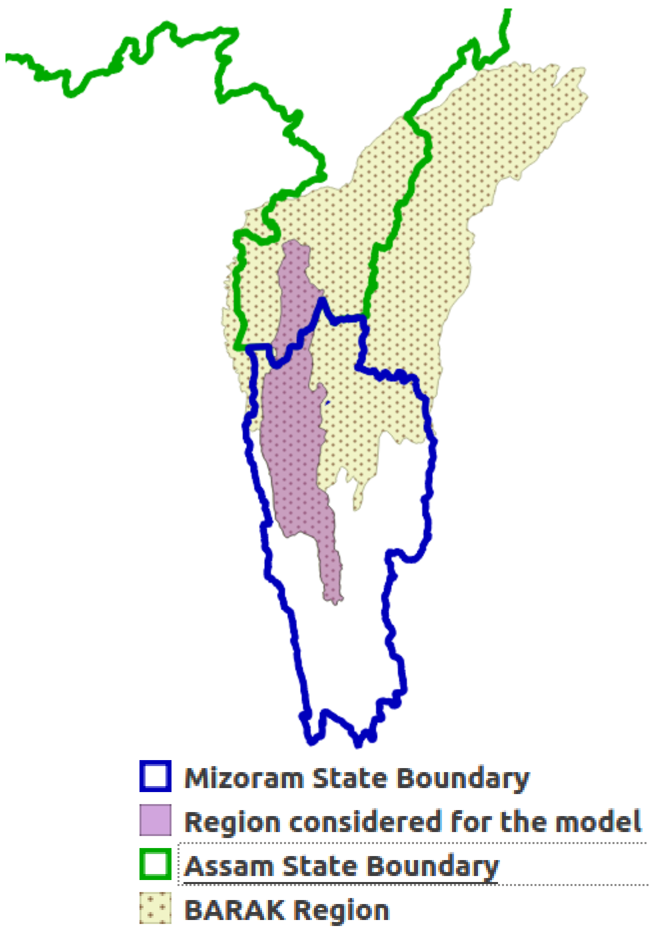


Figure 4.1: Location of the regions of Barak considered for the model

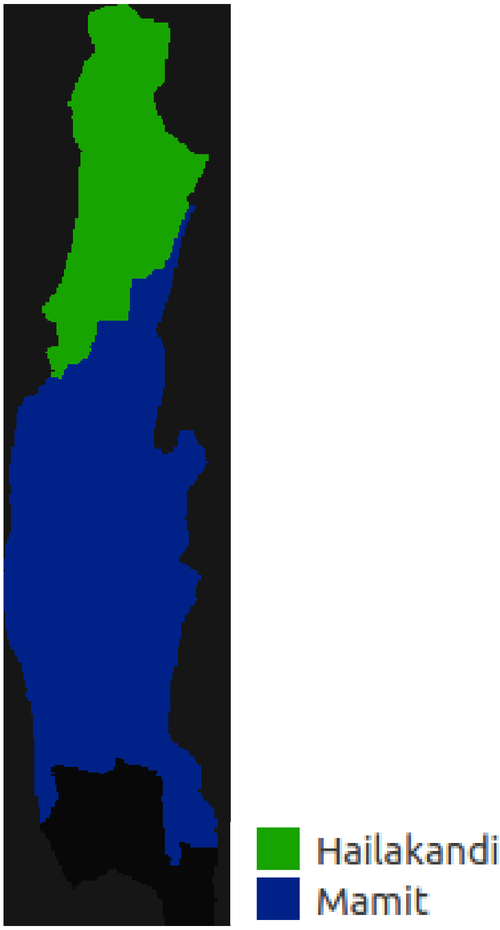


Figure 4.2: A closer look at the regions of Barak considered: Extended Mamit and Hailakandi

4.1.1 Spatial data

The model needs district boundary spatial data which provides us with the political boundary of each of the districts which are treated as individual agents in the model. Elevation data will be used to separate out upland and sedentary cropping areas. Areas with higher elevation would be used for cash crops and lower elevations for rice shifting cultivation. The datasets gathered through various sources were modified to be suitable as an input for the model. All spatial datasets are at a resolution of 500m. Section 4.2 covers the details of the modifications made to the existing datasets to make it suitable for the model.

Land Use Data

Land use data is used to provide the land use map for the base year at a resolution of 500m. It contains five Land use classes namely – cultivation (with sub-classes of irrigated cultivation, seasonal cultivation, shifting cultivation), forests, road, river, and urban. Land use classes of road, river and urban areas are collapsed into a single class for this model. The river and road data that is needed in the model is extracted separately. This land-use map is present for three years - 1988, 1997 and 2005 *(Figure. 4.5)*. Land use map for 1988 is used as base year input and the maps for 1997 and 2005 are used to validate the model simulation outputs. Further details about the modifications made to the land use maps are mentioned in section 4.2.2.

Elevation and Slope Data

Elevation and slope data are used for assigning different agricultural categories to cultivable land. As shown in Figure 4.3, the elevation of the study area shows various land topologies. Depending on elevation and slope different varieties of crops can potentially be grown. These are taken into consideration while deciding the agricultural land type of a particular parcel of land.

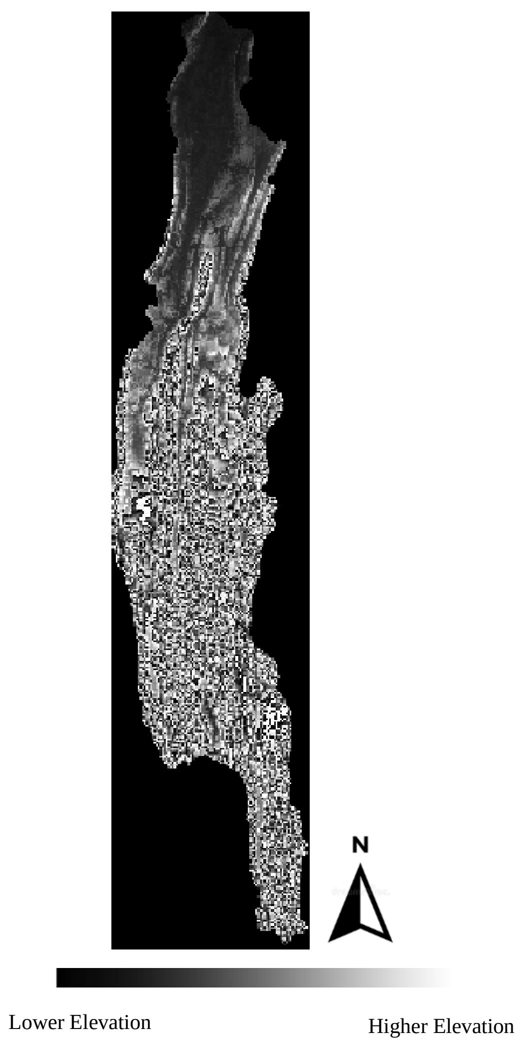


Figure 4.3: Elevation data map for the Barak region at 500 m resolution

Population Data

Population data is needed to calculate food demand for each year. Coupled with population growth rate, it provides a means to track the increase in demand for the area. Population spatial data map was generated based on the land use, topography and the district level population. It is needed for district wise population and hence district demand. Calculation of household income also uses population. Further details about how population dataset was generated are presented in section 4.3. Sources and characteristics of the dataset are mentioned in table 4.1.

Other Ancillary Spatial Data

River data which corresponds to the location of the river flow is used for identifying the cultivated land parcels that practice either irrigation-based paddy cultivation or seasonal/rainfed paddy crop cultivation. For the purposes of this model and based on ground information, it is assumed that all Irrigated rice (IR) crop is grown in close proximity to the river since no artificial irrigation means are available in this area. In addition, road spatial data is used to delineate areas where cultivation may not be possible. River and road data is used to determine the location of irrigated cultivation lands.

Name	Data characteristics	Source
Land use	Land use data with resolution of 500m used. Land use map data for years 1988, 1997, 2005 used for model.	NESAC
Elevation	Elevation data used at a resolution of 500m.	NESAC
Population	Population dataset was generated by distributing population over the area	Generated by using census data. Detailed in section 4.3

Table 4.1: Data used in the model and their characteristics.

4.1.2 Tabular datasets

Crop yield is used in a tabular format as the data provides us with year-wise yield of each of the four varieties of crops. This is used to calculate the food supply of the districts and crop yield is used for calculating the area of cultivable land that is needed to satisfy the food demand. Farmgate price data provides us with price per tonne for each type of crop. This helps calculate household income. Population growth data provides the population increase happening every year and is needed to calculate the increased demands.

4.2 Modified datasets

As all raster datasets were sourced from different organizations or datasets, they had different map projections and cell resolutions. Using a python code, the data was resized, map extents matched and projections converted to a common one. Using python modification of bil files and GDAL module following codes were written to make changes to the data

- A python code that takes as input all the raster files that were to be used and calculates the coordinates of the bounding box that would contain them all. This estimates the size of the new raster files that would be created such that none of the data in any files is lost.
- A python script that reads the raster files into a NumPy array which is then modified so that all the data can be in the same coordinates. The external regions where the original data had no values is given the value 0. The original data is maintained as such in the areas of interest. The points where an error occurred would hold the value 255.

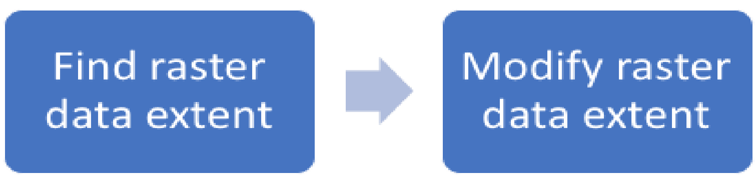


Figure 4.4: Raster data modification

4.2.1 Crop yield dataset modifications

We needed spatial data for crop yield for each year. We have land use spatial data for each year. So, we get the crop type for that land parcel and check the crop yield table to find what was the yield for that particular crop in that year and add to the spatial crop yield map. By doing so we end up with a spatial dataset containing yearly crop yields. Tables 4.3 and 4.4 show the crop yield data generated for Mamit and Hailakandi respectively.

4.2.2 Land use dataset modifications

The land use categories in the dataset can be divided into three categories. The first category is non-consequential land use types. These are the land use categories that do not affect the model run. They include land use categories like urban and built up area, roads etc. These land use categories are ignored in the land use maps used as input in the model as well as the generated maps.

The second category of land use is cultivated land use types. These represent the area under cultivation in the region. The area under these types of land use was divided in two categories for use in the model: irrigated cultivation and seasonal cultivation. Irrigated lands are those with access to artificial irrigation. Proximity to river is used as the determining criteria to classify a cultivated land parcel as irrigated cultivation. The remaining are grouped into seasonal cultivation.

