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Management of Agricultural Systems of the Upland of Chittagong Hill Tracts for Sustainable Food Security

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EXECUTIVE SUMMARY

Chittagong Hill Tracts (CHT) is the only extensive hill area in Bangladesh and it is located in the southern eastern part of Bangladesh. The area of the Chittagong Hill Tracts is about 13,184 sq km, of which 92% is highland, 2% medium highland, 1% medium lowland and 5% homestead and water bodies. Total population of CHT is 13,31,996, of which about 51% is tribal people. Shifting agriculture (*jhum*) is still the cultivation systems in this region with little impact of different plans and programs to promote the agricultural land use patterns. As a result the tribal populations are suffering from food insecurity and the shifting agriculture has led to indiscriminate destruction of forest for food resulting ecological degradation.

Promoting sustainable development in the uplands of Chittagong Hill Tracts poses important challenges. The upland areas are remote, and are mostly inhabited by many ethnic minorities. The majority of the ethnic minorities are Chakma (48%) and Marma (28%). The incidence of poverty is very high. To meet the livelihood needs, upland farmers often use unsustainable land use practices.

Poverty caused by traditional agriculture and environmental degradation in the Chittagong Hill Tracts of Bangladesh need policies and programs for environmentally compatible and economically viable agricultural systems. However, policies and programs aimed at promoting alternative land use systems have failed to achieve expected goals because of inadequate understanding of the evolution of the existing land use systems and forces driving the changes

To understand and design policies and programs of the highly complex agricultural systems and the land use patterns of Chittagong Hill Tracts of Bangladesh, the determinants and patterns of the agricultural systems must be identified and also the systems must be modeled and simulated for management strategies for sustainable development to ensure food security.

The purposes of this study are (i) to study the patterns and determinants of agricultural systems in the Chittagong Hill Tracts of Bangladesh, (ii) to characterise agricultural systems of the Chittagong Hill Tracts, (iii) to estimate the present status of food availability and environmental degradation of the Chittagong Hill Tracts of Bangladesh, (iv) to develop a system dynamics model to simulate food security and environmental degradation at upazila and district level of the Chittagong Hill Tracts of Bangladesh, (v) to develop a multi agent systems (MAS) model to assess household food security and stability of the agricultural

systems, farming systems in particular and land use pattern of the Chittagong Hill Tracts, (vi) to address the different management strategies and development scenarios and (vii) to assess the climate change impacts on upland agricultural systems.

To study the patterns and determinants of agricultural systems; to characterise agricultural systems and to address the present status of food security and environmental degradation of the Chittagong Hill Tracts of Bangladesh a multistage sampling was designed for selecting the farm households from the up lands of the Hill Tracts of Chittagong. The sampling framework consists of primary sampling unit of district, secondary sampling unit of upazila, pre-ultimate sampling unit of village and ultimate sampling of household for the data collection. Bandarban, Rangamati and Khagrachhari, three districts of Chittagong Hill Tracts, were selected for this study because of the poverty caused by traditional agriculture and environmental degradation. Nine upazilas were selected from each of these three districts and three were selected from each district. A total of 1779 households were randomly selected from these three districts.

Principal component analysis was conducted to identify the determinants of the agricultural systems of the Hill Tracts of Chittagong and to determine the patterns of the agricultural systems of the Hill Tracts of Chittagong and a total of 18 selected variables have been transformed into 6 principal components to explain 76.69% of the total variability of the agricultural systems of the Hill Tracts of Chittagong.

Factor analysis was conducted to discover if the observed variables can be explained in terms of a much smaller number variables called factors – covariance or correlation oriented method and it was found that 18 observed variables can be explained by 4 factors, which explain 77.21% of total variability based on method of principal factors. Factor analysis (rotated) allowed us to interpret the results physically in terms of four factors. Factor1 is referred to as ‘infrastructure development’ which explains about 16% of the total variance. The second factor explains about 15% of the total variance and we call it factor 2 as ‘institutional service (training and extension)’. The third factor that explains about 13% of the total variance is referred to as ‘micro credit and NGO service’. The fourth factor explains 10% of the total variance and the factor 4 is referred to as ‘availability of *jhum* land’. These factors must be considered for design and implementation of the sustainable development policy and programs of the uplands of the Hill Tracts of Chittagong.

Cluster analysis was conducted to classify the agricultural systems of 27 villages in the Hill Tracts of Chittagong and the systems were classified as extensive, semi-intensive, intensive and mixed. But one village out of 27 villages is classified as mixed since it manifested almost equally the entities of other three categories of the agricultural systems. Discriminant analysis was conducted for checking the accuracy of the classification of the agricultural systems and the classification error was found to be zero i.e. classification was exactly correct. Farming/agricultural systems of the Hill Tracts of Chittagong must be classified for policy planning and its implementation for sustainable development.

Food security and environmental degradation in terms of ecological footprint of nine upazilas of three districts of the Hill Tracts of Chittagong were estimated. This study shows that the overall status of food security at upazila level is good for all the upazilas (5.04% to 141.03%) except Rangamati Sadar (-24.43) and the best is the Alikadam upazila (141.03%). The environmental status in the CHT region is poor for all the upazilas. The environmental status in the CHT region has degraded mainly due to *jhum* and tobacco cultivation.

The major problems of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong are conflict over land use for shifting agriculture, horticultural crops, teak plantation, soil erosion due to shifting cultivation and existence of extreme poverty. Large scale plantations of teak have created a concern among the tribal people for food because of the fact that about 32 years are needed to get any return and nothing can be grown under the tree. Horticultural plantations with vegetables and spices under trees appear to be a probable solution. Also recent large scale cultivation of tobacco which demands huge amount of fuel wood for curing is a threat to the forest ecosystems in the Hill Tracts of Chittagong.

An integrated and dynamic model has been developed to predict food security and environmental loading for gradual transition of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation. Food security status for gradual transmission of *jhum* land into horticulture crops and teak plantation and crop land into tobacco cultivation which contributes 26% to 52% of the total food security is the best option for the food security, but this causes the highest environmental loading resulting from tobacco cultivation. Considering both food security and environmental degradation in terms of ecological footprint, the best option is gradual transition of *jhum* land into horticulture crops which provides moderate increase in the food security with a relatively lower environmental degradation in terms of ecological footprint.

Computer model to predict the climate change impacts on upland farming/agricultural systems have been developed and climate change impacts on the yields of rice and maize of three treatments of temperature, carbon dioxide and rainfall change of (+0°C, +0 ppm and +0% rainfall), (+2°C, +50 ppm and 20%) and (+2°C, +100 ppm and 30% rainfall) were assessed. The yield of rice decreases for treatment 2, but it increases for treatment 3. The yield of maize increases for treatment 2 and 3 since maize is a C_4 plant. Climate change has little positive impacts on rice and maize production in the uplands of the Hill Tracts of Chittagong. The climate change impacts on the yields of rice and maize are not significant.

Multi Agent System (MAS) emerging sub-field of artificial intelligence that aims to provide both principles for the construction of complex systems consisting of multiple agents and mechanisms for the coordination of independent agent's behaviours. Multi Agent System (MAS) technique was chosen to model the stakeholders' interactions and household food security. The multi agent systems model was designed using object-oriented programming language Small Talk and it is implemented in a CORMAS (Common pool Resources and Multi Agent System) platform. CORMAS is a simulation platform based on the Visual Works programming environment. It has three entities: the households, extension agents and the environment in which the decisions are made. The entities and their attributes were derived from the field surveys. The activity diagrams to represent rule based agents have been identified and the model is used to simulate the household food security for a time horizon of 15 years. The household food security is defined qualitatively using numeric scores of 3 for secured, 2 for more or less secured and 1 for unsecured and the average household food security indicator is defined as the ratio of the food security scores to the maximum possible food security scores. Multi agent system model is used to simulate the interactions among the artificial actors of farmers and agricultural extension officer with the environment for assessing the sustainability of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong for gradual transition from *jhum* cultivation to horticultural crops. The average food security indicator is more or less secured and it decreases with time, but the decrease is not substantial.

Finally the findings of the multivariate analysis and macro and micro level simulated studies have important policy implications for promotion of environmentally sustainable and economically viable agricultural systems. Uplands are confronted with problems of land degradation, deforestation and poverty. The findings suggest that fruit trees with other horticultural crops to control soil erosion and landslides, banning of tobacco cultivation to avoid deforestation, micro credit, extension service, infrastructural development for access to market and development of marketing channels for agro products need promotion of environmentally sustainable and economically viable agricultural systems.

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Nomenclature

BBS	Bangladesh Bureau of Statistics
CHT	Chittagong Hill Tracts
FAO	Food and Agricultural Organization
FS	Food Security
GDP	Gross Domestic Product
ha	Hectare
ha/cap	Hectare/capita
HYV	High Yielding Variety
IFPRI	International Food Policy Research Institute
INFS	Institute of Nutrition and Food Science
km	Kilometer
LYV	Low Yielding Variety
MOFL	Ministry of Fisheries and Livestock
NPV	Net Present Value
NSF	Non-Sufficient Food
PRA	Participatory Rural Appraisal
RDRS	Rangpur Dinajpur Rural Service
SF	Sufficient Food
SRF	Sunderban Reserve Forest
SSR	Self Sufficiency Ratio
Tk	Taka
USDA	United State Department of Agriculture
WHO	World Health Organization

1. INTRODUCTION

Chittagong Hill Tracts (CHT) is the only extensive hill area in Bangladesh and it is located in the southern eastern part of Bangladesh between 21°25´N to 23°45´N latitude and 91°54´E to 92°50´E longitude. The area of the Chittagong Hill Tracts is about 13,184 sq km, of which 92% is highland, 2% medium highland, 1% medium lowland and 5% homestead and water bodies. Total population of CHT is 13,31,996, of which about 51% is tribal people. The upland areas are remote, and are mostly inhabited by many ethnic minorities. The majority of the ethnic minorities are Chakma (48%) and Marma (28%). The incidence of poverty is very high. To meet the livelihood needs, upland farmers often use unsustainable land use practices.

The weather of this region is characterized by tropical monsoon climate with mean annual rainfall nearly 2540 mm in the north and east and 2540 mm to 3810 mm in the south and west. The dry and cool season is from November to March; pre-monsoon season is April-May which is very hot and sunny and the monsoon season is from June to October, which is warm, cloudy and wet.

Agriculture is the main source of livelihood of these populations. Non farm income opportunities are very limited and in some areas non existent. The tribal populations here are the most disadvantaged group of populations in Bangladesh. Shifting agriculture, locally known as *jhum,* is still the cultivation systems in this region with little impact of different government plans and programs to promote the agricultural land use patterns. As a result the tribal populations are suffering from food insecurity and the shifting agriculture has led to indiscriminate destruction of forest for food resulting ecological degradation.

Poverty caused by traditional agriculture and environmental degradation in the Chittagong Hill Tracts of Bangladesh need policies and programs for environmentally compatible and economically viable agricultural systems (Thapa and Rasul, 2005). However, policies and programs aimed at promoting alternative land use systems have failed to achieve expected goals because of inadequate understanding of the evolution of the existing land use systems and forces driving the changes (Rasul *et al.,* 2004)

Promoting sustainable development in uplands of Chittagong Hill Tracts poses important challenges. Uplands are essentially caught in a vicious cycle of poverty, food insecurity and environmental degradations. Land use practices in uplands not only degrade the resource base but also negatively impact on the livelihoods and resources base downstream. Wider environmental impacts also occur in the form of reduced biodiversity, reduced ability of the ecosystem to regulate the stream flow and reduced carbon sequestration.

The agricultural potential of hill soils is mainly low for field crops, but it ranges between low and high for tree crops. Deep soils on level or gently sloping land have the highest potential. Because of impracticality of irrigation, rain fed crop production is practiced in most hill land. The main crops are: transplanted aman, broadcast aus, cowpea, aubergine, cucumber, okra, bitter gourd, sweet gourd, sweet potato, sugarcane, maize, cotton, pineapple, coriander leaf, and some other summer and winter vegetables.

Large scale plantations of teak promoted by Department of Forestry and NGOs have created a concern among the tribal people for food because of the fact that about 32 years are needed to get any return and nothing can be grown under the tree. Horticultural plantations with vegetables and spices under trees appear to be a probable solution. Also recent large scale cultivation of tobacco by national and international commercial tobacco enterprises which demands huge amount of fuel wood for curing is a threat to the forest ecosystems in the Hill Tracts of Chittagong.

To understand and design policies and programs of the highly complex agricultural systems and the land use pattern, the factors affecting the systems must be identified and classified, and modeled and simulated for management strategies for sustainable development to ensure food security.

Multivariate analysis

Shifting cultivation has been practiced for centuries in the Chittagong Hill Tracts (CHT) of Bangladesh. This type of cultivation is characterized by the slash-and-burn method of land preparation, cultivating the farm plot for a year and abandoning it for several years. Shifting cultivation was an environmentally suitable land use in the past when population pressure on the land was low and the fallow period was long facilitating the restoration of vegetation cover and the soil fertility (Nye and Greenland, 1960; Lal, 1973). This shifting cultivation has gradually become an environmentally incompatible land use system with the shortening of fallow period attributed to increasing population pressure, abolition of local people's use and management rights of forests, policies encouraging migration of lowland settlers to CHT, and low investment in agriculture (DANIDA, 2000; Knudsen & khan, 2002; Roy, 2002). Normally, shifting cultivators' strong adherence to traditional values and culture is considered to be the major factor constraining the adoption of location-wise suitable land use (Hamid, 1974). Such a simple explanation cannot be considered satisfactory. The movement from extensive to intensive agriculture is conditioned and sometimes constraints by the national policies and laws (Lele and Stone, 1989; Vosti et al., 2001).

Although shifting cultivation is still remains the dominant land use in the CHT region (DANIDA, 2000; Roy, 1995), in some areas, alternative land uses are gradually evolving. Some tribal communities practice horticulture and agro-forestry, which are considered to be both environmentally and economically suitable; others have diversified their agriculture by integrating trees and livestock with annual crops to improve their economic benefits and reduce possible risks of food shortage and low income (Khan and Khisha, 1970; Roy, 1995).

The history of external intervention in the land use of CHT is more than two centuries old. It is mentioned by British colonial administration and followed by subsequent governments, which have had tremendous impact on land use and management. This entails the analysis of the impact of national policies on land use in CHT. It is necessary to understand how macro and micro level policies influence farmers' decision-making on land use and management (FAO, 1999). Despite growing concern about land use and natural resources degradation in CHT (Araya, 2000; Gafur, 2001), much attention has not been paid to analysis of the role of national policies and laws.

For making any effective plans and programs for agricultural development it is necessary to understand local condition. Classification and characterization of farming/agricultural systems can advance the knowledge and understanding of local conditions (Hardiman, 1990). To promote sustainable land use systems, it is necessary to identify, characterize the existing land-use systems, and explore the factors explaining local variations (Khan and Khisha, 2000).

The real situation in the study area and elsewhere is not homogeneous as revealed by the analysis. Even within a small area, variations are found in land use between farm households because of variation in their characteristics, including access to resources and services. The land use pattern that appears at the spatial-level is an outcome of independent decisions made by hundreds of farm households. Thus, a farm household is a main decision making unit (Chayanov, 1966; Webstar, 1999). While seeking alternatives for more productive and environmentally sound land use systems, firstly it is essential to find out land use patterns resulting from decision made at individual household level. This should be followed by analysis of factors explaining variation in land use patterns. To understand factors influencing variation in land use system it is necessary to understand farmers' land use decision, the way they allocate their resources land, labour, capital in different production systems, organize their activities, combine different production systems such as crop, livestock, tree, annual and perennial crops, and the way they respond with changing environment (Ruthenberg, 1980).

Farm households face different types of problems and possess different types of potentials and act on different way depending on their characteristics. To promote environmentally and economically sound land use, it is necessary to have detailed knowledge about the nature of the land use systems, their complexities and underlying patterns. However, in reality, it is not feasible to look into the land use system of every household. This necessitates the classification of land use systems based on their basic characteristics (Schluter and Mount, 1976: 246; Kobrich et al., 2002). As Ruthenberg (1980;14) mentioned, "in fact, no farm is organized exactly like any other, but farms producing under similar natural, economic and socio-institutional conditions tends to be similarly structured. For the purpose of agricultural development and to devise meaningful measures in agricultural policy it is advisable to group farms with similar structural properties".

Food security and environmental degradation

Food insecurity is a worldwide problem that has called the attention of Governments and the scientific community. It particularly affects developing countries. The scientific community has shown increasing concerns for strategic understanding and implementation of food security policies in developing countries, especially since the food crisis in the 70s. The process of decision-making for sustainable food security is becoming increasingly complex due to the interaction of multiple dimensions related to food security (Giraldo *et al.*, 2008).

Food security is a social sustainability indicator and most commonly used indicators in the assessment of food security conditions are food production, income, total expenditure, food expenditure, share of expenditure of food, calorie consumption and nutritional status etc. (Riely *et al.,* 1999). Accounting tools for quantifying food security are essential for assessment of food security status and also for policy planning for sustainable development.

Ecological footprint is an ecological stability indicator. The theory and method of measuring sustainable development with the ecological footprint was developed during the past decade (Wackernagel and Rees, 1996 and Chambers, *et al*., 2000). The Ecological Footprint is a measurement of sustainability illustrating the reality of living in a world with finite resources and it is a synthetic indicator used to estimate a population's impact on the environment due to its consumption; it quantifies total terrestrial and aquatic area necessary to supply all resources utilized in sustainable way and to absorb all emissions produced always in a sustainable way. Apart from analyzing the present situation, the ecological foot print provides a framework of sustainability planning in the public and private scale.