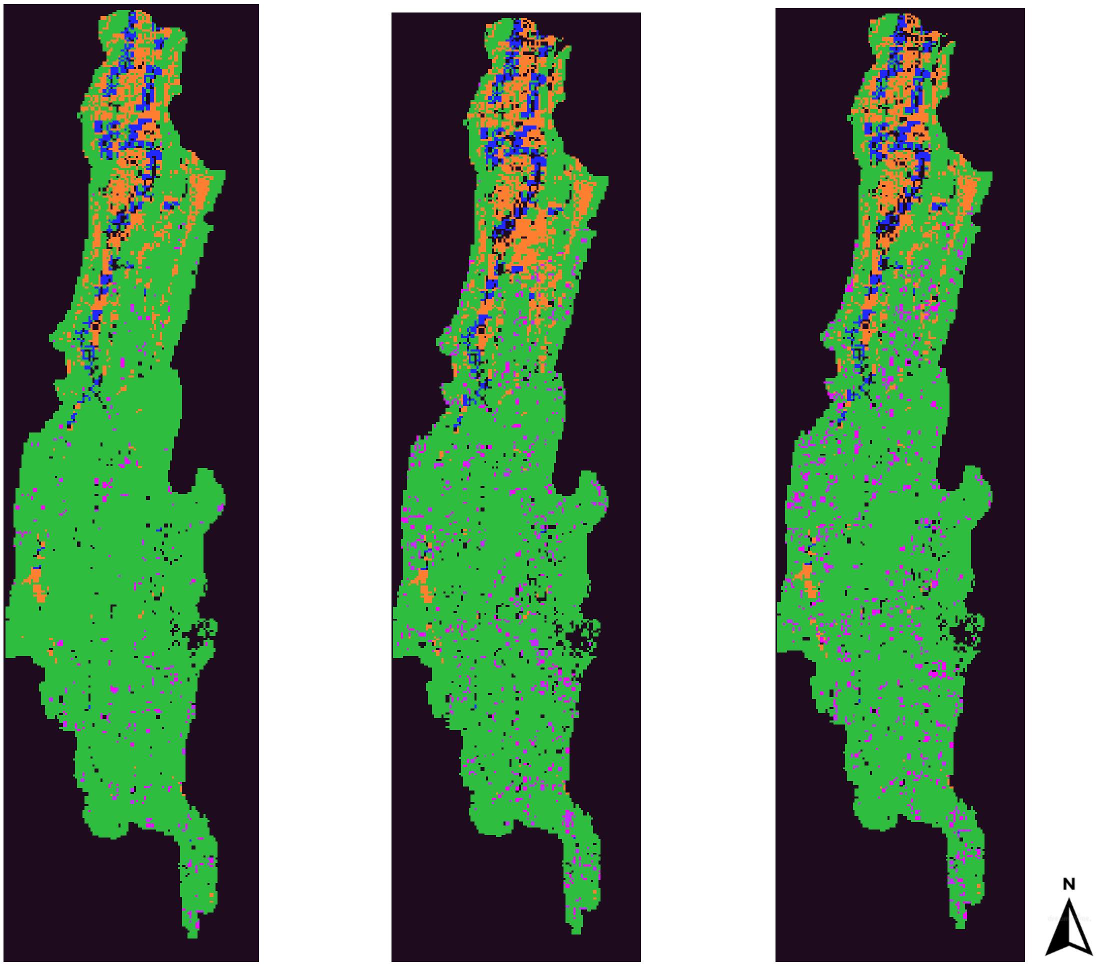
The third category of land use is forests. For the model, forests are potential areas for land use change as well as sites for shifting cultivation. The model does not differentiate between the different types of forests.

The data received from NESAC was present in vector form as shp files and was converted to raster binary form of bil files using GDAL. The various categories forests were combined into one. The land parcels categorized as croplands and plantation were recategorized as cultivated lands. Table A.1 in annex captures the details of reclassification of different land use classes.

To split the cultivated land into irrigated agriculture and seasonal (or rainfed) agriculture, river data was used as rivers are the primary mode of irrigation in the area. Areas within 1km distance from the river were treated as irrigated cultivation and the rest were treated as seasonal cultivation.

Once the land use vector files were modified to have new land use codes, the next step was to convert the vector files to raster. Rasterize function in QGIS was used to convert the files to .tif file. Once we had a tiff raster file, GDAL command line and gdal_translate function were used to convert the tif file to bil format.

gdal_translate -of ENVI LandUse.tif LandUse.bil



Land use map for 1988 Land use map for 1997 Land use map for 2005

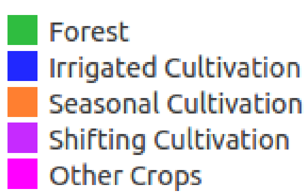


Figure 4.5: Land use maps for 1988, 1997 and 2005 at 500m grid resolution

	2005 Irrigated Cultivation	2005 Seasonal Cultivation	2005 Shifting Cultivation	2005 Forest
1988 Irrigated Cultivation	510	0	0	0
1988 Seasonal Cultivation	0	1480	0	0

1988 Shifting Cultivation	0	0	30	83
1988 Forest	24	339	338	13454

Table 4.2: Land use change matrix between land use maps of 1988 and 2005

4.3 Generated datasets

A spatial dataset of population is required for the model run. It helps us identify the population density in each area under consideration. Population data would also help in calculating the food demand of each region. While the population values for each of the two regions under consideration was readily available through government census data, the data that showed distribution of population in each of the three districts did not exist. Consequently, spatial population data was decided to be generated by using a weighted distribution of the population with the weights determined by the land use of the land parcel. The population spatial data needed for the model run was generated using the land use spatial map and the population figure for each of the two districts. To do so we assigned weights to each land use type. Land uses such as urban were given higher weights whereas dense forests were considered devoid of any population. Based on these weights we distributed the population of Mamit and Hailakandi over the two regions. We came up with each year's population spatial distribution by using this generated map (Fig 4.6).

Figure 4.6: Generated population distribution map for 1988 at 500m grid resolution

Year	Crop yield for irrigated cultivation	Crop yield for seasonal cultivation	Crop yield for shifting cultivation
1988	2.05	1.94	1.47
1989	2.05	1.94	1.47
1990	2.05	1.94	1.47
1991	2.05	1.94	1.47
1992	2.05	1.94	1.47
1993	2.05	1.94	1.47
1994	2.05	1.94	1.47
1995	2.05	1.94	1.47
1996	2.05	1.94	1.47

1997	2.05	1.94	1.47
1998	2.05	1.94	1.26
1999	2.05	1.94	1.49
2000	2.05	1.94	1.66
2001	2.05	1.94	1.57
2002	2.05	1.94	1.62
2003	2.05	1.94	1.66
2004	2.05	1.94	1.57
2005	2.05	1.94	1.57
2006	2.05	1.94	1.5
2007	2.05	1.94	1.5
2008	2.05	1.94	1.5
2009	2.05	1.94	1.5
2010	2.05	1.94	1.5
2011	1.99	1.94	1.06
2012	2.09	1.92	1.1
2013	2.07	1.61	1.13
2014	2.19	2.29	1.18
2015	2.11	1.71	1.23
2016	2.11	1.71	1.18
2017	2.17	1.64	1.18
2018	2.14	1.83	1.18
2019	2.14	1.83	1.18
2020	2.14	1.83	1.18
2021	2.14	1.83	1.18
2022	2.14	1.83	1.18
2023	2.14	1.83	1.18
2024	2.14	1.83	1.18
2025	2.14	1.83	1.18
2026	2.14	1.83	1.18
2027	2.14	1.83	1.18
2028	2.14	1.83	1.18
2029	2.14	1.83	1.18
2030	2.14	1.83	1.18
2031	2.14	1.83	1.18
2032	2.14	1.83	1.18
2033	2.14	1.83	1.18
2034	2.14	1.83	1.18
2035	2.14	1.83	1.18

Table 4.3 Generated dataset for Mamit crop yield

Year	Crop yield for irrigated cultivation	Crop yield for seasonal cultivation	Crop yield for shifting cultivation
1988	2.94	2.8	1.52
1989	2.94	2.8	1.52
1990	2.94	2.8	1.52
1991	2.94	2.8	1.52
1992	2.94	2.8	1.52
1993	2.94	2.8	1.52
1994	2.94	2.8	1.52
1995	2.94	2.8	1.52
1996	2.94	2.8	1.52
1997	2.94	2.8	1.52
1998	2.94	2.8	1.26
1999	2.94	2.8	1.49
2000	2.94	2.8	1.66
2001	2.94	2.8	1.58
2002	2.94	2.8	1.62
2003	3.6	2.87	1.66
2004	3.34	2.42	1.57
2005	2.43	2.85	1.57
2006	3.02	3.23	1.32
2007	2.33	2.95	1.35
2008	3.7	3.26	1.35
2009	3.87	3.49	1.35
2010	3.51	2.99	1.35
2011	3.36	4.03	1.35
2012	3.83	3.86	1.35
2013	3.65	3.52	1.35
2014	3.65	3.52	1.35
2015	3.65	3.52	1.35
2016	3.65	3.52	1.35
2017	3.65	3.52	1.35
2018	3.65	3.52	1.35
2019	3.65	3.52	1.35
2020	3.65	3.52	1.35
2021	3.65	3.52	1.35
2022	3.65	3.52	1.35
2023	3.65	3.52	1.35
2024	3.65	3.52	1.35
2025	3.65	3.52	1.35
2026	3.65	3.52	1.35
2027	3.65	3.52	1.35
2028	3.65	3.52	1.35

2029	3.65	3.52	1.35
2030	3.65	3.52	1.35
2031	3.65	3.52	1.35
2032	3.65	3.52	1.35
2033	3.65	3.52	1.35
2034	3.65	3.52	1.35
2035	3.65	3.52	1.35

Table 4.4 Generated dataset for Hailakandi crop yield

Chapter 5 - Model Implementation and Base Scenario

5.1 Overview

The model starts with the knowledge of the year 1988 and tries to predict the land use maps of 1997. We then compare the predicted maps with the originals and modify the variable parameters of the model to better fit the actual land use data for 1997. With these updated parameters we generate land use maps for the year 2005 and check its accuracy against the actual land use maps of 2005. The model takes into consideration the settled forms of paddy cultivation in the form of irrigated rice and seasonal rice. Shifting cultivation is considered separately. Shifting cultivation happens to satisfy unmet food demands of the region and so all changes considered in the model are in the context of food demand and its supply.

5.2 Implementation level details of the model

The model starts with datasets about population, food needs, crop yields and existing land use map of the area. Firstly, the data required pre-run for the two regions that act as our agents is generated through the following steps:

1. We calculate the population for the region based on the population distribution map of the area.
2. The amount of area under each type of cultivation is calculated for each district.
3. With this information, the supply provided by the district is calculated.

With the data for demand and supply for each of our agents, the model run is started.