Accounting tools for quantifying humanity's use of nature are essential for assessment of human impact and also for policy planning towards a sustainable future. Many pertinent questions pertinent to build a sustainable society can be addressed by using ecological footprint as indicator. This tool has evolved from largely being pedagogical to becoming a strategic tool for policy analysis.

Dynamic behaviour of physical system can be studied by experimentation. Sometimes it may be expensive and time consuming. Full scale experimentation of integrated farming/agricultural system is neither possible nor feasible. Most inexpensive and less time consuming method is to use mathematical model or computer model.

Management of the uplands of the Hill Tracts of Chittagong is a highly complex system containing biological, agricultural, environmental, technological, and socio-economic components. The problem cannot be solved in isolation, an integrated and systems approach is needed. For clear understanding of this complex system before its implementation, it must be modeled and simulated. System Dynamics, a methodology for constructing computer model for dynamic and complex systems, is the most appropriate technique to model such a complex systems.

There is a need to develop a dynamic model to explore management scenarios of policy planning and management of uplands of the Hill Tracts of Chittagong. This type of integrated study in the field of management of uplands of Hill Tracts is relatively new in Bangladesh. Therefore, a dynamics of management of uplands of the Hill Tracts Chittagong need to be studied for a sustainable management of food production, ecology and environment aiming to alleviate the poverty of tribal population and ensure food security.

Climate change impacts

Agriculture plays a dominant role in supporting rural livelihoods and economic growth of Bangladesh. Rice, wheat and maize are the major food crops in Bangladesh. Despite impressive success in increasing the food production in Bangladesh to meet the demands of the rapidly increasing population, the ability to sustain this success is a major concern. Agricultural systems are vulnerable to variability in climate and it can be viewed as a function of the sensitivity of agriculture to changes in climate, the adaptive capacity of the system and the degree of exposure to climate hazards (IPCC, 2001). The productivity of food crops from year to year is sensitive to variability in climate and this affects the food security. Furthermore, Bangladesh is most vulnerable to the impacts of climate variability and change. In the last two decades, there has been rapid development of crop models that can simulate the response of crop production to a variety of environment and management factors. With such models, it is feasible to assess the variations in yields for different crops or management options under given climatic change.

Climate changes include both rapid changes in climatic variables such as temperature, radiation and precipitation, as well as changes in the atmospheric concentration of greenhouse gases, soil water and nutrient cycling and climate changes affect food security. Predicted climate change impacts are essential to design plans and programs to adapt for future conditions. For proper understanding and implementations of the plans and programs of the adaptation strategies of the climate change impacts, the climate change impact systems must be modeled and simulated. Simulation models can assist in examining the effect of different scenarios of future development and climate change impacts on crop production and several crop models are available.

The knowledge and technology required for adaptation includes understanding the patterns of variability of current and projected climate, seasonal forecasts, hazard impact mitigation methods, land use planning, risk management, and resource management. Adaptation practices require extensive high quality data and information on climate, and on agricultural, environmental and social systems affected by climate, with a view to carrying out realistic vulnerability assessments and looking towards the near future.

Multi Agent Systems

The sustainable management of farming systems of the Hill Tracts of Chittagong at household levels inevitably involves not only ecological dimensions but also the social, economic, cultural and political aspects of the utilization of the natural resources. Successful management of the farming systems is, therefore, often complicated by the diversity of the interconnected ecological and socio-economic systems and their interactions, as well as by the increasing number of stakeholders concerned with the collective management of common-pool resources and environmental problems. In addition, the dynamic nature of interactions among diverse factors at various levels and scales frequently leads to highly complex, non-linear and divergent processes and the emergence of new phenomena, which are often unpredictable.

Simulating a stakeholder's activities and interactions requires a tool that is able to represent the individual's knowledge, belief and behaviors. Multi agent system (MAS) is one such tool. MAS is an emerging discipline that evolved from the general fields of decision support system, game theory and artificial intelligence. Over the last few years, there has been significant MAS development in part because of advances in information processing, communication and computer technology. As its name implies, MAS is a general approach that takes into account the presence of multiple agents (actors or stakeholders), each with their unique views, perspectives and behavior. Each agent or actor acts or reacts (or makes decisions) as he/she pursues his/her objective rationally, or according to his/her own rules and behavioral patterns.

There are a number of desirable features that makes MAS a suitable framework for analyzing participatory management of natural resources. First, it is an ideal environment for analyzing participatory management because the system recognizes the existence of multiple agents with their own unique style of decision- making. Second, it also recognizes the strong connections and interactions between and among the actors. The system also takes into account the unique ways each agent endowed with cognitive abilities perceives, reflects, constructs strategies, acts and reacts to the changing resource environment as it is impacted by all the actors/agents.

Objectives of the research

(i) To study the patterns and determinants of agricultural systems in the Chittagong Hill Tracts of Bangladesh

(ii) To characterise agricultural systems of the Chittagong Hill Tracts

(iii) To estimate the present status of food security and environmental degradation of the Chittagong Hill Tracts of Bangladesh.

(iv) To develop a system dynamics model to simulate food security and environmental degradation at upazila and district level of the Chittagong Hill Tracts of Bangladesh

(v) To develop a multi agent systems (MAS) model to assess household food security and stability of the agricultural systems, farming systems in particular and land use pattern of the Chittagong Hill Tracts.

(vi) To address the different management strategies and development scenarios.

(vii) To assess the climate change impacts on upland agricultural systems.

2. REVIEW OF LITERATURE

2.1 Multivariate analysis

Several studies have been conducted on multivariate analysis to search for the factors affecting the performances of natural resources management systems and these include technological adoption and use, women's participation in forestry, classification of irrigation water management district, and also factors affecting agricultural systems and their classification for sustainable development. Some previous studies are critically examined here.

Alimba and Akubuilo (2002) applied factor analysis to investigate the extent of technological change and the effect on rural farm enterprises in southeastern Nigeria and reported that technological change was neutral to most of the perceived negative consequences associated with change. Most of the problems were institutional and farm entrepreneur related. The study recommends that all the identified agencies, institutional and social problems relating to technological adoption and use in farms in the area must be tackled if the needed transformation of agriculture is to be achieved in the new century.

Atmis *et al,* (2007) carried out a Principal Component Analysis to study women's participation in forestry in the Bartın province, located in the West Black Sea Region of Turkey and found that the most important factors affecting women's participation are women's perception related to (1) forest dependence, (2) quality of cooperatives, (3) quality of Forest Organisation, and (4) forest quality. These four factors explained 58% of women's participation. These factors need to be taken into consideration to enhance women's participation in forestry and to achieve sustainable forestry in Turkey.

Rodríguez-Díaz *et al*, (2008) developed a methodology based on multivariate data analysis (cluster analysis) to analyze performance indicators for identifying deficiencies in irrigation district management and determining which measures should be taken to improve them and applied to nine irrigation districts in Andalusia (Spain) and irrigation districts were classified into statistically homogeneous groups for irrigation management.

Kobrich *et al.* (2002) applied multivariate statistical technique to the farming systems in Chilie and Pakistan and advocated the models based on classification schemes should prove to be reliable tools for generating recommendation domains in farming systems.

Thapa and Rasul (2005) classified agricultural systems in the mountain regions of Bandarban in the Chittagong Hill Tracts of Bangladesh and systems were classified into three major groups – extensive, semi-extensive and intensive –using cluster analysis. The factors determining these three types of agricultural systems were analyzed using factor analysis. Discriminant analysis was performed to explore the relative influence of these predicted factors. Institutional support, including land tenure, extension services and credit facilities, productive resource base and the distance to the market and service centres were found to be the major factors influencing agricultural systems. Provision of appropriate institutional support, including a secure system of land tenure, is indispensable for enabling poor mountain farmers to adopt environmentally and economically sound intensive agricultural systems such as plantation, agroforestry and livestock.

Several studies conducted for identifying the factors affecting the system performances either using principal component analysis or factor analysis and classification by cluster analysis are critically examined. But it is logical to use principal component analysis initially to identify factors and further refine the number of factors using factor analysis and classification problems should be solved using cluster analysis supported by discriminant analysis.

2.2 Food security and Ecological footprint

Many studies have been reported on food security and ecological factor, and several studies have been conducted on modeling of food security and ecological footprint. Some studies on food security, an indicator of social stability, ecological footprint, an indicator of ecological stability and previous efforts on management and modeling of food security and ecological footprint are critically examined under the subheadings of food security, food self sufficiency, ecological footprint and modeling of food security and ecological footprint.

Food security

Per capita food availability (cereal) in Bangladesh has declined from 458 g/day in 1990/1991 to 438 g/day in 1998/1999 while per capita fish intake has decreased from 11.7 kg/year in 1972 to 7.5 kg/year in 1990 (Begum, 2002). Also vegetables, the major dietary source of vitamin A, meet only 30 percent of recommended minimum needs.

Food security and hunger focusing on concentration and trend of poverty, pattern of household food consumption and causes of food insecurity and hunger have also been reported and the key findings are demographic and socio-economic conditions of the ultra poor, extent and trend of poverty in Bangladesh, food consumption pattern and level of food insecurity and hunger of the ultra poor and the causes of food insecurity and hunger (RDRS, 2005).

FAO (1996a) defined the objective of food security as assuring to all human beings the physical and economic access to the basic food they need. This implies four different aspects: availability, stability, access and utilization. USDA evaluated food security based on the gap between projected domestic food consumption and a consumption requirement (USDA, 2007).

Mishra and Hossain (2005) reported an overview of national food security situation and identified key issues, challenges and areas of development in policy and planning; also addressed the access and utilization of food and the issues of food and nutritional security.

Bala and Hossain (2010a) reported a quantitative method of computation of food security in terms of food availability and estimated the food availability status at upazila levels in the coastal zone of Bangladesh.

Self sufficiency ratio

Bangladesh achieved impressive gain in food grain production in the last two decades and reached to near self-sufficiency at national level by producing about 26.76 million metric tons of cereals, especially rice and wheat in 2001 (Hossain *et al*., 2002 and Ministry of Finance, 2003). The Self Sufficiency Ratio (SSR) calculated as per FAO's method (FAO, 2001) was stood at 90.1 percent in 2001 and 91.4 percent in 2002. Estimates on food grain gap and SSR reveal that Bangladesh has a food grain gap of one to two million metric tons (Mishra and Hossain, 2005).

Based on the official and private food grain production and import figures the food grain SSR for Bangladesh is gradually declining from 94.1 in 2000-2001 to 87.7 in 2004-2005 and lowest self-sufficiency rate in Bangladesh was in 2005, which could be attributed to the crop damage during the severe flood in 2004 (Mishra and Hossain, 2005).

Ecological footprint

Wackernagel *et al.* (1999) developed a simple assessment framework for national and global natural accounting and applied this technique to 52 countries and also to the world as a whole. Out of these 52 countries, only 16 countries are ecologically surplus, 35 are ecologically deficit including Bangladesh (0.2 gha/cap) and the rest one is ecologically balance. The humanity as a whole has a footprint larger than the ecological carrying capacity of the world. They also pointed out some strategies that can be implemented to reduce footprint.

Monfreda *et al.* (2004) described computational procedure of Ecological Footprint and Biological Capacity systematically with laps and gaps to eliminate potential errors. For the meaningful comparison of the Ecological Footprint all biologically productive areas were converted into the standardized common unit global hectares (gha).

Zhao *et al.* (2005) reported a modified method of ecological footprint calculation by combining emergy analysis which considers all forms of energy in a common unit and compared their calculations with that of an original calculation of ecological footprint for a regional case. Gansu province in western China was selected for this study and this province runs ecologically deficit in both original and modified calculation.

Medved (2006) reported ecological footprint of Slovenia and it was found that current ecological footprint of Slovenia (3.85 gha/capita) exceeds the available biological productive areas (2.55 gha/capita) and significantly exceeds the biological productive areas of the planet (1.90 gha/capita).

Chen and Chen (2006) investigated the resource consumption of the Chinese society from 1981 to 2001 using ecological footprint and emergetic ecological footprint and suggested using emergetic ecological footprint (EEF) to serve as a modified indicator of ecological footprint (EF) to illustrate the resources, environment, and population activity, and thereby reflecting the ecological overshoot of the general ecological system.

Bagliani *et al.* (2008) reported ecological footprint and bio-capacity as indicators to monitor the environmental conditions of the area of Siena (Italian's province). Among the notable results, the Siena territory is characterized by nearly breakeven total ecological balance, a result contrasting with the national average and most of the other Italian provinces.

Niccolucci *et al*. (2008) compared the ecological footprint of two typical Tuscan wines and the conventional production system was found to have a footprint value almost double than the organic production, mainly due to the agricultural and packing phases. These examples suggest that viable means of reducing the ecological footprint could include organic procedures, a decrease in the consumption of fuels and chemicals, and increase in the use of recycled materials in the packing phase.

Bala and Hossain (2010a) reported environmental degradation in terms of ecological footprint at upazila levels in the coastal zone of Bangladesh.

Modeling of food availability and ecological footprint

During the last half century, a number of individuals and institutions have used models with the aim of projecting and predicting global food security, focusing on the future demand for food, supply and variables related to the food system at different levels (MacCalla and Revoredo, 2001). The methodology used to develop the projections and predictions on food relies on correlated models. Such methodology is controlled purely by data and do not give insights into the causal relationships in the system. Several models have been developed to address the food security (Diakosavvas and Green, 1998, Coxhead, 2000, Mohanty and Peterson, 2005, Rosegrant *et al*., 2005, Holden *et al*., 2005, Shapouri and Rosen, 2006, Ianchovichina *et al.*, 2001, FAO, 1996b, Falcon *et al*., 2004).

System dynamics is a problem-oriented multidisciplinary approach that allows to identify, to understand, and to utilize the relationship between behavior and structure in complex dynamic systems. The underlying concept of the System Dynamics implies that the understanding of complex system’s behavior -such as the national food insecurity- can only be achieved through the coverage of the entire system rather than isolated individual parts. Several models have been developed using the System Dynamics around the food security (Bach and Saeed, 1992, Bala, 1999a, Gohara, 2001, Meadows, 1976, Meadows, 1977, Quinn, 2002, Saeed, *et al*., 1983, Georgiadis *et al.*, 2004, Bala, et al., 2000 and Saeed, 2000). Bala (1999b) reported an integrative vision of energy, food and environment applied to Bangladesh.

Shi and Gill (2005) reported a search for concrete policy measures to facilitate the overall sustainability of ecological agricultural development at a county level and developed a system dynamics model to explore the potential long-term ecological, economic, institutional and social interactions of ecological agricultural development through a case study of Jinshan County in China. The model provides an experimental platform for the simulation and analysis of alternative policy scenarios. The results indicate that the diversification of land-use patterns, government low interest loans and government support for training are important policy measures for promoting the sustainable development of ecological agriculture, at least in the case study context. Limited availability of information, risk aversion and high transaction costs are major barriers to the adoption of alternative agricultural practices. In this regard, the importance of capacity building and institutional arrangements are emphasized through the development of an improved policymaking process on agricultural sustainability. This case study highlights the importance of combining the ecological economics analytical framework with the system dynamics modeling approach as a feasible integrated tool to provide insight into the policy analysis of ecological agriculture, and thus set a solid basis for effective policy making to facilitate its sustainable development on a regional scale.

Bala and Hossain (2010b) reported a computer model of integrated management of coastal zones of Bangladesh. This model predicts that expanding shrimp aquaculture industry ensures high food availability at upazila levels with increasing environmental degradation. The model also predicts that if shrimp aquaculture industry continues to boom from the present status to super intensive shrimp aquaculture, a collapse of the shrimp aquaculture industry will ultimately occur turning shrimp aquaculture land neither suitable for shrimp culture nor crop production. The control of growth of the shrimp production intensity stabilizes the system at least in the short run. The control of population and growth of the shrimp production intensity should be considered for stabilization of the system in the long run. The sustainable development of the coastal zone of Bangladesh in the long run without control of both the growth of shrimp production intensity and the population will remain mere dream. It is now high time to design an integrated management system for the coastal zones of Bangladesh for sustainable development. This model can be used to assist the policy planners to assess different policy issues and to design a policy for sustainable development of the coastal zones of Bangladesh. The boost up of coastal agriculture and restriction on rapid growth of shrimp culture and its intensity to reduce ecological footprints are two pathways for sustainable development of food security in the coastal zones of Bangladesh. This study also examines the short-term and long-term policy options for sustainable food security.

The assessment of present state of art of food security, ecological footprint and modeling of food security and ecological footprint prompted to apply develop a new quantitative method of computation of food security (Bala and Hossain, 2010) to understand, design and implement food security policies towards a sustainable future; to address environmental degradation in terms of ecological footprint developed by Wackernagel and Rees (1996) and Chambers, *et al*. (2000) for assessment of human impact and also for policy planning towards a sustainable future and also to develop a computer model to explore management scenarios of policy planning and management of farming/agricultural systems of the Hill Tracts of Chittagong.

Previous efforts on modeling of food security and ecological footprint are critically examined and it supports that system dynamics is the most appropriate technique to model food security and ecological footprint of a region/country.