The model only considers agricultural land parcels for modelling. All other changes to the land use classes are ignored by the model. There exists a preference in land use allocation among agricultural classes. Irrigated cultivation is preferred over all other forms of cultivation. This is due to the higher yield of irrigated cultivation compared to the other forms and the fact that irrigated cultivation is planned and can be predicted accurately. Shifting cultivation, on the other hand, is random and predicting whether a forested land area would be under shifting cultivation is less structured. Similarly seasonal cultivation is preferred over shifting cultivation due to its settled nature and high predictability. The model moves to shifting cultivation allocation only if the yield from irrigated and seasonal cultivation is unable to meet the food demand. Among the agricultural classes as well, the individual classes do not compete for the same land parcel. The model considers a consumption driven economy and hence a consumption driven land use planning is implemented.

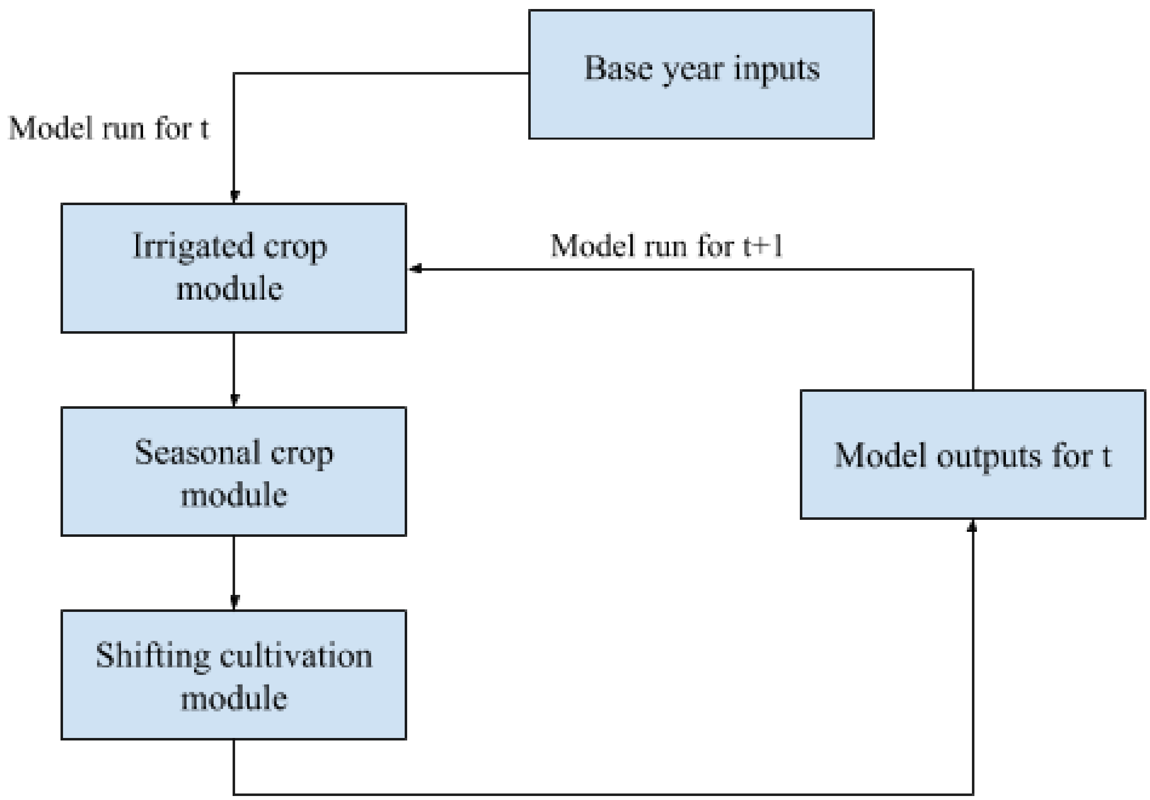


Figure 5.1: Model architecture, where ‘t’ is the year of the model run

5.2.1 Irrigated Crop Module:

The goal of this module is to allot irrigated crop areas. The module takes as input the current demand as well as the supply from the previous year.

With the knowledge of crop yields and food demand, the area of cultivation required to satisfy the demand is calculated. If the rice supply provided by the existing cultivated areas is unable to meet the demand, the irrigated areas are allowed to expand to cultivated areas which satisfy the river proximity. However, we limit the expansion keeping in mind the limited infrastructure growth in the area. Here we assume that as infrastructure grows, areas that relied on seasonal rainfall for agriculture would convert to new irrigation means. Growth in Irrigated cultivation can be represented as,

$$I_{t+1} <= I_t + p(I_t)$$
$$I_{t+1} >= I_t$$

where $I_{t+1}$is the area under irrigated cultivation in year t+1 and I_t is the area under irrigated cultivation in year t and p is the parameter that limits irrigated crop growth. The parameter p is representative of the limited infrastructure resources needed to expand irrigated cultivation. The value of p is experimentally derived over runs of the model.

After adding the new irrigated cultivation areas, the new supply is calculated. If the food demand is still not satisfied, seasonal crop module is invoked with the information about the food demand and the updated supply.

5.2.2 Seasonal Crop module:

This module adds the yearly increase in seasonal cultivation needed to meet the food demand. It takes the updated food supply after the addition of irrigated areas and the food demand of the region.

In seasonal rice module, we model the form of cultivation that relies mainly on rainfall for sustenance. Here we consider the rice demands leftover after irrigated rice expansion, if any. These demands, after translation to the amount of cultivated area needed, are assigned to seasonally cultivated lands. If the food demands are not satisfied by the existing seasonal cultivation, it is expanded based on neighbourhood rules and the slopes in the area. The expansion is however limited by the parameter of seasonal cultivation increase threshold based on resources that are available.

$$S_{t+1} \leq S_t + q(S_t)$$

where $S_{t+1}$is the area under seasonal cultivation in year t+1 and S_t is the area under seasonal cultivation in year t and q is the parameter that limits seasonal crop growth. If the demand is not satisfied even after additional seasonal crop, shifting cultivation module is invoked with the updated supply and the food demand.

5.2.3 Shifting cultivation module:

Traditionally, the land is cultivated for a year, and then left to revegetate naturally for up to 50 years before the entire cycle (locally called 'Jhum') is repeated. Depletion in soil carbon continues throughout the cropping period of one year and extends up to a five-year fallow. This is a major reason why shorter jhum cycles are detrimental to soil fertility. The amount of phosphorous in the soil increases only when the fallow period is more than five years and increases rapidly if the fallow period is more than ten years. A shorter jhum cycle of about five years causes low levels of soil fertility with very slight recovery of soil fertility during the fallow period. [27]

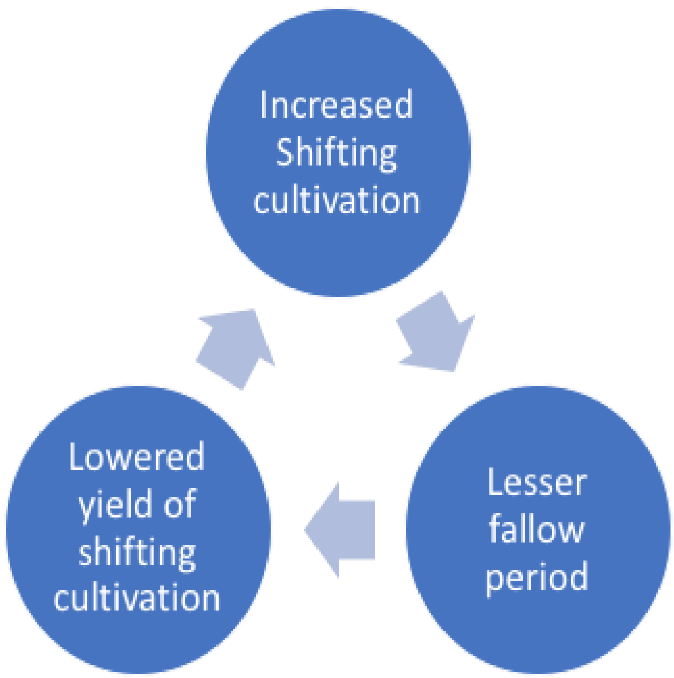


Figure 5.2: Effect of fallow period on shifting cultivation

This module calculates and allocates the shifting cultivation of the region. The rice demand that has not been satisfied by either irrigated or seasonal cultivation are passed on to shifting cultivation. It takes the demand and the supply and based on that allots shifting cultivation areas. All forested regions are allowed to be used to do or expand shifting cultivation. For shifting cultivation, each of the districts' demands is considered separately. As in the other two modules, we calculate the land needed to satisfy the demand based on the yields of shifting cultivation. We observe the existing SC areas and since these areas would not be used for a few years, they are reassigned to other areas that are currently under forest cover. If more areas are needed, random allocations are made from forested areas. All shifting cultivation land is randomly allocated within the existing forest cover. The model also takes into consideration the presence of a non-staple crop that is grown primarily for economic purposes. Based on the observed practices, these crops are assigned to areas that were previously under forest cover.

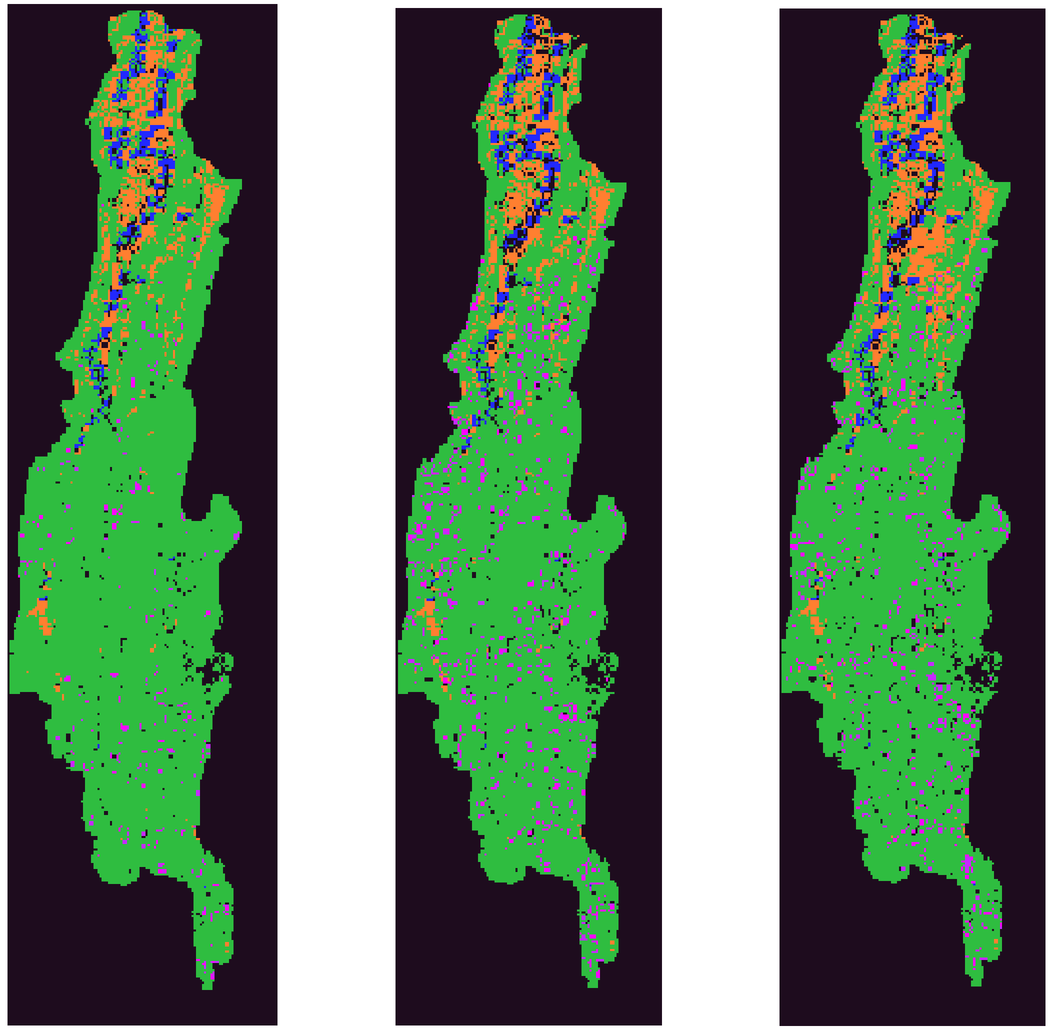
Based on the newly assigned areas of cultivation, the new land use map is generated at the end of each time step. This land-use map is provided as input for next year run of the model. The population growth rate is used to generate the population distribution map for the next year.