2.3 Climate Change Impacts on Rice and Maize

Several studies have been reported on climate change impacts on rice (Karim *et al*., 1996, Aggarwal, *et al*., 1997, Saseendran *et al.*, 2000, DE Silva *et al.*, 2007 and Yao *et al.*, 2007), wheat (Hakala, 1998, Aggarwal *et al*., 2006 a&b, Magrin *et al*., 2005, Anwar, *et al.*, 2007, Ludwig, *et al.*, 2008 and Pathak and Wassmann, 2008) and maize (Mati, 2000, Magrin *et a*l, 2005 and Meza *et al*, 2008).

Tubiello *et al.* (2000) investigated the effects of climate change and elevated CO_2 on cropping systems at two Italian locations and the results suggested that the combined effects of elevated atmospheric CO_2 and climate change at both sites would depress crop yields if current management practices were not modified. Magrin *et al.* (2005) quantified the impact of climate change on crop yields (wheat and maize) in Argentina. Climate changes contributed to increase in yields, especially in summer crops and in the semiarid zone, mostly due to increase in precipitation, although changes in temperature and solar radiation also affected crop yields but to a lesser extent. Pathak and Wassmann (2008) reported an analysis of recent climate trends at two sites in north-west India; assessed the impact and risk of climatic variability on wheat yields and developed an assessment framework to quantify yield impacts due to rainfall variability. Bala and Masuduzzaman (1998) developed system dynamics version of crop growth model based on the Wageningen Agricultural University crop growth model to predict the potential yield and yield under water stress of wheat. Bala *et al.* (2000) also adapted this model to project crop production (rice and wheat) in Bangladesh.

Farm level analyses have shown that large reductions in adverse impacts from climate change are possible when adaptation is fully implemented (Mendelsohn and Dinar 1999). Major classes of adaptation are seasonal changes and sowing dates, different variety or species, water supply and irrigation system, other inputs (fertilizer, tillage methods, grain drying, other field operations), and new crop varieties and the types of responses needed are reduction of food security risk, identifying present vulnerabilities, adjusting agricultural research priorities, protecting genetic resources and intellectual property rights, strengthening agricultural extension and communication systems, adjustment in commodity and trade policy and increased training and education.

Challinor *et al*. (2007) reported three aspects of the vulnerability of food crops systems in Africa. Most studies show a negative impact of climate change on crop productivity in

Africa. Farmers have proved highly adaptable in the past to short- and long-term variations in climate and in their environment. Key to the ability of farmers to adapt to climate variability and change is the access to relevant knowledge and information.

Tao *et al*. (2008) reported around food security presenting a covariant relationship between changes in cereal productivity due to climate change and the cereal harvest area required to satisfy China's food demand and also estimated the effects of changing harvest area on the productivity required to satisfy the food demand; and of the productivity and land use changes on the population at risk of under nutrition.

Smith and Olesen (2010) reported that there exists a large potential for synergies between mitigation and adaptation in agriculture and suggested for development of new production systems that integrate bioenergy and food and feed production systems

More recently Rosenzweig *et al.* (2010) reported preliminary outlook for effects of climate change on Bangladeshi rice and this study shows that aus crop is not strongly affected and aman crop simulations project highly consistent production increase, but boro shows highly probable declines in production.

Several studies conducted on climate change impacts such as increase of temperature and CO_2 concentration and rainfall to address the vulnerability of food crops and its adaptation are examined. Climate change impacts are reported to be either positive or negative and Wageningen Agricultural University crop growth model is the most appropriate model to adapt it for climate change impacts assessment.

2.4 Multi Agent System Modeling

System dynamics methodology provides an understanding of how things change with time. It is appropriate for large and complex systems requiring a study of different potential impacts of various options. This approach was adopted to simulate the highly complex upland agricultural systems of the Chittagong Hill Tracts. But there is another approach called multi agent system. It is well suited to micro level studies – household levels. It focuses more on stakeholder's interactions. It is an emerging sub-field of artificial intelligence (AI). AI can learn new concepts, can reason and draw useful conclusions.

MAS has its roots in the emerging field of artificial intelligence. Hence, most of the early theoretical development of MAS evolved from computer-related work (Ferber, 1999; Weiss, 1999). Recognizing the close analogy between distributed artificial intelligence and individual-based modeling, a number of authors realized the potentials for adopting MAS in natural resource management particularly in areas where the management of the resources are shared among a number of stakeholders. Huston et al. (1988) were perhaps the first to put forward the notion that individuals affecting and affected by a resource are uniquely situated with their own set of beliefs, behaviors and patterns of localized action, reaction and interaction. Following this notion, Hogeweg and Hesper (1990) proposed the use of individual-oriented modeling as an approach to understanding ecological systems. Other authors adopted the same philosophy in modeling ecosystems (DeAngelis and Gross, 1992; Grimm, 1999) including economic systems in particular (Antona *et al*., 1998; Thebaud and Locatelli, 2001) and social systems in general (Axelrod, 1997; Bonnefoy *et al*., 2000; Drogul and Ferber, 1994). In addition, other authors have also explored the methodological parallels between a well-known economic decision tool called game theory and MAS particularly as they relate to community-managed or common property management regimes (Bousquet *et al*., 1996; Barreteau et al., 2002).

Building from these seminal works, MAS has been applied to the modeling of natural resource management. One of the first applications was on common property management regime that is pervasive among developing nations particularly with agriculture and forest-related resources. In this context, much of the initial development and application of MAS was done by Bousquet (1998). Several authors have since applied MAS to a number of cases and studies: irrigation systems (Barreteau and Bousquet, 2000), resource sharing regimes (Thebaud and Locatelli, 2001), natural resource management (Rouchier *et al.*, 2000), game management (Bousquet *et al.*, 2001), economic and social development (Rouchier *et al.*, 2001), and environmental management (Bousquet *et al.*, 1999, 2002).

Barnaud *et al.* (2008), adopted companion modelling (ComMod) approach in the co-construction and use of a MAS model for local stakeholders such as farmers and local administrators and this approach facilitates collective learning among local stakeholders and between them and the researchers. MAS models combined with role-playing games (RPG), aimed to facilitate collective decision-making for the allocation of rural credit in a socially heterogeneous community of small farmers in mountainous Northern Thailand and six scenarios based on different combinations of (i) duration for the reimbursement of loans, (ii) mode of allocation of formal credit among three different types of farms, and (iii) configuration of networks of acquaintances for access to informal credit were considered This case study applied the bottom-up models such as MAS to analyze the functioning of agricultural systems, in particular farm differentiation and rural credit dynamics. The ability of MAS to deal with interactions between social and ecological dynamics and to provide an alternative to classical economic thinking by analyzing the effects at the village level of social interactions among individuals were also highlighted. MAS allowed in particular to consider the fundamental aspect of socioecological systems, i.e. social capital which is a determining factor of sustainability issues. This study suggests that the usefulness of models depends on the modeling process than on the model itself, because a model is usually useless if it is not understood by its potential users.

Dung (2008) studied three critical issues of conflict over water demand, the potential for extreme poverty coupled with economic differentiation, and the potential effect of soil salinization on rice production in rice-shrimp farming systems in Bac Lieu province, Mekong Delta, Vietnam by using Companion Modelling (ComMod) approach including role playing game (RPG) and agent-based model (ABM). In this study, two successive RPG sessions and a RiceShrimpMD ABM were co-constructed between researchers and local involved stakeholders over the period 2006-2009. Lessons learned from the RPGs and five-year simulation results of the RiceShrimpMD ABM show that conflict over water demand for rice and shrimp crop occurs when both rice and shrimp crops coexist in the same period within a plot after September, which is the proposed time to start rice crops. This study supports that the companion modeling approach is an appropriate methodology for opening opportunity to all relevant stakeholders to share their knowledge of and a dialogue on water demand, enhancing better understanding of and collaboration on water management issues for sustainable development.

Naivinit *et al.*, (2010) reported that rainfed lowland rice production in lower Northeast Thailand is a complex and adaptive farming activity. Complexity arises from interconnections between multiple and intertwined processes, affected by harsh climatic and soil conditions, cropping practices and labor migrations. Local rice farmers are very adaptive and adjust the behavior in unpredictable climatic and economic conditions. Better understanding is needed to manage the key interactions between labor, land and water use for rice production, especially when major investments in new water infrastructure are being considered. Based on the principles of the iterative and evolving Companion Modeling (ComMod) approach, indigenous and academic knowledge was integrated in an Agent-Based Model (ABM) co-designed with farmers engaged in different types of farming practices over a period of three years to create a shared presentation of the complex and adaptive social agroecological system in BanMakMai village, in the south of Ubon Ratchathani province. The ABM consists of three interacting modules: Water (hydro-climatic processes), Rice, and Household. Key decisions made are related to: i) rice nursery establishment, ii) rice transplanting, iii) rice harvesting, and iv) migration of household members. The spatially explicit model interface represents a virtual rain fed low land rice environment as an archetypical toposequence made of upper to lower paddies in a mini-catchment farmed by 4 different households, and also includes water bodies and human settlements. The model was found to useful to deepen the understanding of the interrelations between labor migrations and rice production, which helped to strengthen the adaptive management ability.

Potchanasin *et al.* (2008) applied a multi-agent system (MAS) model to capture the complexity and to extrapolate dynamics of farming systems sustainability in the mountainous and conservative forest areas in Northern Thailand. The model integrates biophysical and socio-economic components following a bottom up modeling approach (Becu *et al*., 2003). The heterogeneous elements of the components are modeled through the CORMAS platform with individual attributes and internal dynamic methods – corresponding to real world conditions. The assessment of sustainability was performed at household and village level. Defined indicators were household income, net farm income, household capital, household savings, food security and top soil erosion. Farming systems in the study areas are not sustainable and the food security was the most unsustained issue followed by household savings, household capital, top soil erosion, household income and net farm income. They also concluded that policy development towards sustainability maintaining food security in upland areas is very crucial.

More recent studies on Companion Modeling which is a combination of multi agent system modeling and role playing games demonstrate that Companion Modeling is the most appropriate approach for modeling of farming/agricultural systems in a heterogeneous society at household levels for sustainable development. Essentially it is a participatory approach of multi agent system modeling of management and implementation of natural resources management for sustainable development.

3. MATERIALS AND METHODS

3.1 Field Level Sample Survey

A multi stage sampling was designed for selecting the farm households from the Hill Tracts of Chittagong consisting of Bandarban, Rangamati and Khagrachhari districts. The sampling framework consisting of primary sampling unit of district, secondary sampling unit of upazila, pre-ultimate sampling unit of village and ultimate sampling of household for the data collection is shown in Table 1. First of all nine upazilas were randomly selected from each of the three districts and these districts are shown in Fig. 1. Then three villages were randomly selected from each upazila. The ultimate sampling units (i.e., farm household) from each of the villages were selected by stratified random sampling method with proportional allocation, where farm categories viz., landless (<.05 acre), marginal (0.05-0.49 acre), small (0.5-2.49), medium (2.5-7.49) and large (7.5 & above) farms were considered as the strata. Multi-stage sampling procedure designed in this study was used to select a total of 1779 households and the selected villages are shown in Table 2.

Table 1 Framework of a multistage stratified sample survey

Stage	**Sampling Unit**	**Restricted to**
1	District	Primary sampling unit
2	Upazila	Secondary sampling unit
3	Village	Pre-ultimate sampling unit
4	Households	Ultimate sampling unit

3.2 Questionnaire development

To assess the factors affecting the farming/agricultural systems of the Hill Tracts of Chittagong and their determinants, two sets of questionaire were developed with emphasis on traditional crop production system (jhum) and environmental degradation and also food security and environmental degradation at upazila levels. These are shown in Appendix A and B respectively. Two sets of questionnaire were pre-tested and necessary improvement was made.

Fig.1. Map of Bangladesh

3.3 Data collection

Purposeful random sampling was conducted for primary data collection and four different categories of farm size were considered and these are landless, marginal, small, medium and large. Pre-tested questionnaire was used for primary data collection from individual farmers. Data on population, crop, aquaculture, livestock and forestry were collected to estimate the present status of food security at upazila levels in Bangladesh from upazila office of Government Department of Statistics, Agriculture, Fishery and Livestock. In addition, a

Focus Group Discussion was held with the Sub-Assistant Agricultural Officers of 10 Blocks of Khagrachhari Sadar Upazila on *jhum* cultivation on 16 April 2009 in the Khagrachhari Upazila Agricultural Extension Office. Also the research Team visited several plantation models with fruit and forest species including DAE suggested individual farm model and Police Battalion Model of Mohalchhari.

Collected data and information were compiled, edited, summarized and analyzed. A database was prepared in Excel for computation of the descriptive statistics and multivariate analysis of the farming/agricultural systems, and food security and ecological footprint. Excel format permits easy change or refinement of any data and the subsequent computation of the descriptive statistics and multivariate analysis of the farming/agricultural systems, and food security and ecological footprint. for changed or refined data in the designed Excel computation mode automatically. A database prepared for computation of food security and ecological footprint are shown in Appendix C.

Table 2 selected villages from the Hill Tracts of Chittagong

District	Upazila	Village
Bandarban	Sadar	Chemidulupara, Getsemonipara, Farukpara
	Ali kadam	Noapara, Monshapara, D.P. Palangpara
	Ruma	Bethelpara, Bogalake para, Hatimathapara
Rangamati	Sadar	Khamarpara, Uluchhari, Tanchangapara
	Barkal	Kyangpara, Bangailbaichha, Bhushanchhara
	Kaptai	Chitmorong, Karigorpara, Chhoto Paglipara
Khagrachhari	Sadar	Golabari, Bogra Chhara, Nolchhara para
	Mahalchhari	Lamuchhari, Uchcha Kangailchhari, Mohamunipara
	Dighinala	Doluchhari, Netrojoypara, Joy Durgapara

3.4 Multivariate analysis

Multivariate analysis is necessary to assess the relevance of the selected variables to the problem being investigated (Aldenderfer and Blashfield, 1984). Although there is no general rule for selecting the variables, first selection is based on researchers' previous experience and knowledge of the study area regarding the objectives of the study. A total of 18 quantitative and qualitative variables were initially selected to study their interrelationships by multivariate analysis. The multivariate technique is to analyse the data with small number of variables as per as possible keeping the basic information unaffected. The technique of analysis with minimum number of variables is called ‘Data Reduction’ technique. The principal component analysis (PCA) and factor analysis (FA) are two data reduction techniques. Principal component analysis (rotated and unrotated) and factor analysis were conducted to determine the determinants and patterns of agricultural systems of the Hill Tracts of Chittagong and also to identify the farming/agricultural systems (Johnson and Wichem, 2003). The multivariate analyses covered in this study are:

(a) Principal component analysis

(b) Factor analysis

(c) Cluster analysis

(d) Discriminant analysis

Principal component analysis

Principal component analysis transforms a number of correlated variables into a smaller number of uncorrelated variables called principal components or factors based on statistical variance. Basically, the principal component analysis is a technique to obtain linear combinations of representative variables for a multidimensional phenomenon that exhibit maximum variance and which, at the same time, are orthogonal.

Let us consider the linear combinations of p variables $X_1, X_2,..., X_p$:

$$\begin{aligned} Z_1 &= c_1'X = c_{11}X_1 + c_{12}X_2 + ... + c_{1p}X_p \\ Z_2 &= c_2'X = c_{21}X_1 + c_{22}X_2 + ... + c_{2p}X_p \\ &\vdots \qquad\qquad\qquad \vdots \\ Z_p &= c_p'X = c_{p1}X_1 + c_{p2}X_2 + ... + c_{pp}X_p \end{aligned} \tag{1}$$

Then the variance and covariance of Z_i’s are

$$\begin{aligned} Var(Z_i) &= c_i'Var(X)c_i \qquad i = 1, 2, ...,p \\ Cov(Z_i, Z_k) &= c_i'Cov(X)c_k \qquad i, k = 1, 2, ..., p \end{aligned} \tag{2}$$

The principal components are those uncorrelated linear combinations Z_1, Z_2, ..., Z_p whose variances in (1) are as large as possible.

The first principal component is the linear combination with maximum variance. That is, it maximizes Var(Z_1) $= c_1'\Sigma c_1$. It is clear that Var(Z_1) = $c_1'\Sigma c_1$ can be increased by multiplying any c_1 by some constant. To eliminate this indeterminacy, it is convenient to restrict attention to coefficient vectors of unit length. We therefore define

First principal component = linear combination $c_1'X$ that maximizes

$$\text{Var}(c_1'X) \text{ subject to } c_1'c_1 = 1 \quad (3)$$

Second principal component = linear combination $c_1'X$ that maximizes

$$\text{Var }(c_2'X) \text{ subject to } c_2'c_2 = 1 \text{ and Cov } (c_1'X, c_2'X) = 0 \quad (4)$$

At the ith step, ith principal component = linear combination $c_i'X$ that maximizes

$$\text{Var }(c_i'X) \text{ subject to } c_i'c_i = 1 \text{ and Cov } (c_i'X, c_k'X) = 0 \text{ for } k < I \quad (5)$$

In this study, the number of variables can be reduced and a small number of principal factors will explain most of the variance (Rodriguez Diaz, 2004). As principal component analysis is based on statistical variance, the first chosen factor accounts for most of the variance in the data. The second is chosen in the same way but it has to be orthogonal to the first. The last factor explains all the residual variance (Kim, 1970; Lawley and Maxwell, 1971).