5.3 Execution and results

The land use maps shown in Figure 5.3 show the change in agricultural patterns in the area over a period of about 20 years at a resolution of 500m. Between the years of 1988 and 1997, we can see an increase in the shifting cultivation of the region. The land use map of 2005 shows a significant increase in seasonal cultivation. This signifies the change towards sedentary forms of agriculture.

As it can be observed from the figure, the northern region has a significantly higher concentration of irrigated lands while the southern region mainly has shifting cultivation. The northern region also has a higher concentration of seasonal cultivation. These are the more settled regions of the area, that are more densely populated and have better access to infrastructure. The access to infrastructure facilitates the seasonal cultivation increase in the region.

The southern region however is more heavily forested with lower population densities. Over the period of 20 years, the heavily forested region does not undergo any drastic transformation. There is some increase in the shifting cultivation in the region, but the region is not transformed towards settled forms of agriculture. These regions are predominantly rural areas with little access to infrastructure resources which limit their move towards settled agriculture.



Actual land use map for 1988 Actual land use map for 1997 Actual land use map for 2005

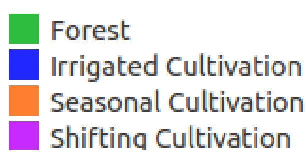
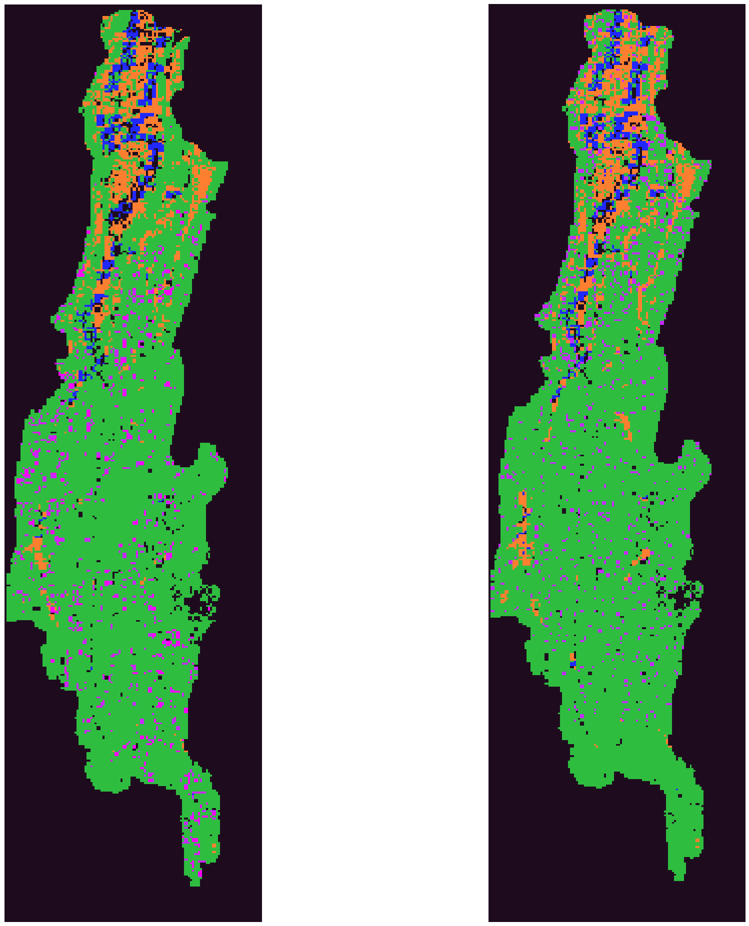


Figure 5.3: Actual land use maps of Barak valley for years 1988, 1997 and 2005 respectively derived from satellite imagery at 500m grid resolution

5.3.1 Test run: 1988 – 1997

First a test run of the model is conducted for a period of 9 years with the initial input of land use map for 1988. This model will generate a land use map for 1997 as output. Based on the analysis of this output, the model parameters will be fine-tuned. If the test run shows reasonable accuracy, it is understood that the model is established and can be used to predict future land use patterns.



Actual land use map for 1997 Modelled land use map for 1997

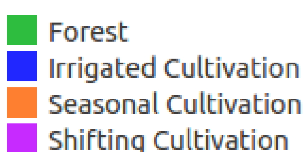


Figure 5.4: Modelled vs actual land use maps for 1997 at 500m grid resolution

The accuracy of the model is calculated using a confusion matrix. The columns of the confusion matrix represent the land use pattern generated by the model and the rows represent the actual land use pattern as captured through remote sensing data.

The spatial accuracy of the model will vary with each run as the generated spatial location of shifting cultivation land parcels will vary in each run.

The model is executed initially with the land use map of 1988 as input. The model run is conducted for a period of 9 years. The result of this run gives us the land use map of 1997. This land use map shows the modelled distribution of different forms of agriculture in the region.

Based on the actual land use map of 1997, the parameters of the model are fine-tuned. The model is rerun for the years up to 1997 with the updated parameters. We calculate the accuracy of the model using a confusion matrix. The confusion matrix for 1997 against the actual land use distribution map for the same year shows that the updated model has an accuracy of about 98%. (See Table 5.1) After some fine-tuning of the model parameters, we were able to achieve a 98% accuracy from the model. Since the accuracy of the 1997 land use map generated as output by the model is good, these model parameter values can be said to represent the prevailing conditions in the region with a reasonable accuracy and will be used to predict the land use for all further years.

Model parameter values after model fine-tuning

- Irrigated cultivation increase threshold: 0.003
- Seasonal cultivation increase threshold: 2.8

Accuracy: 0.988	Predicted Irrigated cultivation	Predicted Seasonal Cultivation	Predicted Shifting Cultivation
Actual Irrigated cultivation	510	0	1
Actual Seasonal Cultivation	13	1472	3
Actual Shifting Cultivation	0	6	48

Table 5.1: Confusion matrix and accuracy for year 1997

5.3.2 Validation run: 1997 - 2005

Based on the confusion matrices in Table 5.1 the model performs with an accuracy of 98% in the year 1997. When the model is run for the year 2005, the confusion matrix shows an accuracy of about 94%. Based on these results the model shows a reasonable amount of accuracy in predicting the land use of the Barak valley region.

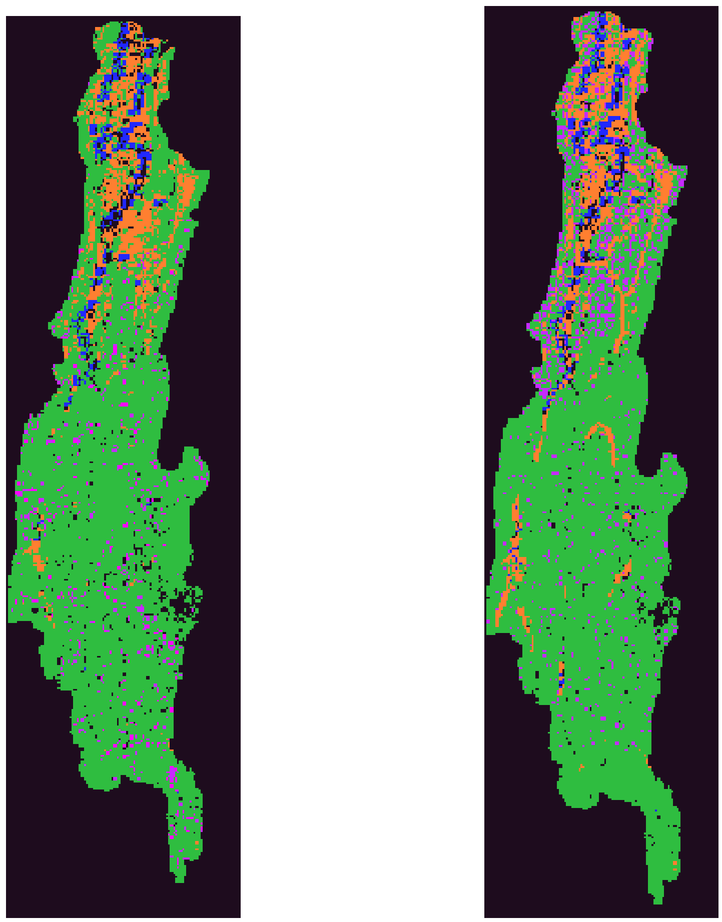
Interestingly, the two districts under consideration show distinct patterns of land use changes. As can be inferred from Figure 5.2, the northern district of Hailakandi shows more areas under irrigated cultivation as compared to Mamit district which show a high percentage of area under forests and shifting cultivation. The districts under consideration have different primary land uses and continue to have so over a period of approximately 20 years. Our model is able to capture these differences quite well in the two districts

Accuracy = 0.94	Predicted Irrigated cultivation	Predicted Seasonal Cultivation	Predicted Shifting Cultivation
Actual Irrigated cultivation	510	2	3
Actual Seasonal Cultivation	21	1478	96
Actual Shifting Cultivation	0	7	40

Table 5.2: Confusion matrix and accuracy for year 2005

The overall accuracy of the model results is 98.8% in 1997 and 94% in 2005. The different districts might have different conversion rates which might be causing this drop in accuracy. While the model is able to decide between different land uses, such distinct differences in the land use patterns in the two districts might be giving rise to the drop in accuracy observed here.