Factor analysis

Factor analysis can be considered as an extension of principal component analysis (Johnson and Wichern, 2003). Factor analysis attempts to simplify complex and diverse relationships that exist among a set of observed variables by uncovering common dimensions or factors that link together the seeming unrelated variables, and consequently provides insight into the underlying structure of the data (Dillon and Goldstein, 1984).

Factor analysis extracts principal factors that explain much of the total variation. As the exact external shape of the factor structure is not unique, one factor solution can be transformed into another one or rotated to a terminal solution. This can achieve simpler and more meaningful factor patterns, instead of the highly complex extracted factors that are related to many of the variables rather than to just a few (Kim, 1970; Comrey and Lee, 1992). In factor analysis, the observed values are explained through a linear combination of factors and a residual. Basically, the factor model is motivated by the argument that all variables within a particular group are highly correlated among themselves, but have relatively small correlations with variables in different groups.

There exist a difference between principal component analysis and factor analysis. In principal component analysis, the components are so selected that they can explain maximum variation in the original data set. On the contrary, in factor analysis, a small number of common factors are extracted so that these common factors are sufficient to study the relationships of original variables. The fraction of each variable's variance which is explained by the total of the extracted factors is known as communality. Communality presents the extent of overlap between the extracted factors and the variable and it equals the sum of squares of the variable's loading across factors (Comrey and Lee, 1992). The common factor analysis is a covariance or correlation oriented method based on the assumption that each variable is influenced by a set of shared or common factors whose loadings determine their correlations with the variable.

In practice, it is not easy to decide how many factors should be retained in a particular problem. As factors are extracted from large to small, the corresponding Eigenvalues are declining. If the Eigenvalues are plotted against the factors, a straight line can be drawn through the smaller values and the larger Eigenvalues will fall above the straight line. It can be proposed that the number of factors to be retained is at the point where the last small factor is above the line, giving an indication of how many factors there are (Comrey and Lee, 1992). All the factors with eigenvalues of 1 or more can be retained in principal component analysis and factor analysis (Kaiser’s rule).

In fact, we should like to see a pattern of loadings is such that each variable is loaded highly in a single factor and small to moderate loadings in the remaining factors. However, it is not always possible to get this simple structure, although a nearly ideal pattern can be achieved by factor rotation. Kaiser (1958) has suggested an analytical measure of simple structure known as the varimax criterion and it is applicable if the factor analysis is done by principal factor method. So, the solution of factors obtained by principal factor method were rotated using varimax method to a terminal solution that can deliver simpler and more meaningful factor patterns, instead of the highly complex extracted factors, whereby the factors are independent of each other. This rotation does not influence the test of adequacy of the factor model.

The basic common factor-analytic model is usually expressed as

$$X = \Lambda f + e \qquad (6)$$

where X = p-dimensional vector of observed variables, $X' = (X_1, X_2, ..., X_p)$,

f = q-dimensional vector of unobservable variables called common factors,

$f' = (f_1, f_2, ..., f_q)$,

e = p-dimensional vector of unobservable variables called specific or unique factors,

$e' = e_1, e_2, ..., e_p)$, and

$\Lambda = p \times q$ matrix of unknown constants called factor loadings,

$$\Lambda = \begin{pmatrix} \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1q} \\ \lambda_{21} & \lambda_{22} & \cdots & \lambda_{2q} \\ \vdots & \vdots & & \vdots \\ \lambda_{p1} & \lambda_{p2} & \cdots & \lambda_{pq} \end{pmatrix} \qquad (7)$$

There are p specific or unique factors and it is generally assumed that the unique part of each variable is uncorrelated with each other or with their common part.

Agricultural land use decisions are complex, involving large number of bio-physical and institutional factors. To identify the interrelationships between the variables and the basic patterns of the interrelationships we will use factor analysis. Highly correlated variables are grouped and each group represents a factor. Factor analysis extracts principal factors that explain much of the total variation. The factors may be institutional support, productive resources, distance to the market and service centers

In this study we consider the most popular methods of parameter estimation – principal component and principal factor methods and the solution from these methods can be rotated in order to simplify the interpretation of the factors. Current estimation and rotation methods require iterative calculations that must be done in a computer. Several computer programs are now available for this purpose.

Cluster analysis

Cluster analysis (CA) is conducted for solving classification problems - degree of association is strong between the members of same cluster. Cluster analysis is a more primitive technique where no assumptions are made concerning the number of groups or the group structure. Grouping is done on the basis of similarities or distances (dissimilarities). There are many methods for estimating the distance or similarity between two sample objects. The most commonly used distance measure, is the squared Euclidean distance and is given by

$$d_{ij} = \sum_{k=1}^{p} (X_{ik} - X_{jk})^2 \qquad (8)$$

The agglomerative hierarchical method is used for clustering. The method starts under the assumption that all the sample objects belong to different clusters and there are as many clusters as there are sample objects. This assumption is considered as the first step of the method. At the second step, two of the objects are combined into a single cluster. At the third step, either a third case is added to the cluster already containing two objects or two additional objects are merged into a new cluster. At the subsequent steps, either individual objects are added to clusters or already existing clusters are combined. The method continues until all objects are merged to a single cluster. The cutting point of the hierarchical tree (dendrogram) can be selected through subjective inspection or by plotting the number of clusters against the change in the fusion coefficient, that is, the difference between the distance coefficient at one clustering stage and the previous one.

The variables characterizing the agricultural systems are selected. The selected variables are area under shifting agriculture, forest, horticulture and rice cultivation, proportion of pineapple cultivators, average number of banana trees, other fruit trees, timber trees, cattle, goats, sheep, pigs and poultry.

Discriminant analysis

The adequacy of classification of cluster analysis can be checked by discriminant analysis. Discriminant analysis can be employed as a useful complement to cluster analysis. After identifying the factors influencing agricultural systems, the relative importance of each factor in determining the system was analyzed. Discriminant analysis was used to identify the specific variables which define individual groups of observations.

Discriminant analysis is a technique of studying the relationship between a nominal variable and a set of interval variables. Two situations may arise in such studies. In one situation the researcher may be interested in the effect of the interval variables (influencing factors) on the nominal variable (response or dependent variable). Here the situation is very much like the multiple regression analysis. The basic difference is that in multiple regression the dependent variable is measured at interval level while in discriminant analysis the dependent variable is nominal. The researcher may be interested in the simultaneous differences in the set of interval variables caused by their assignment to different categories or groups. In this case the nominal variable with different groups is acting as the independent variable while the set of interval variables are treated as dependent variables. The second one is of our situation.

3.5 Computation of food security

Food security is a situation in which people do not live in hunger or fear of starvation. Food security exists when all people at all times have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2002). Food security for a household means access by all members at all times to enough food for an active and healthy life. Food security includes at a minimum (1) the ready availability of nutritionally adequate and safe foods, and (2) an assured ability to acquire acceptable foods in socially acceptable ways (USDA, 1999). USDA evaluated food security based on the gap between projected domestic food consumption and a consumption requirement (USDA, 2007). All food aid commodities were converted into grain equivalent (kg) based on calorie content. Based on USDA concept the food security is defined as:

Food availability status = (Food available from different sources and also equivalent food from different sources - Food requirement) / Food requirement (9)

Yusuf and Islam (2005) reported that the daily food requirement data of the Bangladesh Bureau of Statistics (BBS) and the Institute of Nutrition and Food Science (INFS) are not adequate and consumption of such a diet would produce physiological deficiencies of both energy and protein leading to protein-energy malnutrition as well as micronutrient malnutrition and proposed a dietary composition for balanced nutrition in Bangladesh as shown in Table 3. The total food intake proposed is 2345 kcal/cap and it is midway between the values suggested by WHO (2310 kcal) and FAO (2400 kcal). The proposed 2345 kcal is equivalent to 1.357 kg of rice based on price. All food aid commodities were converted into grain equivalent based on economic returns (price in Taka) to compute the food security. Based on this concept the food security is computed as (Bala and Hossain, 2010a)

Food Availability Status = ((Food available from crops + Food available from aquaculture and equivalent food from income of aquaculture + Food available from livestock and equivalent food from income of livestock + Food available from forestry and equivalent food from income of forestry) – Total food requirement) / Total food requirement (10)

Table 3. Daily balanced food requirement

SL. No.	Food Item	Amount (gm)	Price (Tk. /kg)	Total price (Tk.)	Equi rice (kg)	kcal
1	Rice	312	26.60	8.30	0.312	1086
2	Wheat	60	28.00	1.68	0.063	209
3	Pulse	66	55.00	3.63	0.136	228
4	Animal products	126	110.00	13.86	0.521	176
5	Fruits	57	30.00	1.71	0.064	41
6	Vegetables	180	12.00	2.16	0.081	113
7	Potato	80	12.00	0.96	0.036	71
8	Oil	36	80.00	2.88	0.108	324
9	Sugar and Gur	22	30.00	0.66	0.025	88
10	Spices	14	20.00	0.28	0.011	09
Total		953		36.12	1.357	2345

Positive food availability status means surplus food and negative food availability status means shortage in food supply to lead healthy life. The structure of food availability status computation is shown in Fig. 2. Off farm income is taken into account at household levels and it is not shown in Fig. 2.

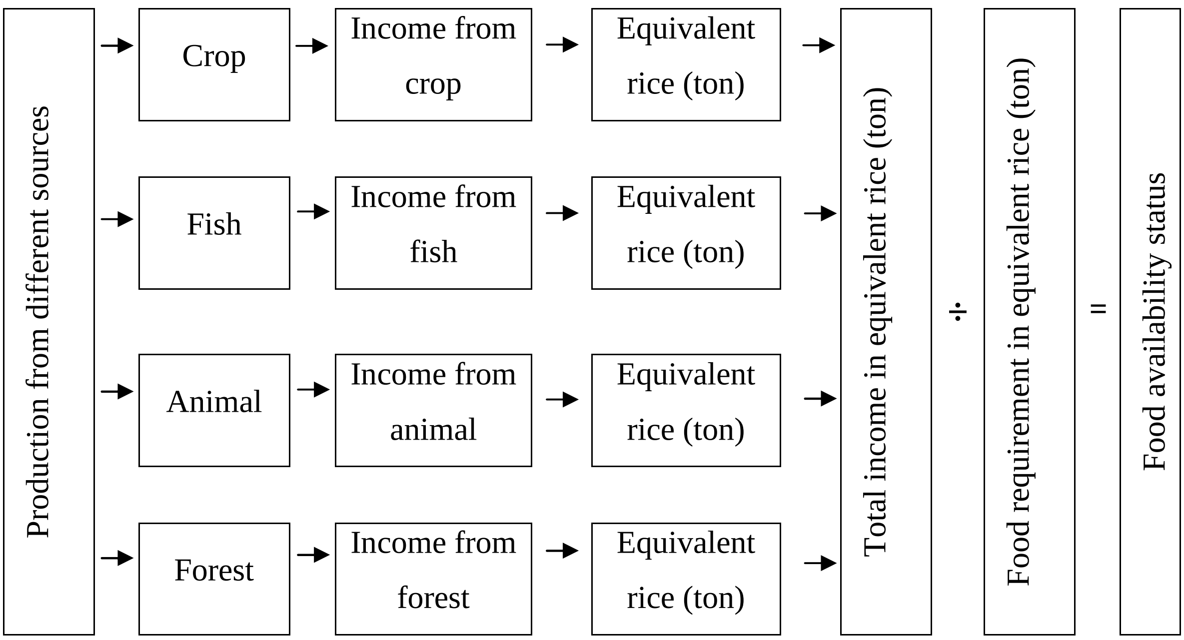


Fig. 2. Structure of food security computation

Self Sufficiency Ratio (SSR) is calculated as per FAO's method (FAO, 2001) to the extent to which a country relies on its own production resources. SSR is defined as:

$$SSR = \text{Production} / (\text{production} + \text{imports} - \text{exports}) \qquad (11)$$

3.6 Computation of ecological footprint and biological capacity

Ecological footprint represents the human demands, taking into accounts the production and supply of resources (energy, food and materials) and assimilation of the wastes (in all forms) generated by the analyzed system. Ecological footprint of a given population is the total area of productive land and water required to produce all the resources (energy, food and materials) consumed and to absorb the waste generated by that population of a region or nation using prevailing technology and resource management practices. The ecological footprint calculation is based on the average consumptions data are converted into uses of productive lands. The bioproductive land is divided into 6 categories according to the classification of the World Conservation Union: (1) cropland; (2) grazing land; (3) forest; (4) fishing ground; (5) build-up land; (6) energy land.

Total ecological footprint is the sum of the ecological footprints of all categories of land areas which provide for mutually exclusive demands on the bio-sphere. Each of these categories represents an area in hectares, which is then multiplied by its equivalence factor to obtain the footprint in global hectares. One global hectare is equal to 1 ha with productivity equal to the average of all the productive ha of the world. Thus, one ha of highly productive land is equal to more global hectares than 1 ha of less productive land. The ecological footprint can be expressed as

$$\text{Footprint (gha)} = \text{Area (ha)} \times \text{Equivalence Factor (gha/ha)} \qquad (12)$$

Where,

Equivalence Factor = world average productivity of a given bioproductive area / world average potential productivity of all bioproductive areas.

Equivalence factor represents the world average productivity of a given bioproductive area relative to the world average potential productivity of all productive areas and it is the quantity of global hectares contained within an average hectare of cropland, build-up land, forest, pasture or fishery. The structure of the computation of ecological footprint is shown in Fig. 3.

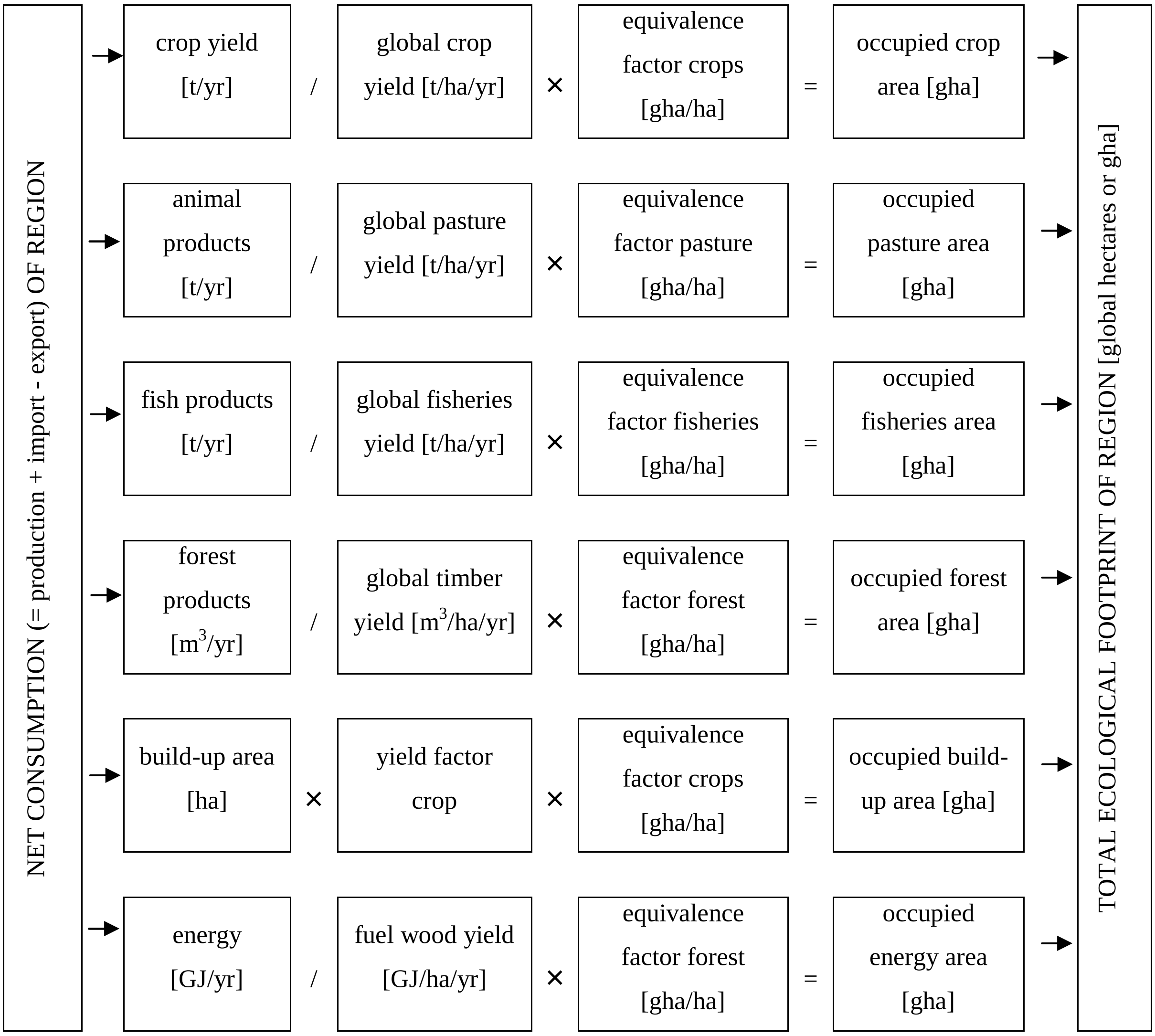


Fig. 3. Structure of ecological footprint computation

An important part of the ecological footprint analysis of a region or zone is represented by the calculation of its Biological Capacity (Biocapacity) that takes into account the surfaces of ecologically productive land located within the area under study. Biological capacity represents the ecologically productive area that is locally available and it indicates the local ecosystems potential capacity to provide natural resources and services. Biological capacity is the total annual biological production capacity of a given biologically productive area. Biological capacity can be expressed as

$$\text{Biocapacity (gha)} = \text{Area (ha)} \times \text{Equivalence Factor (gha/ha)} \times \text{Yield factor} \quad (13)$$

Where,

Yield factor = Local yield/ global yield

Total biocapacity is the sum of all bioproductive areas expressed in global hectares by multiplying its area by the appropriate equivalence factor and the yield factor specific to that country/locality. The structure of the computation of biocapacity is shown in Fig. 4. Biological capacity can be compared with the ecological footprint, which provides an estimation of the ecological resources required by the local population. The ecological status is expressed as the difference between biocapacity and ecological footprint. A negative ecological status (BC < EF) indicates that the rate of consumption of natural resources is greater than the rate of production (regeneration) by local ecosystems (Rees, 1996). Thus, an ecological deficit (BC < EF) or surplus (BC > EF) provides an estimation of a local territory's level of environmental sustainability or unsustainability. This also indicates how close to sustainable development the specific area is.

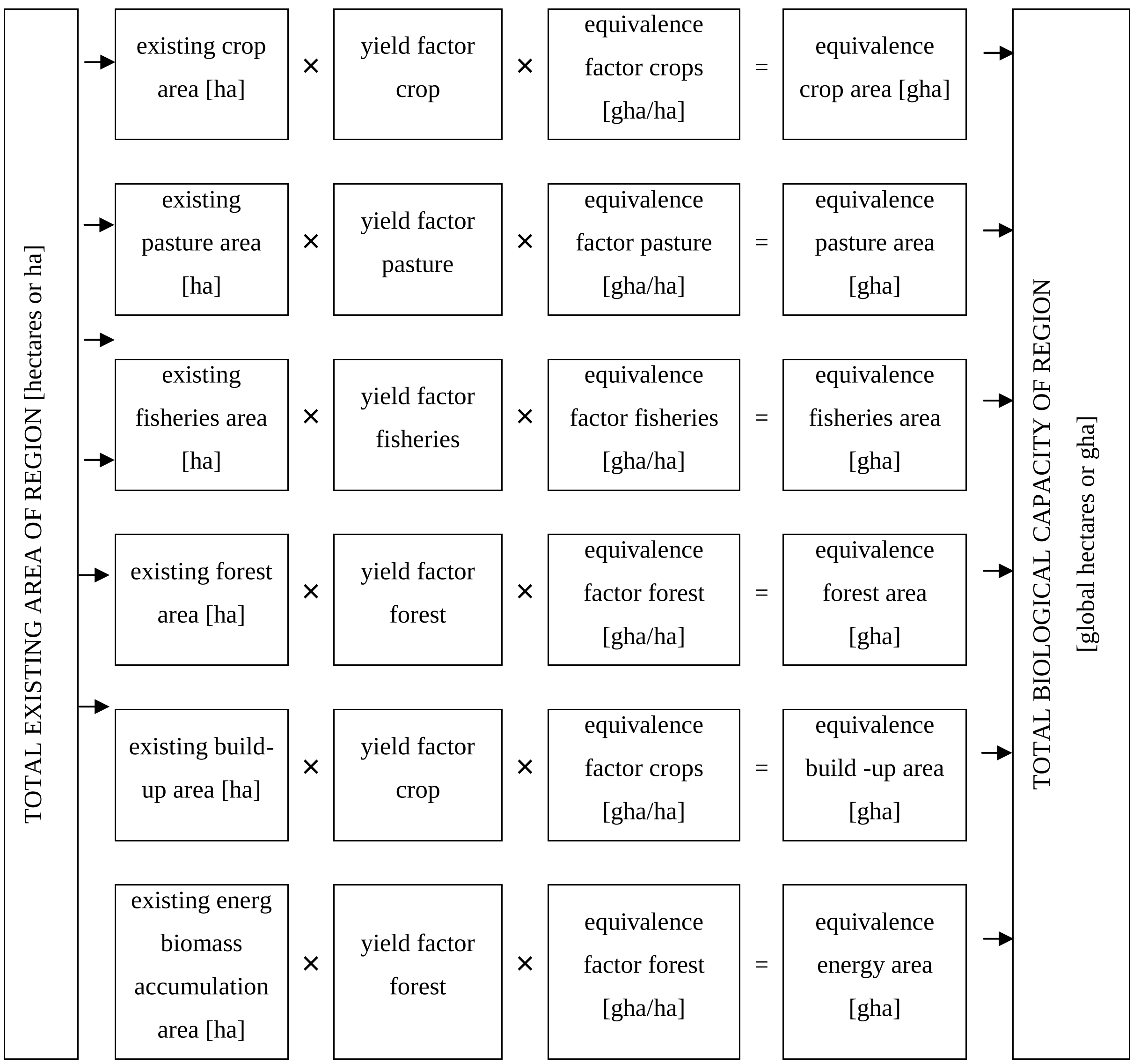


Fig. 4. Structure of biological capacity computation

3.7 Modeling of upland agricultural systems

The management system of the uplands of agricultural systems of the Hill Tracts of Chittagong consists of population, crop production, tobacco, forestry and ecological sector. The system as a whole can be described in terms of interconnected blocks. Block diagram representation of the uplands of agricultural systems of the Hill Tracts of Chittagong is shown in Fig. 5. Although usually crop production includes jhum, horticulture and tobacco production, tobacco is shown as a separate block to draw attention to the rapidly expanding tobacco cultivation. The major influences to a sector from other sectors and its influences on the other sectors are shown in the diagram. Jhum area is converted into horticultural crop area and forest area and crop area is converted into tobacco area. Major contributions to the food security of the Hill Tracts come from the jhum production, crop production, horticultural production, tobacco production and forest production and the environmental degradation i.e. ecological footprint comes from mainly jhum production, tobacco production and soil erosion. The simplified flow diagram of integrated farming/agricultural system is shown in Fig. 6. The building blocks of the model are stock and flow. The stock is a state variable and it is represents the state or condition of the system at any time t. The stock is represented by a rectangle. The flow shows how the stock changes with time and it is represented by valve symbol. The flow with arrow towards the stock indicates inflow and the flow with arrow outwards indicates outflow. The lines with arrow are influence lines and the direction indicates the direction of information flow. The variable/factor at the starting point indicates the variable/factor affecting the variable/factor at the terminating point and this in essence shows how one variable/factor influences other variable/factor with direction of information flow. In Fig. 6 jhum area is a stock variable and land transfer rate for hort is outflow from the stock – jhum area. The line starting from the population to population growth with arrow towards the population growth indicates that population level depends on population growth. The STELLA flow diagram of the detailed model is shown in Fig. 7. This model is essentially a detailed mathematical description of the system and it is a system of finite-difference integral equations. The system of equations of the model is given in Appendix-E. The principles of System Dynamics are given in Bala (1999a).

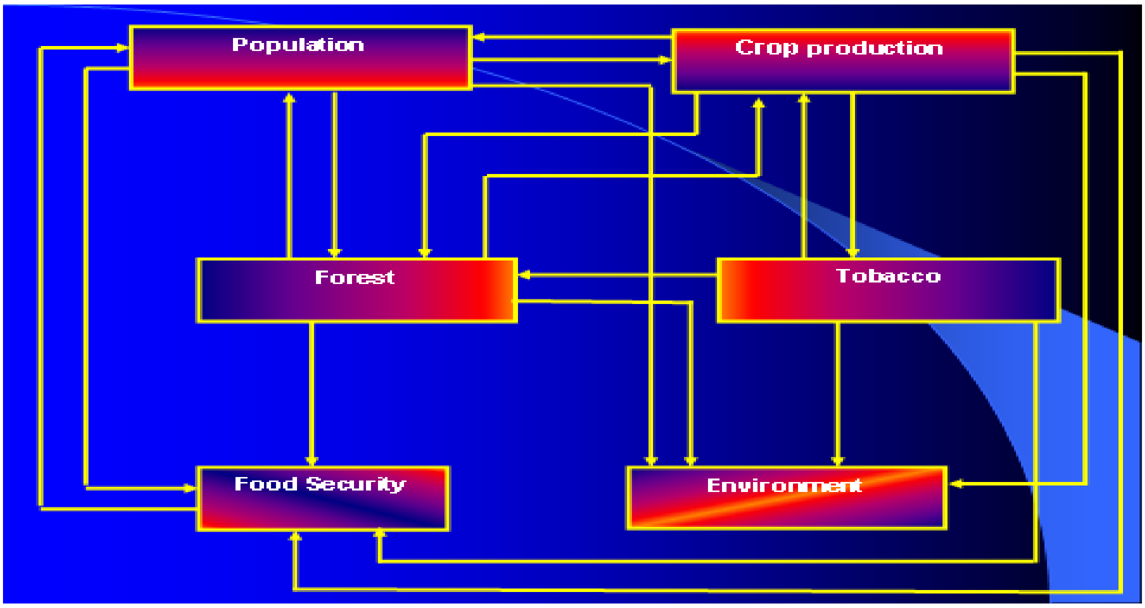


Fig. 5. Interrelationships of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong

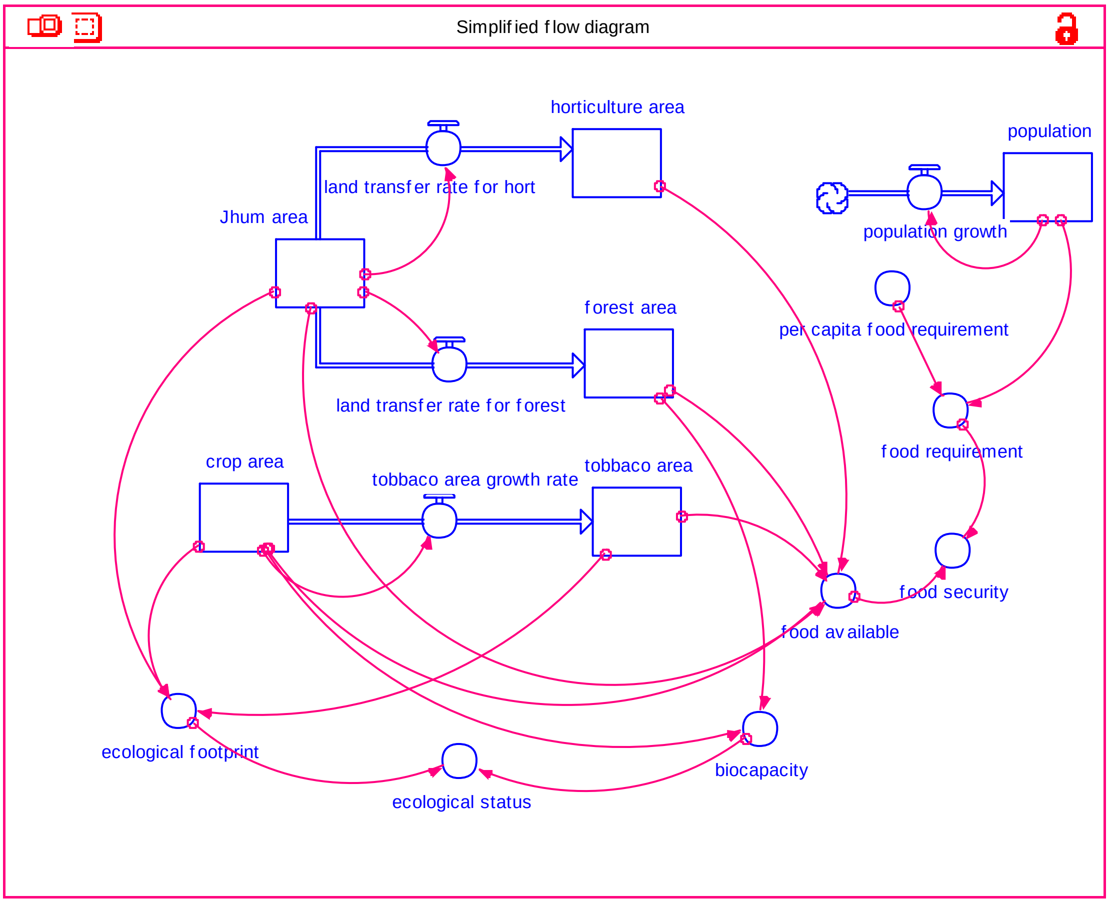


Fig. 6 Simplified flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong

In this study three policy options are considered and these are (i) gradual transfer of crop (rice) area into tobacco area and *jhum* area into horticultural area, (ii) gradual transfer of *jhum* area into horticultural area, and (iii) rice plus *jhum* area.