With this model we have tried to understand the reasons behind the distribution of cultivable land in Barak valley. The irrigated form of cultivation, even though high yielding, is unable to support the food demands of the region, primarily due to the absence of infrastructure that would support its expansion. Owing to this the lesser yielding forms of cultivation like seasonal and shifting cultivation are heavily depended upon to bridge the gap between supply and demand. This causes an extreme pressure on the forested regions in the area and shifting cultivation is still prevalent in the area despite there being policies against it.



Actual land use map for 2005 Modelled land use map for 2005

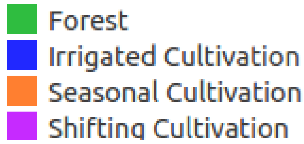


Figure 5.5: Modelled vs Actual land use maps for 2005 at 500m grid resolution

Chapter 6 - Scenario Building and Simulation

Based on the model runs and the accuracy results presented in the previous chapter, the model can be said to have reasonable accuracy. Since model is stable, we want to understand the policy and decision-making interactions and their effects on the ground. For this we have come up with four different scenarios, including the business-as-usual scenario, each representing a specific form of social or policy change. Each of these scenarios is run for a further period of 30 years (2005 - 2035). We want to explore the effect of social and economic factors on land use and agriculture patterns. All these scenarios are run independently. Since the districts vary widely in their land use patterns, the scenarios are analysed in a district-wise pattern.

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	508	1631	62
Mamit	26	188	345

Table 6.1. Number of land parcels of 25Ha each under various forms of land use for the year 2005

6.1 Development of scenarios

6.1.1 No growth of settled agriculture

The first scenario created was one in which there was no increase in lands under irrigation. This corresponds to a policy change that deprioritizes infrastructure growth in the area. Lack of infrastructure growth in the area would limit the growth of irrigated cultivation since people would have to rely on the river for irrigation and hence would not be able to expand irrigated agriculture practices. The agriculture patterns are expected to move from high yielding irrigated cultivation towards low yielding seasonal and shifting cultivation. This scenario helps to understand what effects the growing population and increased demand have on the land use change, when there is no policy intervention.

6.1.2 Incentivisation settled agriculture

The second scenario created was one in which settled forms of agriculture are incentivized through policy changes coupled with high infrastructure investments in the area. In this case we remove the capping parameters on the growth of irrigated and seasonal cultivation practices. This scenario expects a huge shift from shifting cultivation to settled cultivation forms and hence is favourably viewed towards Land use-cover changes.

6.1.3 Doubling of population

A third scenario was simulated that considers the social factors involved. We want to simulate what the land condition would be if there is a massive migration from nearby places to Barak valley accompanied by its growth. Hence, we presume doubling the population of each of the districts. This scenario is expected to put a massive strain on land resources to meet the food demand of the increased population.

6.1.4 Business as usual

With the business-as-usual scenario, the model is allowed to run as-is. The parameter values are kept same as in the initial model run from 1988-2005. The parameter values are those that most accurately predicted the land use map for 2005. Through this scenario we want to look at the changes in land use of the region when no drastic policy changes are made for the area.

As shown in Figure 6.1, we consider an environment vs economic development axis-based quadrant method to explain the four scenarios that were chosen modelling potential land use changes. The positive x-axis corresponds to increased efforts for ecological conservation and the negative x-axis denotes no efforts being made for ecological conservation. Similarly, the y-axis denotes economic growth of the region. If we plot each of the scenarios on the quadrant, we come up with a figure as shown in Figure 6.1. The BAU scenario, lies in the third quadrant as in BAU scenario, we are not taking any special efforts towards ecological conservation. Also, since minimal efforts are being put into the growth of irrigation infrastructure, the economic growth does not seem to be great.

By contrast, for the scenario of incentivization of settled agriculture placed in the first quadrant, there are great investments being made into building irrigation infrastructure. This points to economic growth. As a result of increased irrigated cultivation, the amount of shifting cultivation is expected to reduce which helps in ecological conservation.

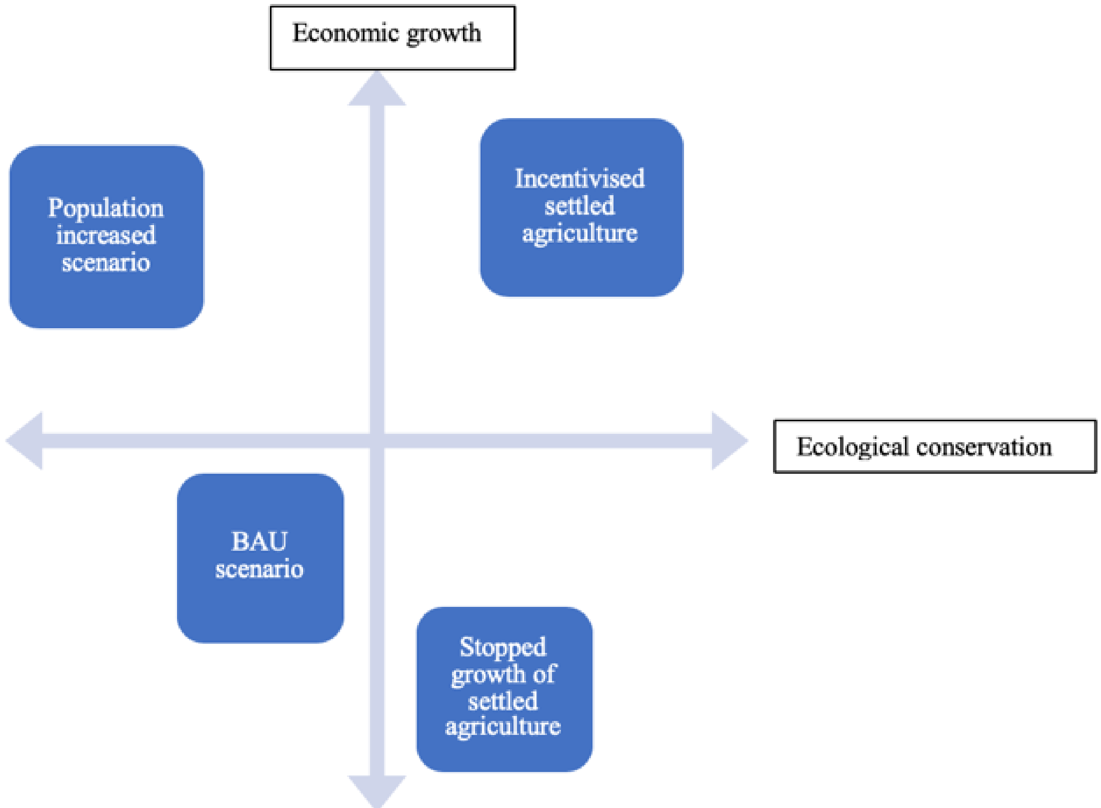


Figure 6.1: Economic growth vs ecological conservation quadrant

The scenario where population is increased is placed in the second quadrant and can be seen as an economic growth which has raised the food consumption and demands. The increased demands however, put a huge stress on the environment and leads to exploitation of land.

The scenario where growth of settled agriculture is stopped, is placed in the fourth quadrant. Stopped growth of settled agriculture can be seen as restrain on investments in infrastructure, which points towards a decrease in economic development. The decreased infrastructure growth slowly but surely pushes towards high areas of lands under shifting cultivation which leads to degradation of forest cover.

Since the districts vary widely in their land use patterns, the scenarios were analysed in a district-wise pattern. Our initial model runs also pointed towards a look into district wise analysis of land use patterns.

6.2 Results of scenarios

The two districts under consideration have very different land use patterns. The district of Hailakandi has a mix of urban and rural populations. With the presence of urban areas, the district also has a much higher population than the neighbouring district Mamit. Hailakandi has around 40% of its area under settled cultivation of which irrigated cultivation occupies 25%. Shifting cultivation is minimal but present in around 2% of the total district area.

The district of Mamit has more of a rural population. It is sparsely populated and is a heavily forested district. Around 92% of the total land area in the district is forested. Shifting cultivation is practiced in the area and occupies around 6% of the total district area. The settled forms of agriculture are not as prominent taking up less than 2% of the land area. The district has low population and consequently low food demands as is evident by the low percentage of agricultural land in the district.

6.2.1 Business-As-Usual Scenario

The district of Hailakandi has a higher percentage of land under irrigated cultivation. It also has a higher population density. The population of Hailakandi is more than five times the population of Mamit for any given year. Consequently, the demand of the district is much higher than that of Mamit district.

Hailakandi has a good mix of irrigated, seasonal and shifting cultivation with more practice of settled agriculture. The district of Mamit however has more reliance on shifting cultivation. The amount of area under irrigated cultivation is very low in the district due to a lack of infrastructure resources.
Mamit however has both seasonal as well as shifting cultivation that cater to the food demands of the district.

Parameter List

- Irrigated cultivation increase threshold: 0.004
- Seasonal cultivation increase threshold: 2.8

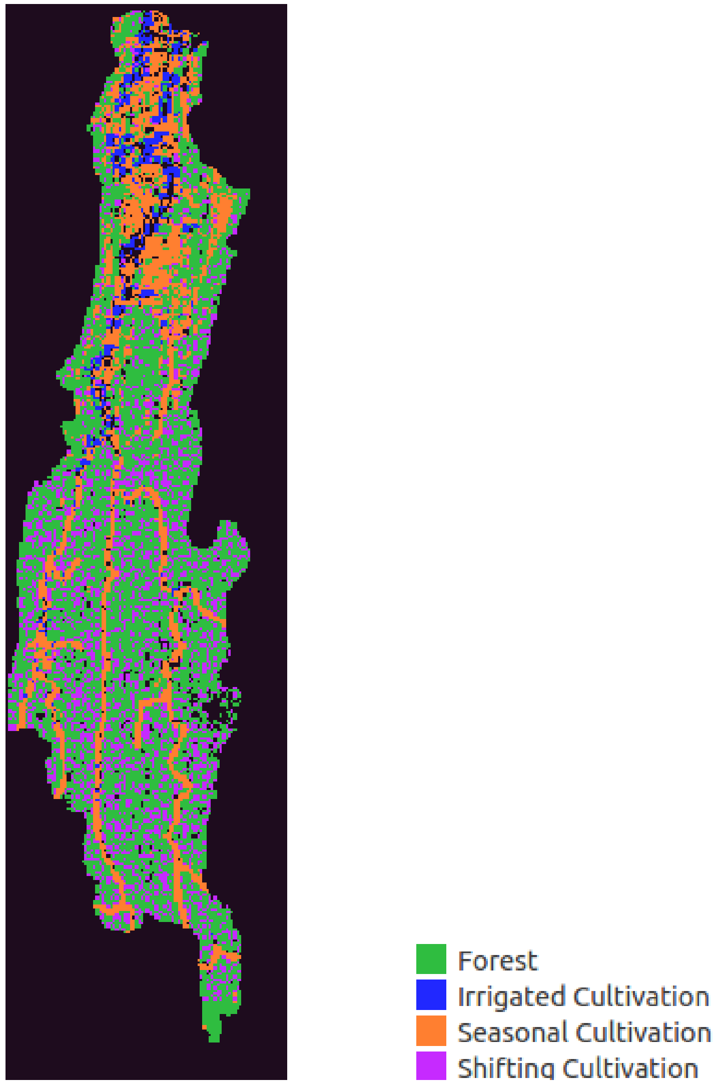


Figure 6.2: Land use map for 2035 when simulated with business-as-usual scenario at 500m grid resolution

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	572	1768	598
Mamit	82	1488	3971

Table 6.2: Amount of land under various forms of land use in the business-as-usual scenario for the year 2035

6.2.2 Incentivization of settled forms of agriculture

When settled forms of agriculture are allowed to grow with no restrictions, we can see a shift towards the high yielding irrigated cultivation. The settled forms of cultivation have much higher yields irrespective of the district.

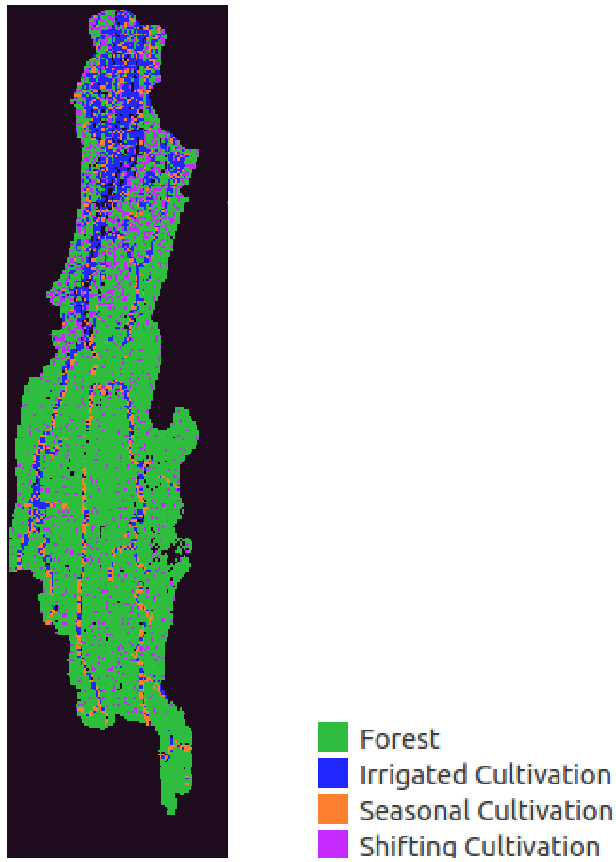


Figure 6.3: Land use map for 2035 when simulated with incentivization of settled forms of agriculture scenario at 500m grid resolution

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	925	1120	832
Mamit	390	87	23

Table 6.3: Amount of land under various forms of land use in the incentivized settled agriculture scenario for the year 2035

Compared to the BAU scenario, we can see a huge increase in the area under irrigated cultivation for both the districts. The amount of area under seasonal cultivation and shifting cultivation falls. This is due to the high yield of irrigated cultivation which can satisfy the food demands of the region more easily. Both the districts show a remarked reduction in the area under shifting cultivation.

Parameter List

- Irrigated cultivation increase threshold: 100
- Seasonal cultivation increase threshold: 100

6.2.3 Stopped growth of irrigated cultivation

When increase of irrigated cultivation is stopped completely, there occurs a shift towards other forms of agriculture to meet the food demand. In the district of Hailakandi, there occurs a shift towards shifting agriculture. The shifting cultivation of the district increases to meet the food demand of the district.

For the district of Mamit, there occurs an increase in the land under seasonal cultivation. For Mamit, the yields of seasonal and irrigated cultivation are almost the same. Hence the shift in seasonal cultivation is enough to meet the food demands of the district.

Since the irrigated cultivation growth rate is very slow, we do not see much effect on agriculture patterns once its stopped. So, another scenario is run where growth of all forms of settled agriculture is stopped.

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	508	1833	623
Mamit	26	1546	3980

Table 6.4: Amount of land under various forms of land use in the stopped irrigated cultivation increase scenario for the year 2035

Parameter List

- Irrigated cultivation increase threshold: 0
- Seasonal cultivation increase threshold: 2.8

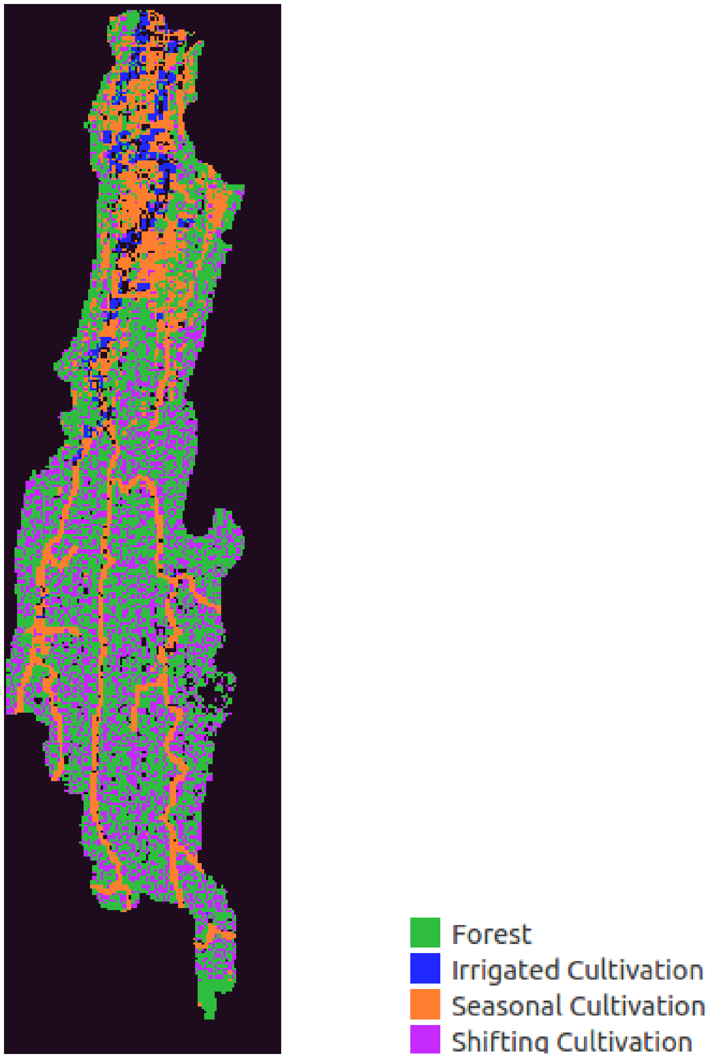


Figure 6.4: Land use map for 2035 when simulated with stopped growth of irrigated cultivation scenario for the year 2035 at 500m grid resolution

For the district of Hailakandi, shifting cultivation increases rapidly from the Business-as-usual scenario. With the increase of irrigated and seasonal forms of agriculture stopped, shifting cultivation rises to meet the increasing food demands. The district of Hailakandi has a large variation between the yields of settled forms of agriculture and the yield of shifting agriculture. Consequently, more shifting cultivation area is needed to meet the same food demand.

For the district of Mamit, the areas under settled forms of agriculture are very less. When their growth is restricted, the food demands need to get satisfied through shifting cultivation. Consequently, a jump in area under shifting cultivation is seen. The higher increase in shifting cultivation compared to Hailakandi can be attributed to two facts, i.e., the lower number of land parcels under settled agriculture and the fact that Mamit district being primarily rural district has more scope for shifting cultivation as compared to Hailakandi.

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	508	1631	923
Mamit	26	188	6267

Table 6.5: Number of land parcels of 25Ha each under various forms of land use in the stopped irrigated cultivation increase and stopped seasonal cultivation increase scenario for the year 2035

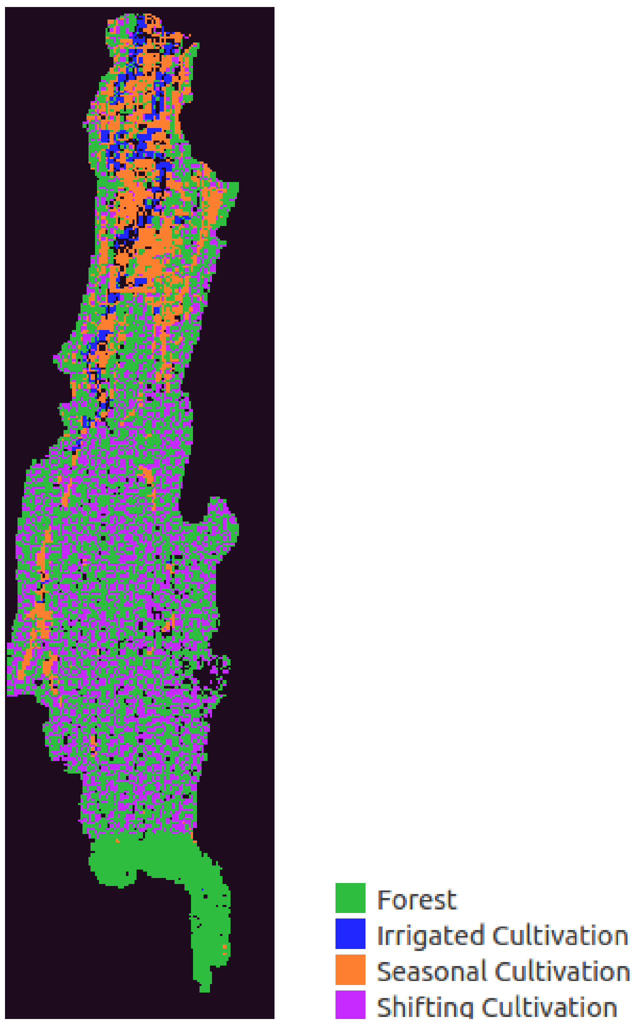


Figure 6.5: Land use map for 2035 when simulated with stopped growth of all settled agriculture scenario for the year 2035 at 500m grid resolution

6.2.4 Population doubled

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
Hailakandi	569	1775	2618
Mamit	85	1497	10000

Table 6.6: Amount of land under various forms of land use in the doubled population scenario for the year 2035