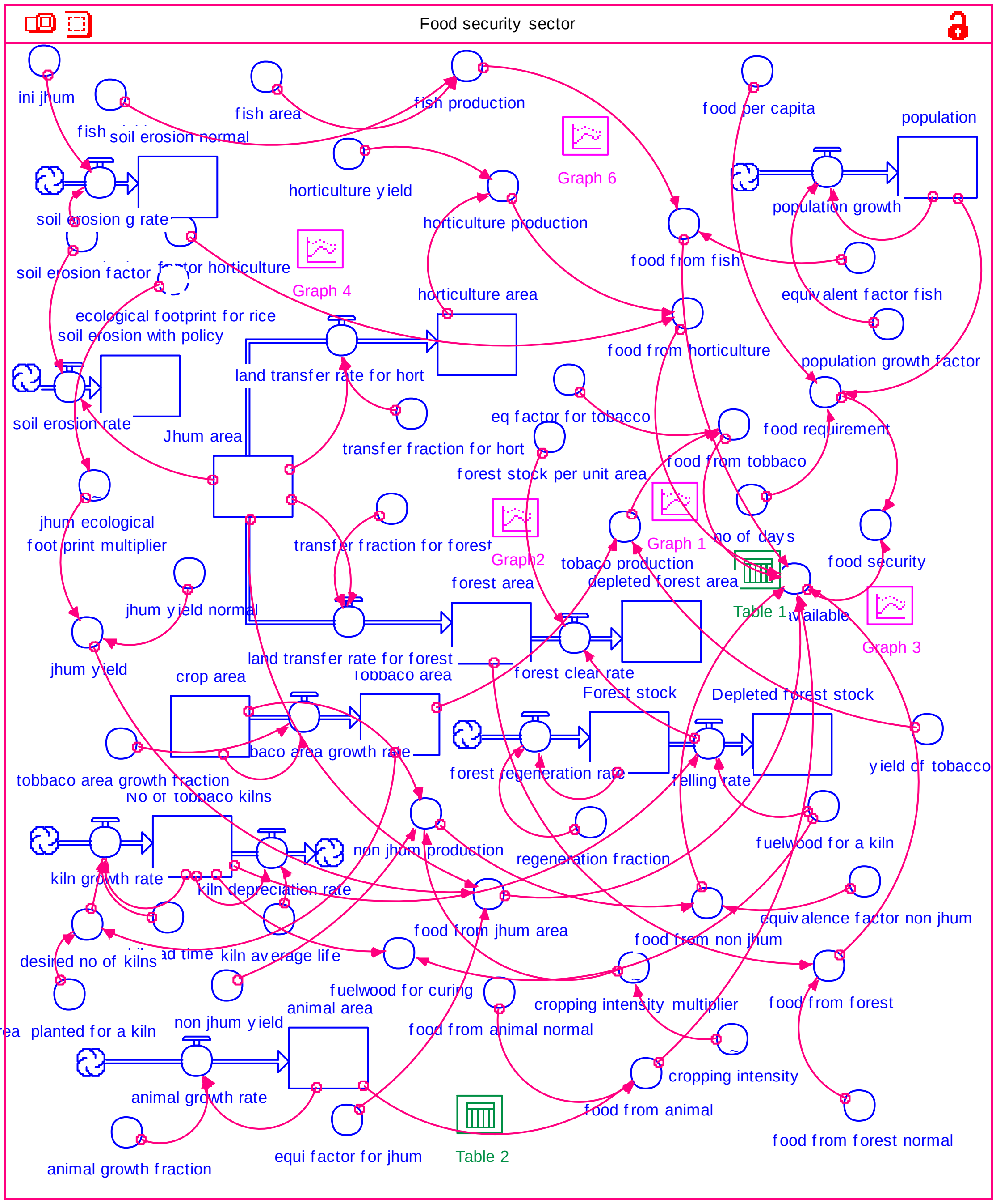


Fig. 7. STELLA flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong

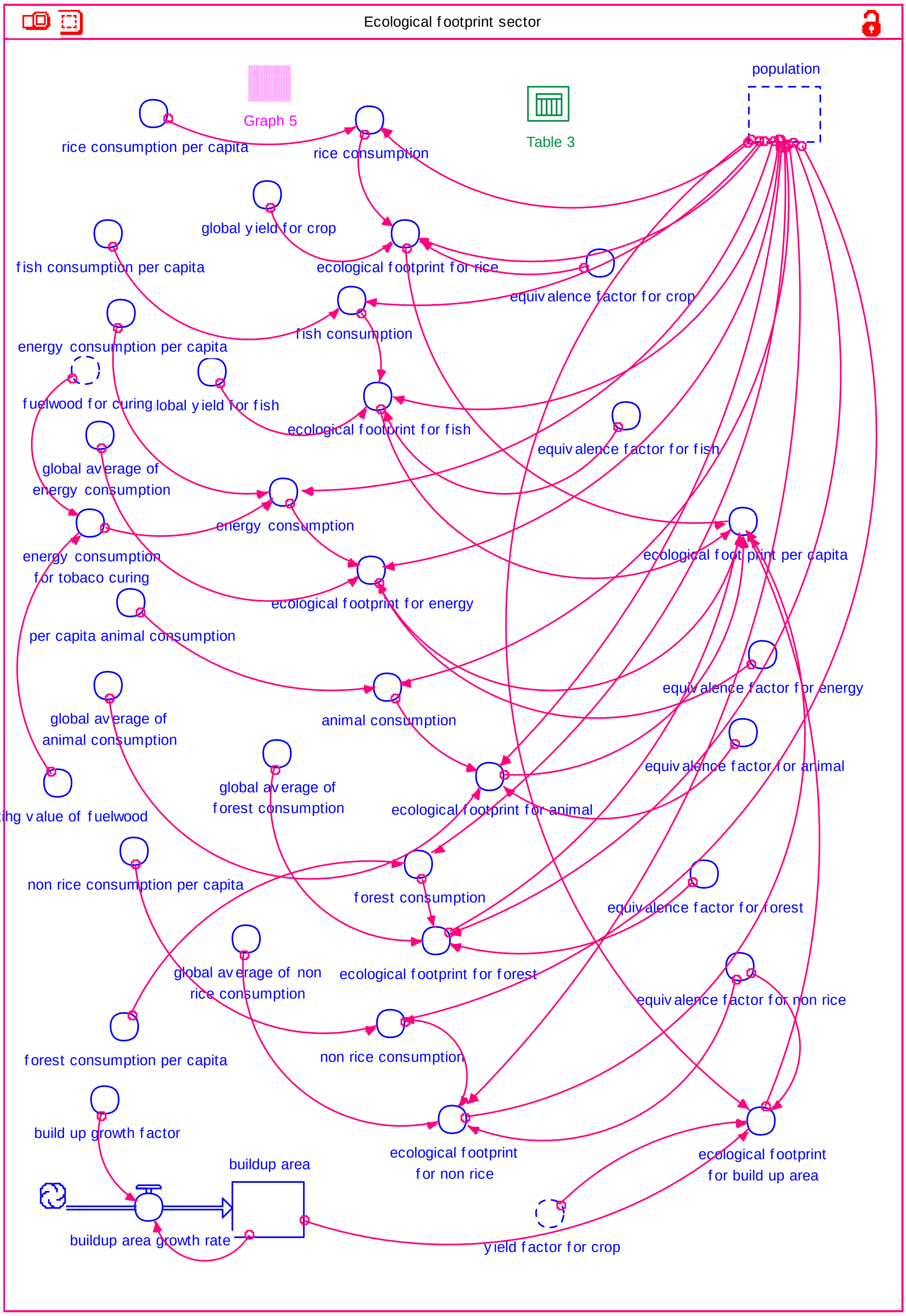


Fig. 7. STELLA flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong (Continued)

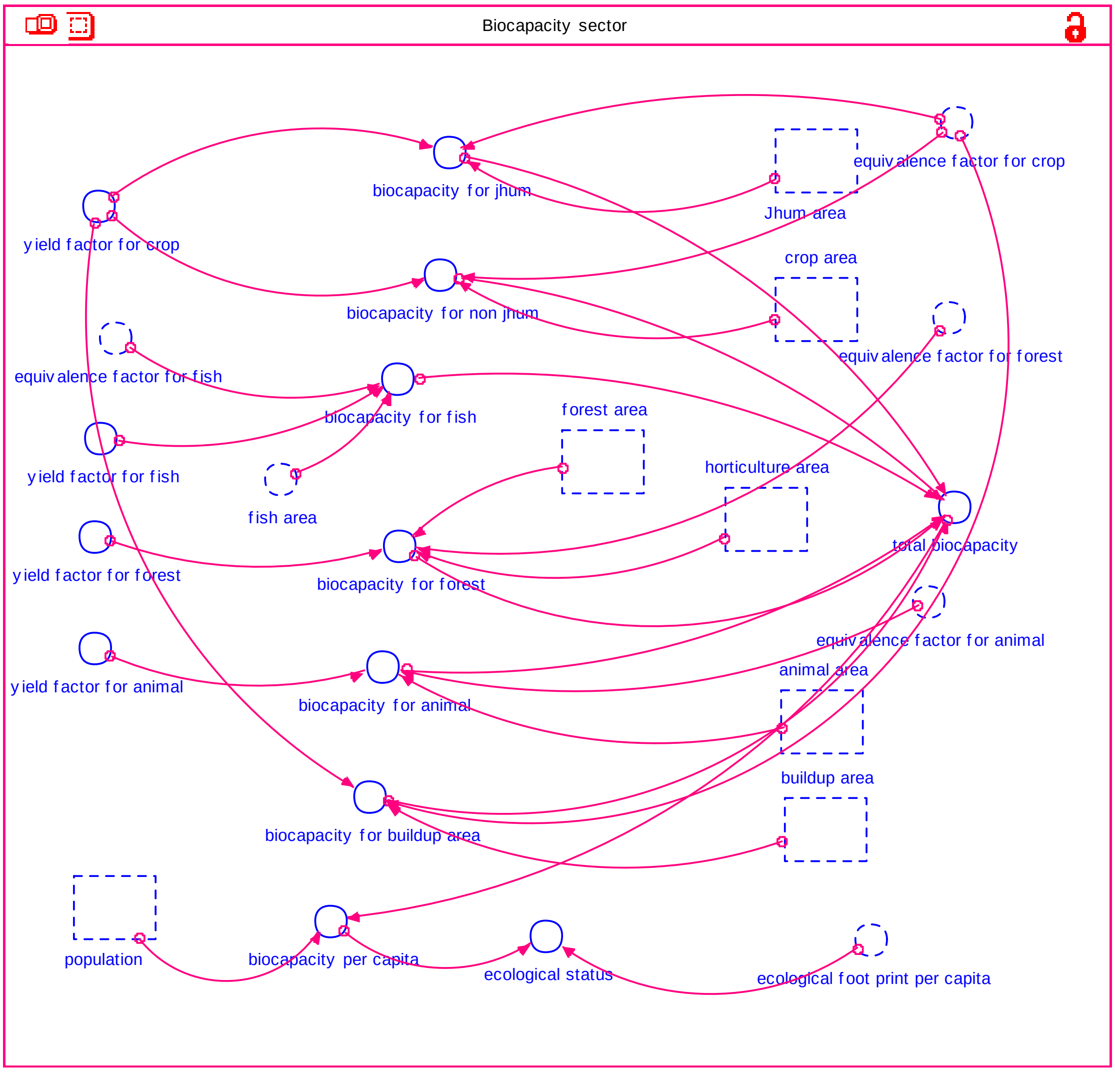


Fig. 7. STELLA flow diagram of management system of the uplands of agricultural systems of the Hill Tracts of Chittagong (Continued)

3.8 Climate Change Impacts

Computation of canopy photosynthesis from the incoming photosynthetically active radiations forms the central part of the crop growth simulation models. The growth rate of the crop is calculated as a function of radiation use efficiency, photosynthetically active radiation, total leaf area index and a crop/ cultivar specific extinction coefficient. The crop model used for climate impacts assessment of several crop development and growth processes and the relationships among them are shown in Figure 8. These development and growth processes are dry matter production, dry matter partitioning, leaf area growth and phenology.

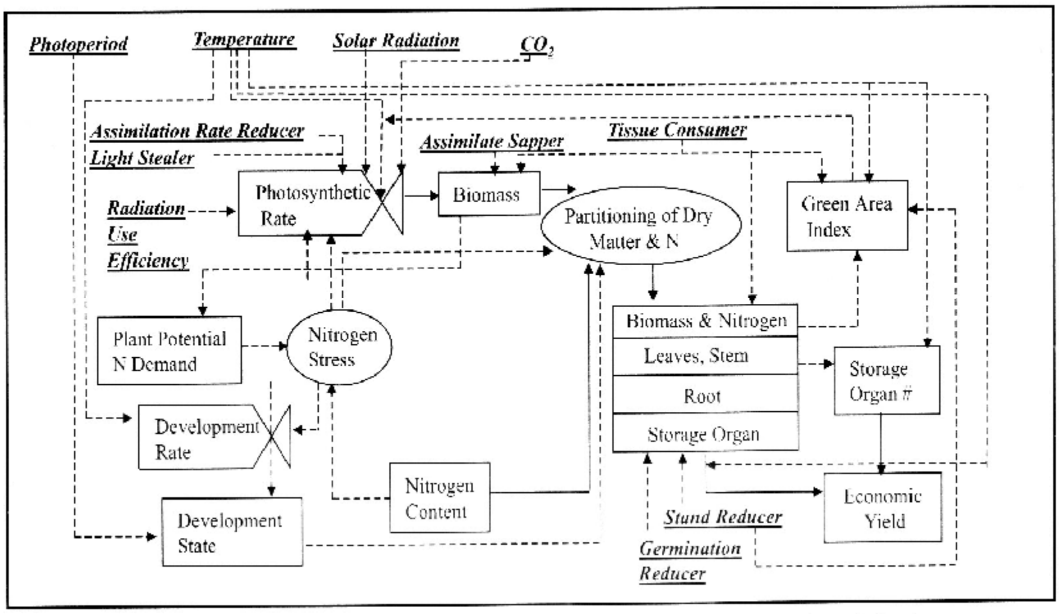


Fig. 8 Crop growth model (Bala, 2010 a)

Dry matter production

Several models including SUCROS, MACROS, WTGROWS and ORYZA calculate dry matter production as a function of gross canopy photosynthesis, depending on the detailed calculations of the distribution of light within the canopies, the radiation absorbed by the canopy, and photosynthesis light response curve of leaves (Bouman et al., 2000). Growth and maintenance respirations are calculated as a function of tissue N-content, temperature and crop-specific coefficients. This methodology although yields very accurate results, poses practical difficulties because of its requirement for detail and careful measurements. More or less similar results can generally be obtained under normal radiation situations by calculating the net dry matter production as a function of the radiation use efficiency. This approach was utilized in the present model. Pre-determined values of the radiation use efficiency were input in the model as a function of crop/cultivar. This was further modified by the development stage, abiotic and biotic factors. The effect of temperature mimics a crop-specific decrease in photosynthesis due to adverse mean daytime temperature. But, CO_2 increases the relative photosynthesis in C3 plants, whereas this effect on C4 plant is negligible. This was simulated by a crop-specific input that increases radiation use efficiency as a function of ambient CO_2. Radiation interception of crops has been calculated as a function of total Leaf Area Index (LAI), incident solar radiation, radiation captured by the pests and weeds and a crop/cultivar-specific extinction coefficient. The latter is also sensitive to the age of the plant. The growth rate of the crop were calculated as a function of radiation use efficiency, radiation intercepted by the crop, total leaf area index, radiation captured by the pests and crop/cultivar specific extinction coefficient as follows:

$$GCROP = RUE * PAR * (1 - EXP(- KDF * (LAI - PSTPAR))) \quad (14)$$

Where, GCROP = net crop growth rate

RUE = radiation use efficiency

PAR = photosynthetically active radiation

KDF = extinction coefficient

LAI = leaf area index

PSTPAR = radiation captured by the pests

Dry matter portioning

The net dry matter available each day for crop growth was partitioned into roots, leaves, stems, and storage organs as a crop-specific function of development stage. Allocation was made first to roots, which gets increased in case the crop experiences water, or nitrogen stress. The remaining dry matter was allocated to the above ground shoot from which a fraction was allocated to leaves and stems. The balance dry matter was automatically allocated to the storage organs.

A fraction of carbohydrates partitioned to the stems was treated as non-structural reserves depending on the crop and development stage. These reserves accumulate more if the growth rate of storage organs lags behind the current dry matter production. After anthesis, in addition to current assimilates, 10% of the previously accumulated reserves are mobilized every day and used for storage organ growth (Penning de Vries et al., 1989).

The net growth rates of leaves, stems, roots and storage organs were calculated based on the growth rate of the crop, fractions allocated, death due to senescence, and losses due to pests and during transplanting if any. The weights of green leaves, dead leaves, stem, roots, and storage organs were updated every day based on their initial weights at seedling emergence and the daily growth rates were calculated. The net weight of the storage organs was adjusted for their energy content (Penning de Vries et al., 1989). Allocation to leaves is computed as:

$$RWLVG = GCROP * FSH * FLV - (DLV + SUCKLV) \quad (15)$$

Where RWLVG = net growth rates of leave

GCROP = net crop growth rate

FSH = fraction allocated to shoots

FLV = fraction allocated to leaves

Similar procedure is adopted for stems and roots.

Leaf area growth

The leaf area growth was calculated based on initial leaf area index and its growth rate. The latter was obtained by multiplying the increment in leaf weight by the specific leaf area. During initial stages, there is a greater control over the area formation, and hence for this period net growth rate is calculated based on a thermal time-dependent relative growth rate of leaf area index (Kropff et al., 1994). The integrated photosynthetic areas of stems, sheaths and spikes have been estimated to be between 10 and 100% of green leaf lamina areas depending upon the crop. Since the number of the tillers/branches is not simulated, the non-lamina area was calculated as a crop-specific function of the maximum leaf lamina area index and a sequence rate that is accelerated by temperature. The photosynthesis characteristics of the non-lamina green areas were assumed to be the same as those of leaves.

Simulation of sequences (DLAI) is based on several empirical constants relating to shading, ageing, nitrogen mobilization, temperature, water stress and death due to pests and diseases. The loss leaf area and weight due to ageing and tiller mortality were assumed to commence once stems starts expanding. Shading in dense stands accelerates senescence. Higher or lower temperatures can accelerate rate of senescence depending upon the crop. The water stress also accelerates senescence depending upon its severity. After anthesis, considerable nitrogen is mobilized from leaves for the grain development in most annual crops. This can induced rapid senescence. This was simulated in this model by making senescence of leaves also dependent on the fraction of nitrogen mobilized from leaves everyday once the storage organ start filling up. Net effective leaf area for photosynthesis and transpiration are thus the sum of the leaf areas and non–lamina green area after subtracting all losses due to senescence and insect feeding.

$$RLAI = LAII + GLAI - DLAI - LALOSS \quad (16)$$

Where, RLAI = net leaf area growth rate

LAII = initial leaf area index

GLAI = leaf area growth rate

DLAI = death rate of leaf area index

LALOSS = net loss of leaf area index due to pests

Phenology

The total development of a crop has been quantified based on development stages (DS), a dimensionless variable having a value of 0 at sowing, 0.1 at seedling emergence, 1.0 at flowering and 2.0 at maturity (Keulen and Seligman, 1987). This was calculated by integrating the temperature-driven development rates of the phases from sowing to seedling emergence, seedling emergence to anthesis, and storage organ filling phases.

The rate of development of sowing to seedling emergence phase is controlled by the thermal time. Since water stress delays emergence in many crop plants, the thermal time can be increased depending upon the available water fraction in surface soil layer. Thus, two parameters have been used to quantify duration of this phase for different crop/varieties: thermal time from sowing to emergence and base temperature for this period.

Seedling emergence to anthesis phase is generally divided into three major sub-phases depending upon the environmental factors affecting these and the organs formed and these are basic juvenile phase, photosensitive phase and storage organ formation phase. Considering the fact that the thermal times for different sub-phases may not be easily available, the entire duration of this phase is governed by a single thermal time. The latter is calculated based on base, optimum and maximum temperatures. The rate of development was linearly related to the daily mean temperature above base temperature up to the optimum temperature. Above this optimum temperature, the rate decreases until the maximum temperature is reached. If temperature goes below the base temperature or above the maximum temperature, the rate of development becomes zero. The rate of crop development is therefore, accelerated depending upon the crop/intensity of stress.

$$DRV = HUVG * DAYLC * MAXSTD / TTVG \quad (17)$$

Where, DRV = rate of development during vegetative phase

HUVG = thermal time of the day

DAYLC = correction factor for the photoperiod-dependent thermal time

MAXSTD = stress effect of water and nitrogen

TTVG = thermal time required for entire phase

Climate changes

Climate changes affect food security. Predicted climate change impacts are essential to design plans and programs to adapt for future conditions. Crop growth model discussed above was used to simulate the crop production for climate change conditions. Radiation use efficiency changes for the changes in temperature and CO_2 levels as a result of climate change and these changes have been incorporated in this crop model to assess the climate change impacts on crop production.

3.9 Description of the MAS model

Multi agent System (MAS) can be defined as a collection of autonomous entities interacting with each other and with their environment (Ferber, 1999). Contrary to conventional modelling techniques, MAS are not expressed in terms of variables, functions and equations, but it is expressed in terms of agents, objects and environment. In addition to a natural and intuitive description of a system, they can capture emergent phenomena resulting from the interactions of individual entities. This is why they are sometimes called "bottom-up" models (Boulanger and Bréchet, 2005) and are closely linked to the concept of complex systems.