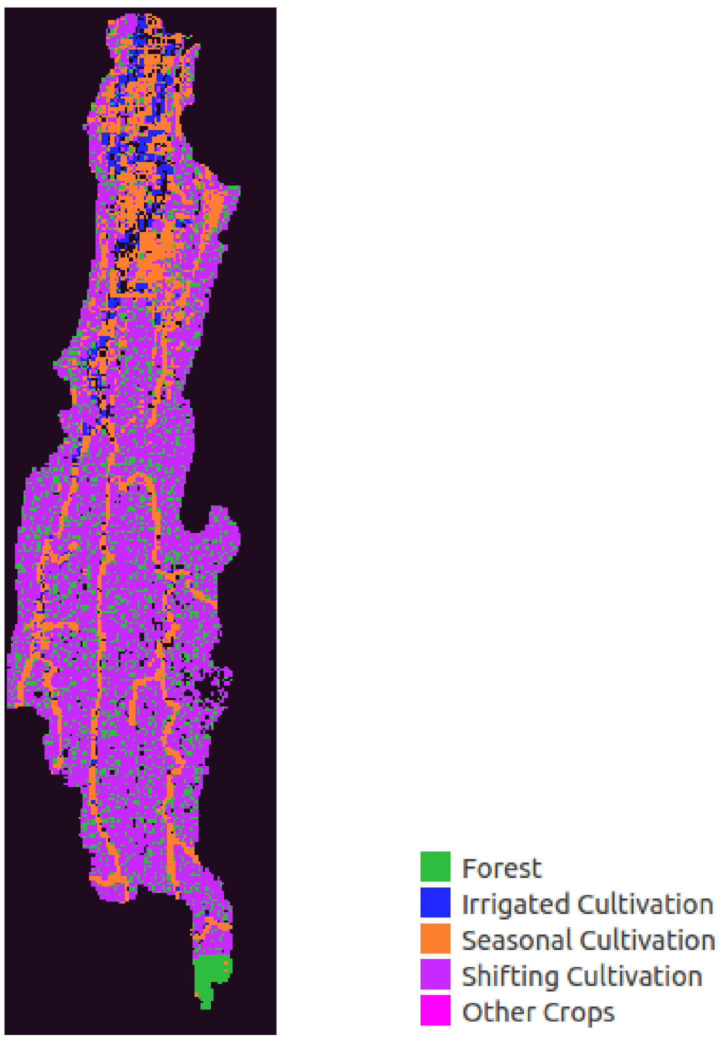


Figure 6.6: Land use map for 2035 when simulated with doubled population scenario at 500m grid resolution

Parameter List

- Irrigated cultivation increase threshold: 0.004
- Seasonal cultivation increase threshold: 2.8

The scenario where population is doubled puts a lot of stress on the land resources of the region. Due to the presence of better infrastructural resources, Hailakandi is able to handle the spike in population a little better than the district of Mamit. The irrigated cultivation increases to meet the increased demand, but due to infrastructure limits, isn't able to rise sufficiently enough to meet the increased food demand. There occurs an increase in seasonal cultivation to support the increased demand of the population. However, this increase in seasonal cultivation as well is not enough to satisfy the food demand. We see a sharp increase in shifting cultivation for Hailakandi district.

Mamit has a lower population than Hailakandi. We see an increase in settled agriculture but owing to lower infrastructure resources, these are not enough for the doubled population. Consequent a drastic increase in shifting cultivation is seen which increases to approximately three times the BAU value to account for the increased food demands of the district

6.3 Discussion of results

In Figure 6.7, we can see the changes in shifting cultivation over the various scenarios for the two districts. Hailakandi is a mix of urban and rural areas and has a lower shifting cultivation area than its neighbouring district of Mamit which is primarily a rural district.

For the district of Hailakandi, the amount of area under shifting cultivation does not change much when increase of irrigated cultivation is stopped. When all forms of settled agriculture are stopped, we do see a slight increase in the shifting cultivation area. This is to compensate for the gap in demand-supply created when settled forms of agriculture are restricted. However, when settled forms of agriculture are allowed to expand unbounded, we see an immediate drop in shifting cultivation. This is so because the high yielding settled form of cultivation can meet the food demand of the region through efficient utilization of land resources. When population of the district is doubled, we see a sudden increase in shifting cultivation. The settled forms of agriculture in this scenario are unable to meet the food demands of the district as such growth cannot be rapid and consequently fall back on shifting cultivation to meet the demand-supply gap.

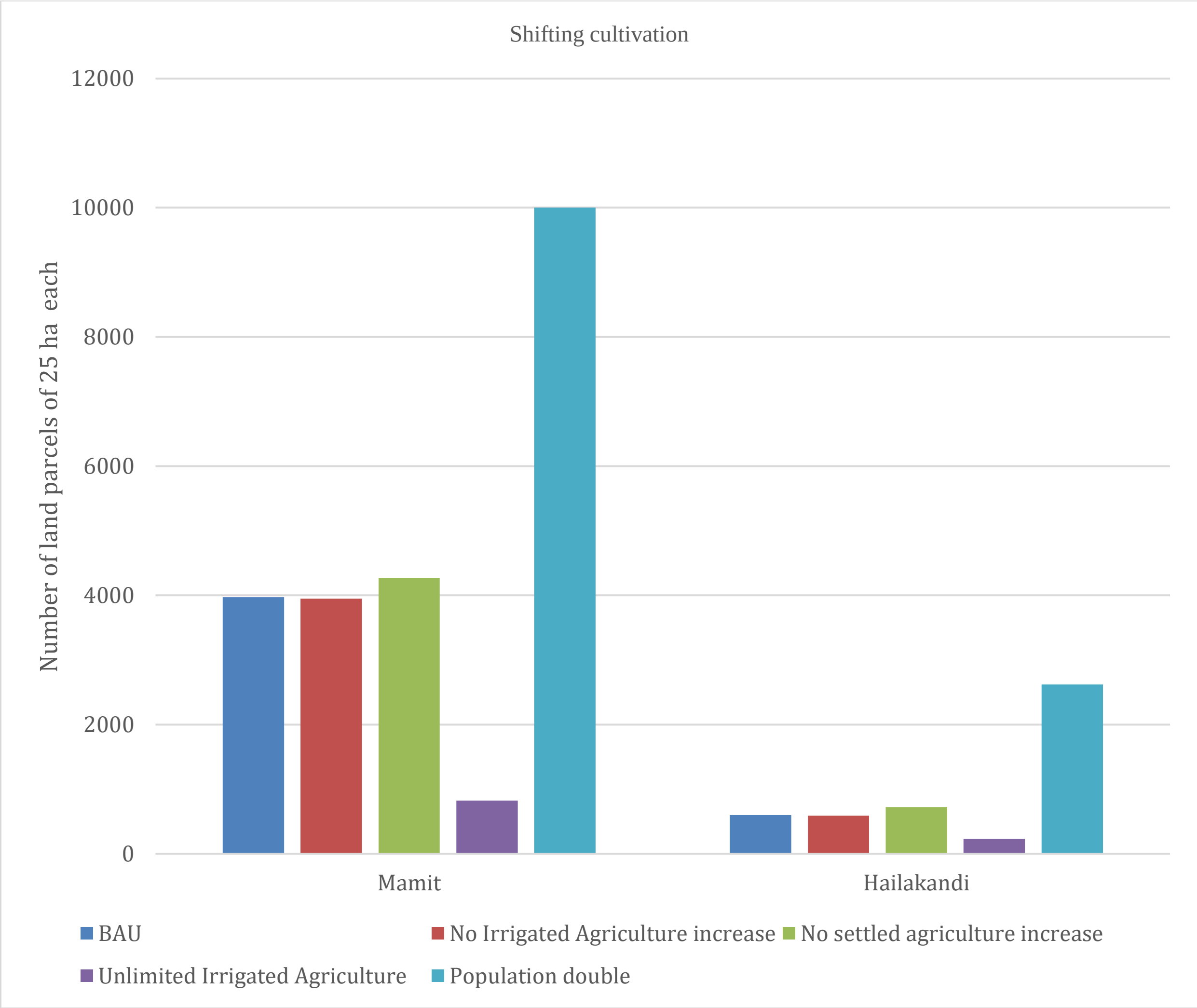


Figure 6.7: Changes in shifting cultivation over different scenarios

As seen in Figure 6.7, the district of Mamit has a much higher area under shifting cultivation. Shifting cultivation in Mamit too follows a pattern similar to the shifting cultivation in Hailakandi district. The area under shifting cultivation in stopped irrigated agriculture scenario, remains almost same as the BAU scenario. This can be explained by the absence of irrigated cultivation in Mamit district. Since the district of Mamit has very less area under irrigated cultivation, stopping the growth of irrigated cultivation does not affect the district greatly. When both forms of settled agriculture are restricted, we do see a slight increase in shifting cultivation as it grows to meet the food demand of the district. As in the district of Hailakandi, we see a huge increase in shifting cultivation when population is doubled. Owing to the lack of settled agriculture in the region and low yields in shifting cultivation lands, a huge strain is put on the land resources to meet the increased food demand. Contrastingly, when settled agriculture is allowed to grow unbounded, the increase in irrigated and seasonal cultivation is able to meet the food demands of the district more efficiently. Consequently, shifting cultivation of the district falls. Analysing these scenarios show that with proper infrastructural development shifting cultivation can be decreased and eventually discontinued in these districts.

Now let's look at the changes in irrigated cultivation over the different scenarios simulated as shown in Figure 6.8. We can observe that area under irrigated cultivation is much higher for Hailakandi district. This is due to better infrastructure resources in the region. The district of Hailakandi is more urbanized and consequently has more population as well. Mamit on the other hand has higher percentage of its area under forests.

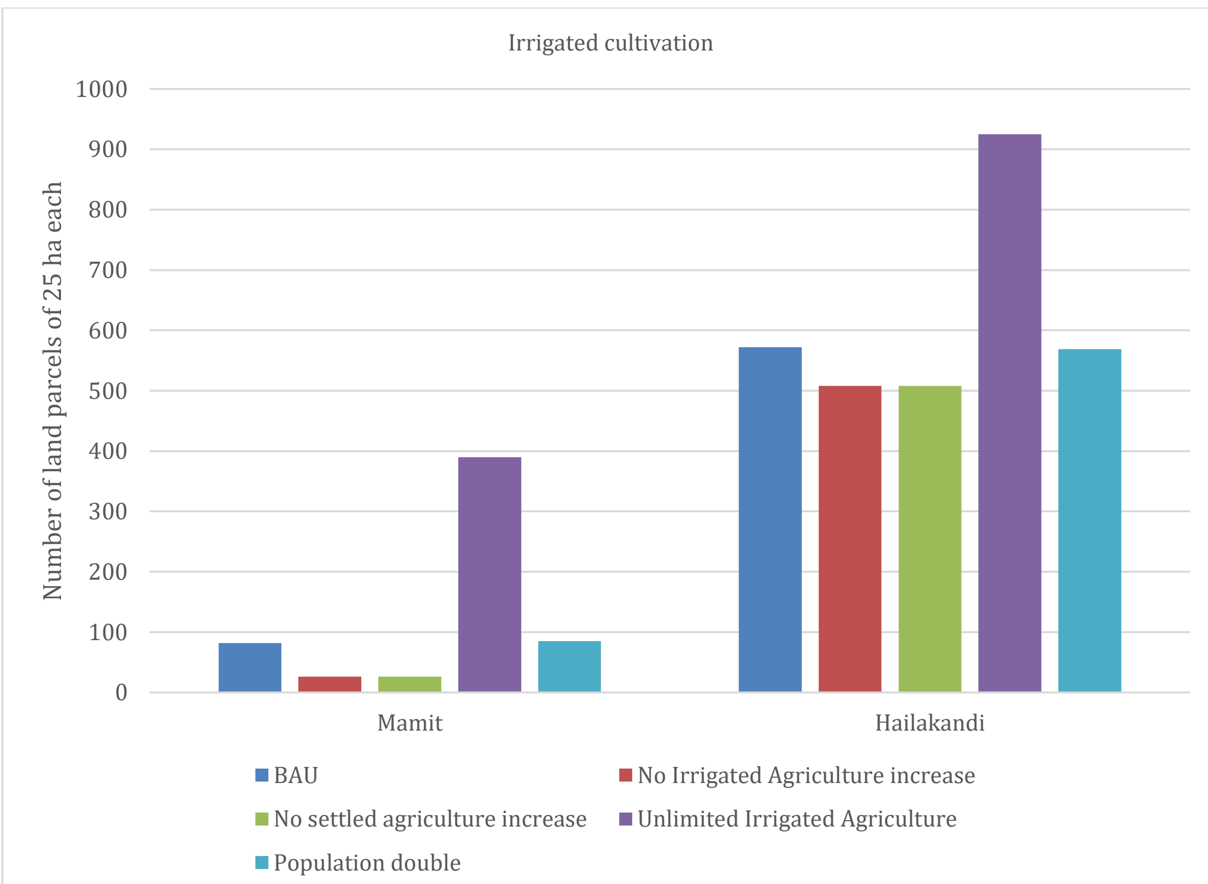


Figure 6.8: Changes in irrigated cultivation over different scenarios

Over the scenario runs for Hailakandi, we can see that when a cap is put on the growth of irrigated cultivation, there is not much difference from BAU scenario. This is due to the low increase rate for irrigated cultivation which demonstrates the low rate of infrastructure growth. When population is doubled for the district, we can see an increase in irrigated cultivation. However, since the irrigated cultivation is limited by infrastructure growth, we do not see a drastic change. When the cap on increase of irrigated cultivation is removed and settled forms of agriculture are allowed to grow freely, we can see a huge jump in irrigated cultivation. This increase in the higher yielding irrigated cultivation meets the food demands of the district more efficiently and shifting cultivation is no longer needed.

For the district of Mamit, the area under irrigated cultivation is much lower. When irrigated cultivation is not allowed to increase, we can see a drop compared to the BAU scenario which shows minimal lands under irrigated cultivation. Even when population is doubled, there is not a huge change in the area of irrigated cultivation. This is due to the limited infrastructure resources in the region that limit the growth of irrigated cultivation. However, when the irrigated cultivation growth is incentivized, we see a huge increase in area under irrigated cultivation can be achieved. This shows the potential of the district for adapting to more efficient forms of agriculture which can be encouraged by investing in infrastructure growth of the region.

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
BAU Scenario	572	1768	598
Incentivization of settled agriculture	925	1120	832
Stopped growth of irrigated cultivation	508	1833	623
Population doubled	569	1775	2618

Table 6.7: Number of land parcels of 25Ha each under various forms of land use in Hailakandi for the year 2035

These analyses shows that the two districts, even though geographically close, display different behaviours in the various scenarios. This further illustrates the fact that effect of government policies needs to be taken into account when predicting changes in land use. For the district of Hailakandi, area under shifting cultivation decreases when settled forms of agriculture are incentivized. This shows that increasing infrastructure investments in the area can give a push towards the move from shifting cultivation to more settled forms of agriculture. For the district of Mamit on the other hand, significant amounts of areas remain under shifting cultivation even when settled forms of agriculture are incentivized. This shows that the district might need non-technological interferences to understand the widespread usage of shifting cultivation and how to bring more areas under settled agricultural forms.

	Irrigated Cultivation	Seasonal Cultivation	Shifting Cultivation
BAU Scenario	82	1488	3971
Incentivization of settled agriculture	390	87	23
Stopped growth of irrigated cultivation	26	1546	3980
Population doubled	85	1497	10000

Table 6.8: Number of land parcels of 25Ha each under various forms of land use in Mamit for the year 2035

Chapter 7 - Discussions and Conclusions

An agent-based land-use model was generated that takes into account both spatial datasets like land use data as well as non-spatial data like population growth. The spatial data provides information about the geographical characteristics of the region and the non-spatial data provides the socioeconomic parameters for consideration. The model generates data like population and food supply for each of the districts, on a year-on-year basis, that act as agents for the model.

Initially, the model run was executed for 1988-1997 which generated a land-use map for 1997. Based on the actual land use map of 1997, the parameters of the model were fine-tuned to get a better estimate of the land use areas across the two districts. The map generated with updated parameters was analyzed and it gave an accuracy of nearly 98% for the year 1997. With these updated parameters, the model was then run from 1997 to 2005. Comparing the predicted 2005 land use map with the actual 2005 land use map, the confusion matrix showed an accuracy of about 94%. Based on these results it is established that the model mimics the land use changes in the southern part of Barak valley well and can be used to study and assess the changes other land use change drivers pose to the region.

The model was further used to generate multiple simulation scenarios for the year 2035, to understand the policy and decision-making interactions and their effects on the ground. In each of the four scenarios, either ecological or economic consideration was the prime driver of change, and its effects were studied in combination with other existing land use conditions. A district wise analysis of the two districts of Hailakandi and Mamit show that depending on whether the district is largely rural, has dense or sparse population, and had appropriate access to infrastructure development, the land use responses are different. The BAU scenario shows that without intervention of any kind, it is difficult to stop the spread of shifting cultivation due to the land pressures from population growth and the need for increased returns from the land. While more focus on infrastructure and incentivising settled forms of agriculture can help control or move away from shifting cultivation, the rate of this change is dependent on both socio-economic and bio-physical conditions of the region.

The model prediction is limited by the data quality and better granular/scale data with varied classes may help in better understanding some of these field-level interactions. Similar statements can be made about the socio-economic and infrastructure data in a spatially explicit way, along with the development plan information, if any, which can enable a better understanding of the current situation and hence better predictions. A wider variety of land uses can be considered for modelling and their interactions studied for improving our understanding of this region and its dynamics.

As part of further improvement to the model, land use can be modelled in the area by considering competitiveness between the different land-use types, as the current model considers land use allocation between different agricultural types to be non-competing. Similarly, non-agricultural land uses are excluded from consideration in this model. Land uses like urban areas can affect where agriculture expands, which hasn't been considered in this work. The simulation scenarios presented can be expanded to include more complex cases that take into account more than one socio-economic factor and how they affect the environment.

Annexure

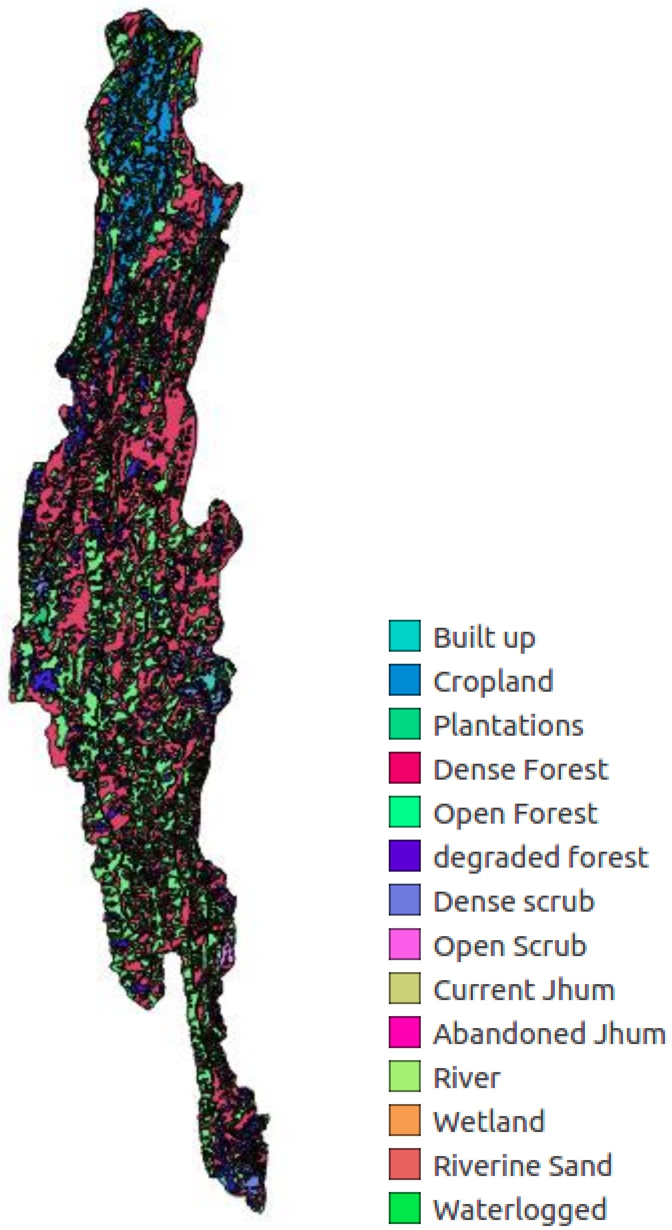


Fig A.1: Land use map for initial dataset

Original LU	**Reclassified LU for model**
Built up	Non-usable
Cropland	Cultivated land
Plantation	
Dense forest	Forest
Open forest	
Dense deciduous	
Open deciduous	
Scrub forest	
Dense scrub	
Open scrub	
Current Jhum	Initial shifting cultivation area
Abandoned jhum	Forest
River	River

Wetland	Non-usable
Sandy	
Waterlogged	

Table A.1: Land use conversion followed for modifying initial dataset into data used by the model

Related Publications

1. Jyoti Misra & Rajan, KS. (2018). Modelling Shifting Cultivation and Changes to Land Use in Barak Valley. Proceedings of the 39th Asian Conference on Remote Sensing. Kaula Lumpur, Malaysia. Oct 15-19, 2018.
2. Jyoti Misra & Rajan, K. S (2020). Shifting cultivation practices in Barak valley, India – Policy scenarios from a spatially explicit land use model. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Nice, France. 2020 Aug 31-Sep 3.

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