In the field of economy, MAS is an alternative to classical economic thinking (Arthur, 1991; Arthur et al., 1997; Jager et al., 2000; Kirman, 1999; Rouchier and Bousquet, 1998; Tesfatsion and Judd, 2006). In conventional economic theories, the behaviour of a group of individuals is represented by a single average meta-actor. General interest is observed in the sum of individual interests. Moreover, individuals' behaviours are formalized following a rational-actor approach, i.e. as Homo economicus which are self-regarding individuals maximizing their own well-being with unlimited cognitive resources. While these conventional economic models have proven their usefulness in many situations, it is argued that these models fail to capture some important nuances of reality. Instead, the behaviour of a group of individuals can be considered as a set of interactions among heterogeneous individuals, generating aggregate phenomena that are different from the behaviour of an average meta-actor (Kirman, 1999). Alternative models of human actors' behaviour also emphasize that actors take decisions with limited cognitive resources, as their perception of reality is biased and incomplete. Moreover, human actors are not necessarily self-regarding and isolated (Jager et al., 2000). Social dimensions and interactions such as imitation, exchanges of information, mutual aid and cooperation can be key factors affecting both micro-level processes and macro-level outcomes. MAS are considered as a promising tool to study such alternative economic theories.

MAS are of particular interests to researchers in the field of renewable resource management (Bousquet and Le Page, 2004; Lansing and Kremer, 1993). Several adapted MAS simulation platforms were developed such as Cormas (Bousquet et al., 1998), Netlogo (Wilensky, 1999), Repast (North et al., 2006) or Swarm (Minar et al., 1996). After comparing the strengths and weaknesses of six main families of modelling techniques (such as macro-econometric models, system dynamics models, Bayesian networks, etc.) to assess environmental, economic and social impacts of development policies, Boulanger and Bréchet (2005) concluded that MAS was the most promising one to deal with sustainable development issues.

The major problems of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong are conflict over land use for shifting agriculture, horticultural crops, teak plantation, soil erosion due to shifting cultivation and existence of extreme poverty since the shifting agriculture is culturally inherited by the farm households and they consider it still to the best practice where the researchers, extension and NGO officers are working for promotion of horticultural crops and teak plantation. Conflict in this context can be considered as interest incompatibility or livelihood loss. Identification of farming/ agricultural systems and better coordination of land use and collaboration among the farmers and stakeholders is essential to solve these problems. Multi Agent System (MAS) an emerging sub-field of artificial intelligence that aims to provide both principles for the construction of complex systems consisting of multiple agents and mechanisms for the coordination of independent agent’s behaviours. In this case, MAS is selected since our focus is on stakeholders of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong. The research was aimed at future scenarios, improving the well-being of stakeholders and improving the sustainability of the stakeholders of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong. Based on available knowledge the model is based on the participation of the stakeholders and it is described using stochastic and deterministic concepts. The purpose of the model is to study the dynamic behaviour of the system based on action and interaction of the stakeholders.

MAS is a robust approach for analyzing and simulating complex systems involving multiple agents with mechanisms for coordination of independent agents' behaviors. The most significant component of MAS is an agent. While there is no generally accepted definition of 'agent', it can be considered as an entity with goals, actions and domain knowledge, situated in an environment. The way an agent acts is called its 'behavior' (Stone and Veloso, 1997). MAS focuses on systems in which many intelligent agents interact with each other. The basic structure of multi agent systems is shown in Fig. 9. The agents are considered to be autonomous entities whose interactions can be either cooperative or selfish. That is, the agents can share a common goal or they can pursue their own interests (Sycara, 2000). Flores-Mendez (1999) stated that agents are entities within an environment with capabilities to sense, reflect and act. This means that agents are not isolated entities, and that they are able to communicate and collaborate with other entities. Hence, MAS examines individual actions (i.e. individual- based) as well as collective assessment of all agents' reflections and actions.

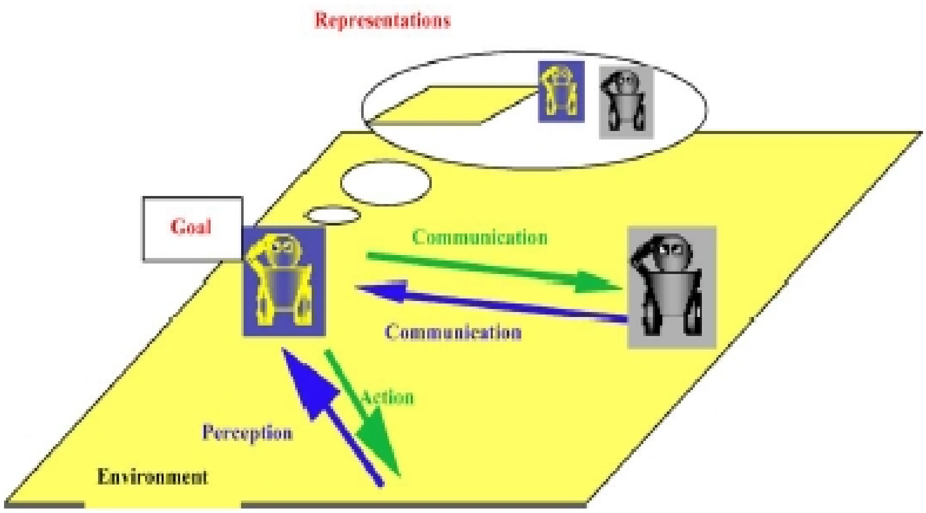


Fig. 9 Structure of multi agent systems

Agents operate and exist in some environment. The environment might be open or closed, and it might or might not contain other agents. If it contains other agents, it can be seen as a society of agents or MAS. Ossowski (1999) illustrated the coordination among agents as shown in Fig. 8. It sets out from autonomous agents that pursue their individual goal within the background of a common social structure. The bold arrows indicate social interaction processes that the agents are involved in and that influence the characteristics and achievement of their goals. Thin arrows denote functional effects. A chain of functional effects can be recognized: norms influence and social interactions modify individual goals of agents so that their actions become instrumental and may lead to a collective action.

The communication protocols enable agents to exchange and understand messages. For instance, a communication protocol might specify that the following messages can be exchanged between two agents (Weiss, 1999): Propose a course of action; accept a course of action; reject a course of action; retract a course of action; disagree with a proposed course of action; or counter propose a course of action.

The MAS model was implemented under the CORMAS (Common pool resources and multi-agent systems, http://cormas.cirad.fr) simulation platform specifically designed to model interactions between ecological and social dynamics for renewable resource management (Bousquet *et al.*, 1998).

Model entities and structure

The multi agent system model is designed to address the gradual transion from *jhum* to horticulture crops and the randomly selected village must have *jhum* cultivating households. The farm households in the selected village do not cultivate tobacco, but the majority of the farm households cultivate *jhum*. The model main social agents (household farmer and agricultural extension officer), passive objects (crops), and spatial entities (farms and plots) and their relationships are presented in Fig. 10 and this UML class diagram shows the attributes (variable or permanent characteristics) and methods (possible actions during simulations) assigned to each model's entity. Thirty agent farm households are represented in the model and this corresponds to the actual farm distribution in the village. In the model, the three types of farmers differ by their initial amounts of land per capita.

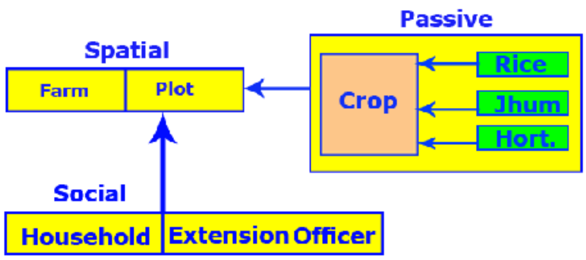


Fig. 10 UML class diagram

The time step is the crop year and each simulation is made of 15 successive crop years. Each year, each agent "Household" checks the cash needed (household saving = household income – household expenditure) to transfer from traditional (*jhum*) agriculture to horticultural crops and if it is available and extension service is also available, part of the traditional agriculture is transferred into horticultural crops. The activity diagram of this decision making is shown in Fig. 11.

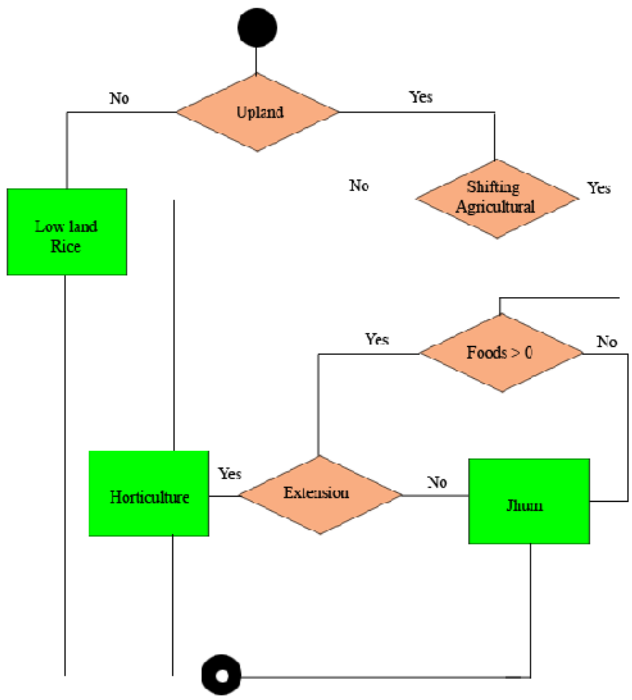


Fig. 11 Activity diagram

Multi Agent System (MAS) technique was chosen to model the stakeholders' interactions and household food security. The multi agent systems model was designed using object-oriented programming language Small Talk and it is implemented in a CORMAS (COmmon pool Resources and Multi Agent System) platform. CORMAS is a simulation platform based on the Visual Works programming environment (Bonsquet et al., 1998). It has three entities: the households, extension agents and the environment in which the decisions are made. The entities and their attributes are derived from the field surveys. The activity diagrams to represent rule based agents have been identified and the model is used to simulate the household food security for a time horizon of 15 years. The household food security is defined qualitatively using numeric scores of 3 for secure, 2 for more or less secure and 1 for unsecure (Barakat, 2009) and the average household food security indicator is defined as the ratio of the food security scores to the maximum possible food security scores.

4. RESULTS AND DISCUSSIONS

4.1 Descriptive statistics

To identify the factors affecting agricultural factors, the descriptive statistics of the potential candidates for such factors are presented here. Its principal objectives are (a) data reduction and (b) interpretation. Table 4 shows the mean values and standard deviations of the potential candidates of variables used to reproduce the total system variability, much can be accounted for by a small number of components or factors. Fig. 12 to Fig. 24 shows the percentage distributions of the important variables affecting the agricultural systems and its classification.

Table 4. Descriptive statistics for the variables (quantitative and qualitative) used in principal component analysis and factorial analysis

Variables	Mean[1]	Standard error
Proportion of Buddhist farmers (%)	62.18	7.47
Average years of schooling	3.80	0.10
Average distance to road (km)	1.15	0.04
Average distance to local market (km)	5.18	0.13
Average distance to upazila (km)	8.10	0.17
Average annual off-farm income (Tk/HH)	28884.40	960.51
Average annual consumption cost (Tk/HH)	57594.30	365.37
Average hill area (acre/HH)	3.25	0.09
Average plain land (acre/HH)	0.94	0.03
Average jhum land (acre/HH)	0.71	0.03
Proportion of HHs that used power tiller (%)	20.26	4.35
Proportion of HHs that attended in training program (%)	42.89	4.01
Proportion of HHs that received formal micro credit (%)	28.08	3.40
Proportion of HHs that received informal micro credit (%)	13.50	1.99
Proportion of HHs that received both formal and informal micro credit (%)	2.86	1.05
Proportion of HHs that had contract with extension agents (%)	62.13	4.59
Proportion of HHs that had contract with NGO agents (%)	24.18	2.71
Proportion of HHs that had electricity (%)	33.95	5.39

[1]Weighted mean and corresponding standard error are computed as the sampled farms are not equal in number for all the villages.

Fig. 12 shows the percentage distribution of farms in 27 villages of the Hill Tracts of Chittagong. The percentage of medium farms is the highest in each of the three hill districts- Bandarban, Khagrachhari and Rangamati (46%-49%). In each of these districts, the second highest percentage is observed for small farms (25%-34%) and large farms are in the third position (12%-14%).The lowest percentage is recorded for marginal farms in Bandarban (3%) and Rangamati (3%) whereas the Bangladesh average is 39%. Percentage of landless farmers (10%) is recorded as the highest in Bandarban. The overall percentage of the landless is 7% whereas Bangladesh national average is 14%. Barkat et al. (2009) also reported that about 6% households living in rural CHT do not own any land.

Fig. 13 shows the land use patterns in the 27 villages of the Hill Tracts of Chittagong. The highest area under shifting cultivation (jhum) is observed in Rangamati (17.96%) followed by Bandarban (15.46%) and Khagrachhari (13.12%). Area under horticulture is about the same in Rangamati (28.16%) and Bandarban (27.77%). The highest area under forestry is used in Bandarban (40.42%) followed by Rangamati (35.88%) and Khagrachhari (28.85%). The overall forest cover is 35.87% which is above world average value of 30%. The highest plain area is found in Khagrachhari (29.84%) where rice cultivation is most widely practiced. The second highest plain area used for rice cultivation is in Bandarban (15.47%).

Fig. 14 shows the population by ethnic origin/tribes in the 27 villages of the Hill Tracts of Chittagong. The highest percentage of the population recorded is Marma (34.96%) followed by Chakma (30.98%, Bangali (8.98%), Bawm (8.75%), Tripura (7.86%), Tanchangya (4.38%), Mro (2.41%), Murang (0.95%) and others (0.73%). Thus, the Hill Tracts of Chittagong are dominated by tribal population.

Fig. 15 shows the population by religion in the 27 villages of the Hill Tracts of Chittagong. Most of the populations in Chittagong Hill Tracts are Buddhists (62.18%). Hindu (17.73%), Christian (10.33%) and Muslim (8.81%) are in second, third and fourth position respectively. Thus, the budhists are religious majority while muslims are religious minority in the Hill Tracts of Chittagong.

Fig. 16 shows the population by profession in the 27 villages of the Hill Tracts of Chittagong. The percentage of full time farmers is the highest in Khagrachhari (49.24%) followed by Rangamati (45.91%) and Bandarban (40.23%). Service holders are the highest in Rangamati (2.09%). But highest the percentage of day labourers and businessmen are found in Bandarban (9.99% and 2.20%). Thus, main occupation of the people of the Hill Tracts of Chittagong is agriculture.

Fig. 17 shows distribution of land use patterns by cultivation methods in the 27 villages of the Hill Tracts of Chittagong. Farmers mostly use traditional method of cultivation in each of the hill districts. The highest percentage of power tiller users is in Khagrachhari (30.61%) followed by Bandarban (12.33%) and Rangamati (8.35%).

Fig. 18 shows the status of training received by the farmers in the 27 villages of the Hill Tracts of Chittagong. The highest percentage of farmers who received training on agriculture is found in Khagrachhari (70.34%) followed by Rangamati (54.78%) and Bandarban (48.60%).

Fig. 19 shows the micro credit status in the 27 villages of the Hill Tracts of Chittagong. More than 50% of the farmers do not receive any type of micro credit for their agricultural activities. In Khagrachhari, this percentage is the highest (62.55%). More than one-fourth of the farmers under study have taken micro credit in formal way (28.17%) and informal micro credit receivers are about half of the formal (13.52%). Percentage of formal micro credit is the highest in Rangamati (33.22%), followed by Khagrachhari (29.85%) and Bandarban (22.61%). On the other hand, percentage of informal micro credit is the highest in Bandarban (18.50%) followed Rangamati (13.39%) and Khagrachhari (7.22%). The overall coverage of formal micro credit is low.

Fig. 20 shows extension service provided to farmers in the Chittagong Hill Tracts. Extension service is more or less same in all of the three districts (58.88% to 66.35%). In Khagrachari, the percentage of the farmers who had contact with extension agents is the highest (66.35%) and it is the lowest in Bandarban (58.88%). The extension service provided is quite extensive for the hill tracts of Chittagong. However, still there exists a lot of scope.

Fig. 21 shows NGO service provided to farmers in the Chittagong Hill Tracts. NGO service is poor in Chittagong Hill Tracts (15.78% to 31.86%). Nevertheless, it is the highest in Bandarban (31.86%) and the lowest in Khagrachhari (15.78%).

Fig. 22 shows the distribution of access to electricity in the Hill Tracts of Chittagong. Electricity facility is very poor in the hill districts. In Khagrachhari, access to electricity is the poorest (14.52%). The access to electricity in Rangamati is 43.38% while the national average in Bangladesh is 33%. Also Rangamati has the highest percentage of consumers of solar electricity (5.57%).

Fig. 23 shows the distribution of farm household by banana plantation. Banana is cultivated almost all the places in Chittagong Hill Tracts (43.91% to 68.82%). Banana cultivation is the highest in Khagrachari and lowest in Bandarban. However, all of the districts have the potential of further increase in banana plantation for economic development of the Chittagong Hill Tracts if infrastructures and marketing facilities exist.

Fig. 24 shows the percentage distribution of households having pineapple plantation in the Hill Tracts of Chittagong. In Bandarban the largest percentage of households (18.21%) has pineapple plantation while in Rangamati very few of the farmers (2.09%) are engaged in pineapple cultivation. However, all of the districts have the potentials of pineapple cultivation if infrastructures and marketing facilities are developed.

4.2 Focus Group Discussion

Findings of the Focus Group Discussion indicate that the *jhum* land is allowed to the farmers for cultivation by the leader of the locality. The ownership is controlled by him. Generally *jhum* cultivations once was practiced in land on 12 – 15 year cycle basis (which is universally accepted practice worldwide). This cycle of cropping has been reduced to 3 – 4 years, degrading natural soil nutrient status resulting in low productivity of crops. The problem is aggravated due to practice of burning of vegetation of the land for *jhum* cultivation in the month of March, making the hill soils naked and exposed to erosion. The eroded soils from the hills have created the problems of navigation in the river and lake and destroy the natural ecosystem of fish and other aquatic fauna and flora, etc. The participants in the FGD expect that this system of cultivation will not exist in near future due to population pressure and loss of productivity of land and biodiversity.

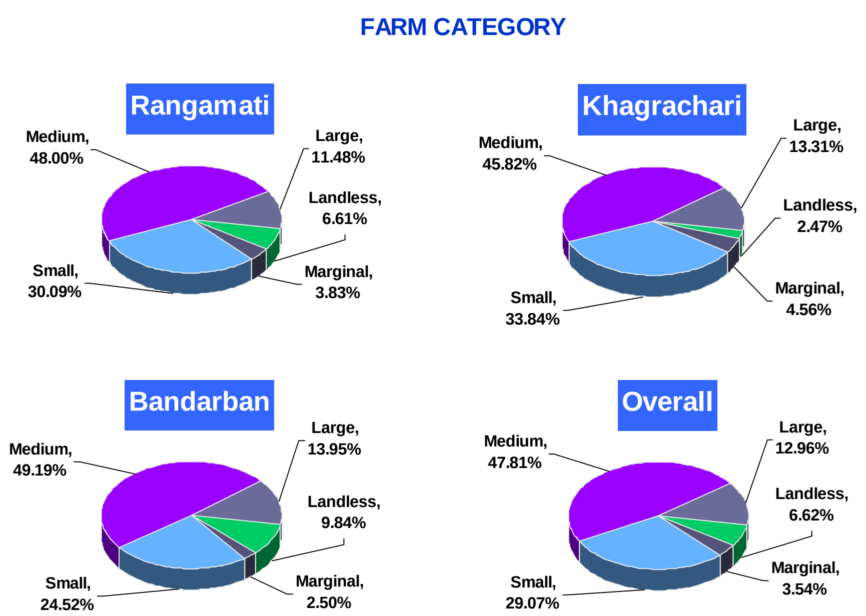


Fig. 12. Farm category distribution

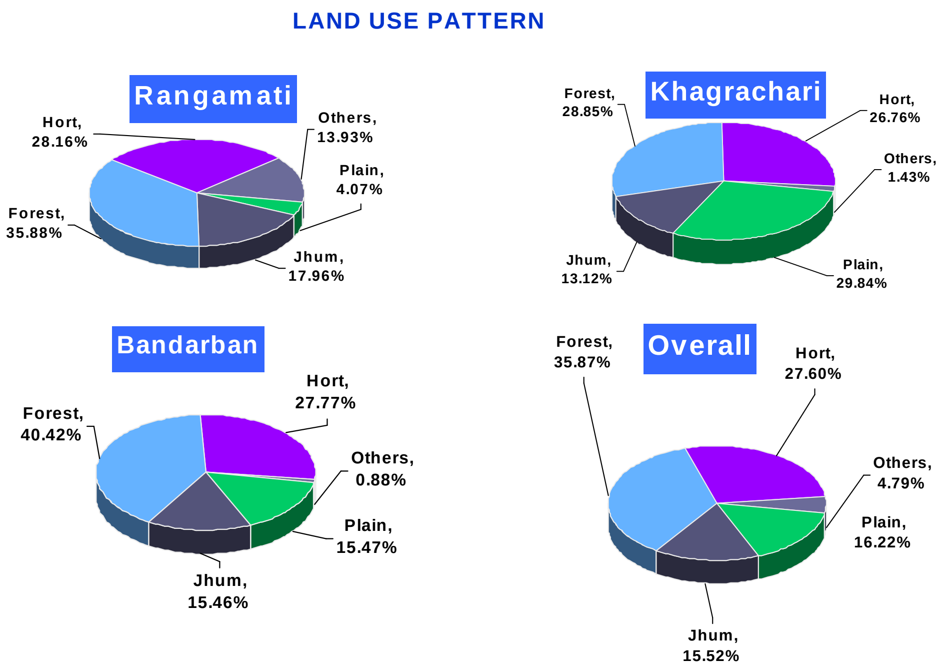


Fig. 13. Distribution of land use patterns

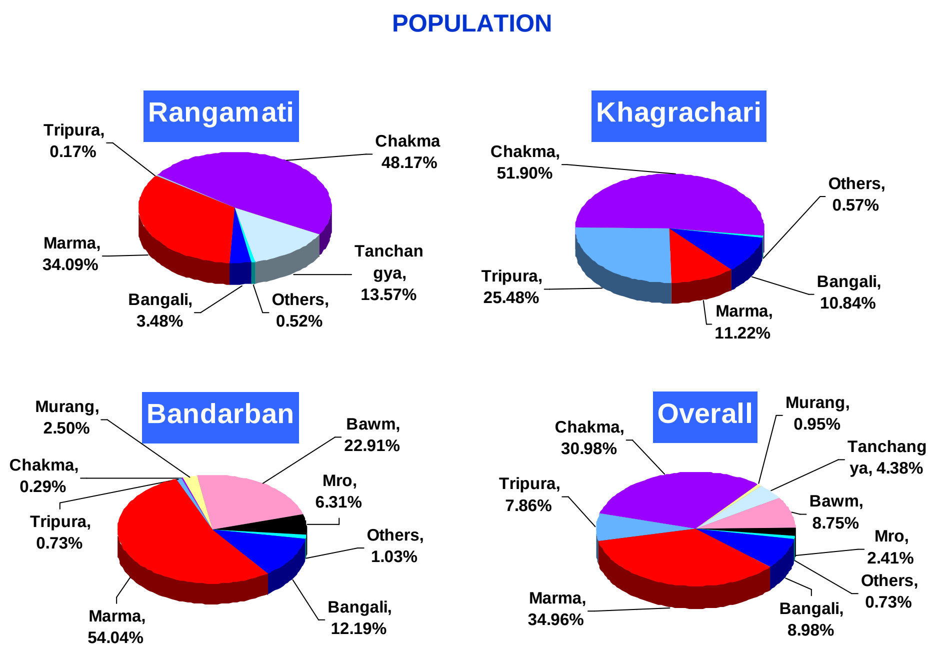


Fig. 14. Distribution of population

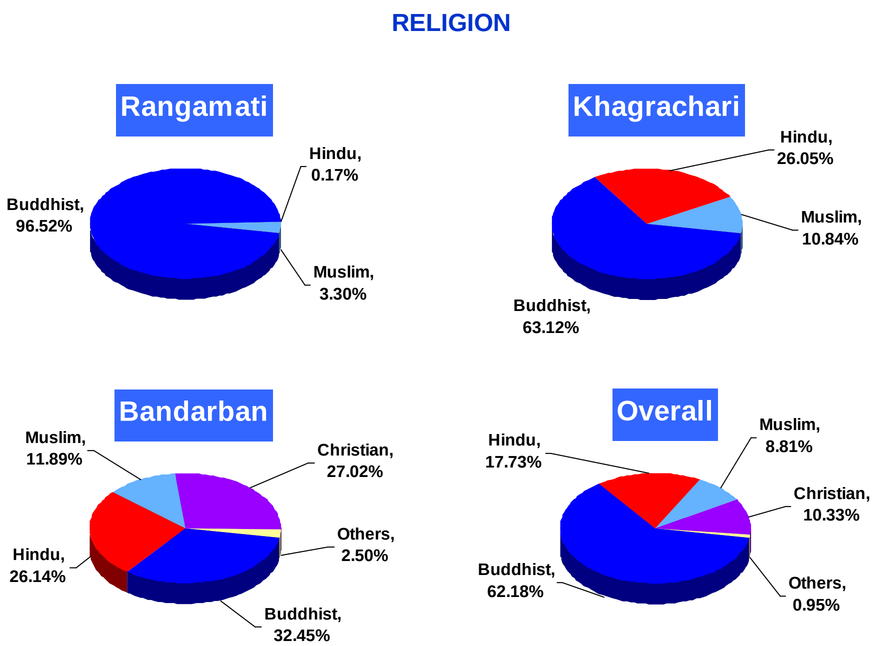


Fig. 15. Distribution of population by religion

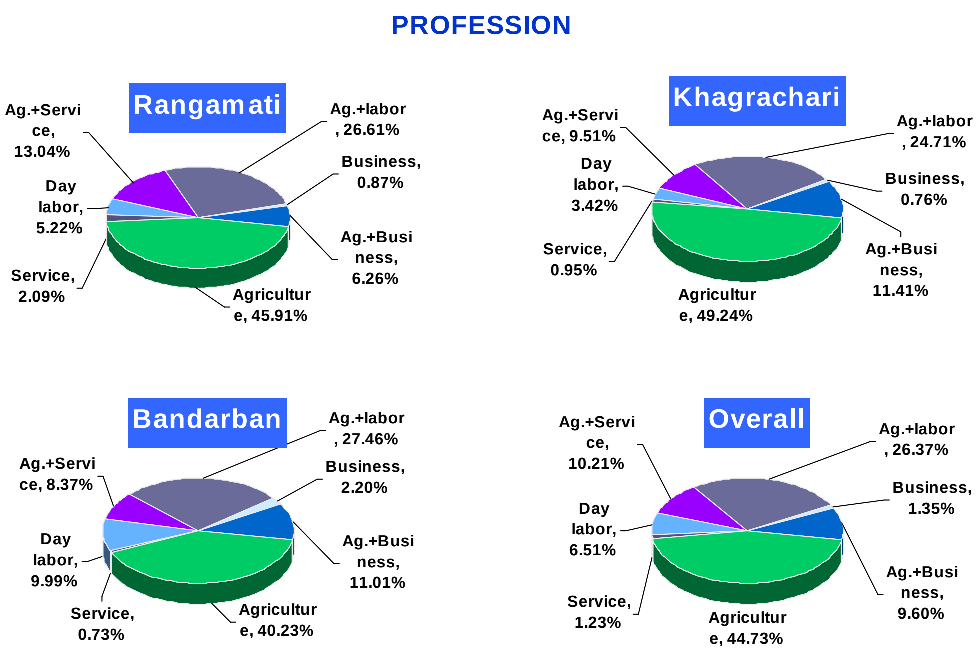


Fig. 16. Distribution of population by profession

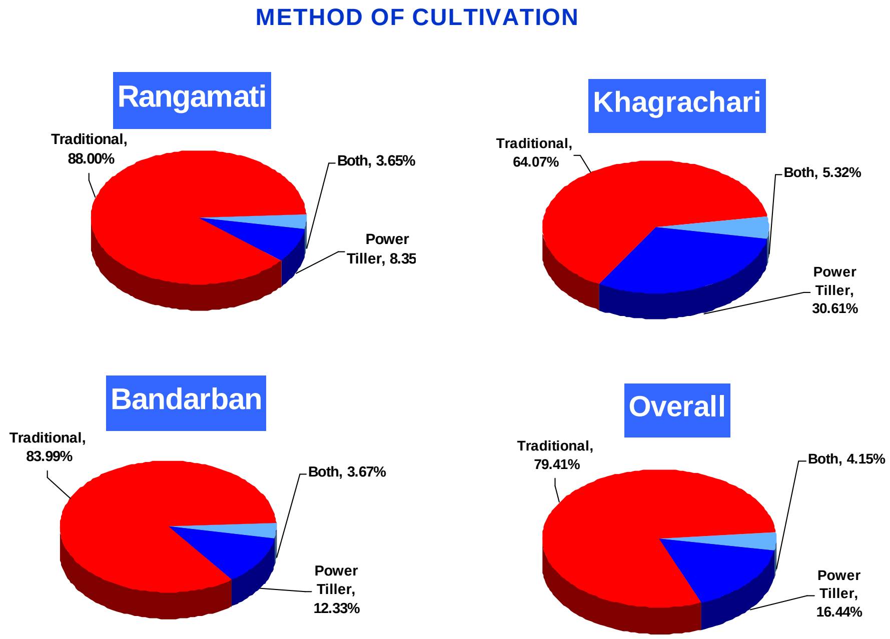


Fig. 17. Distribution of land use patterns by cultivation methods

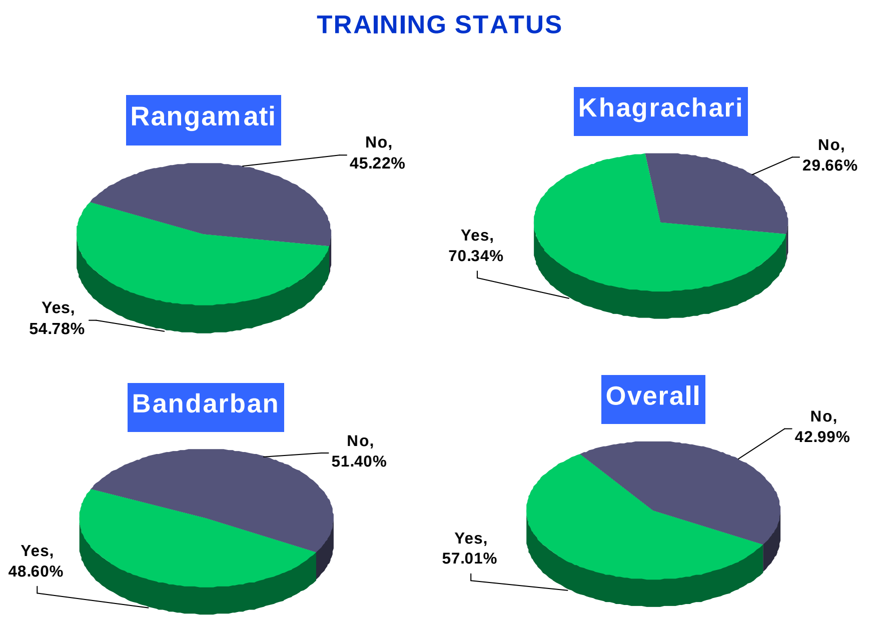


Fig. 18. Training status

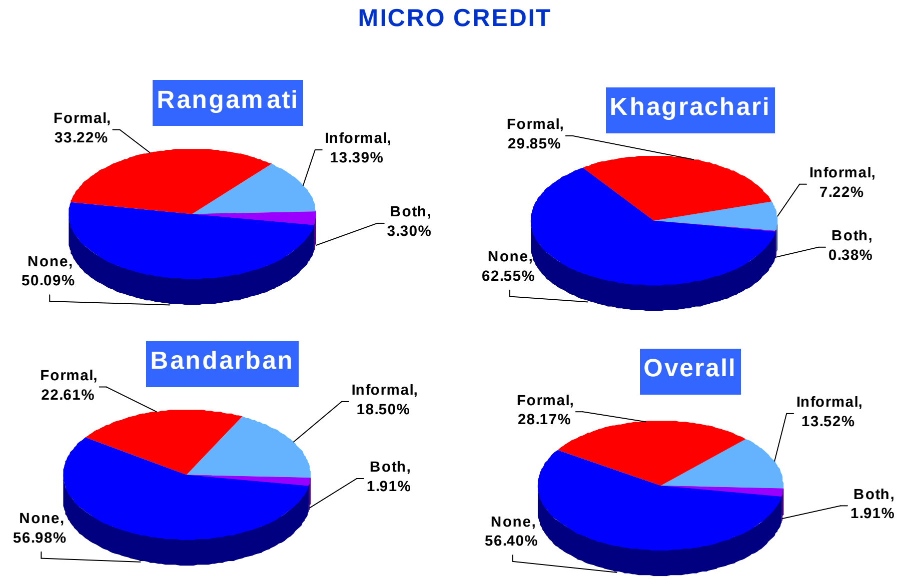


Fig. 19. Distribution of farm household by use of micro credit

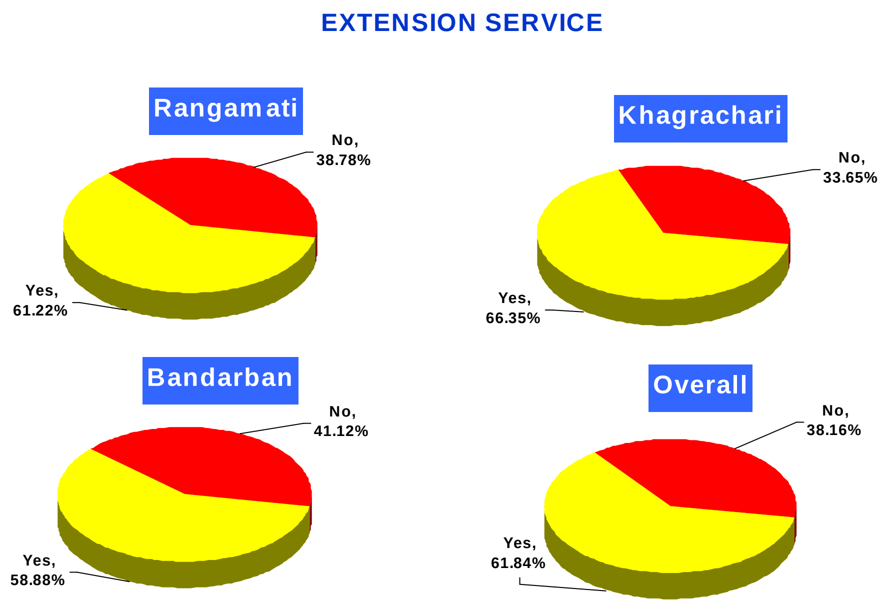


Fig. 20. Distribution of farm household by extension service

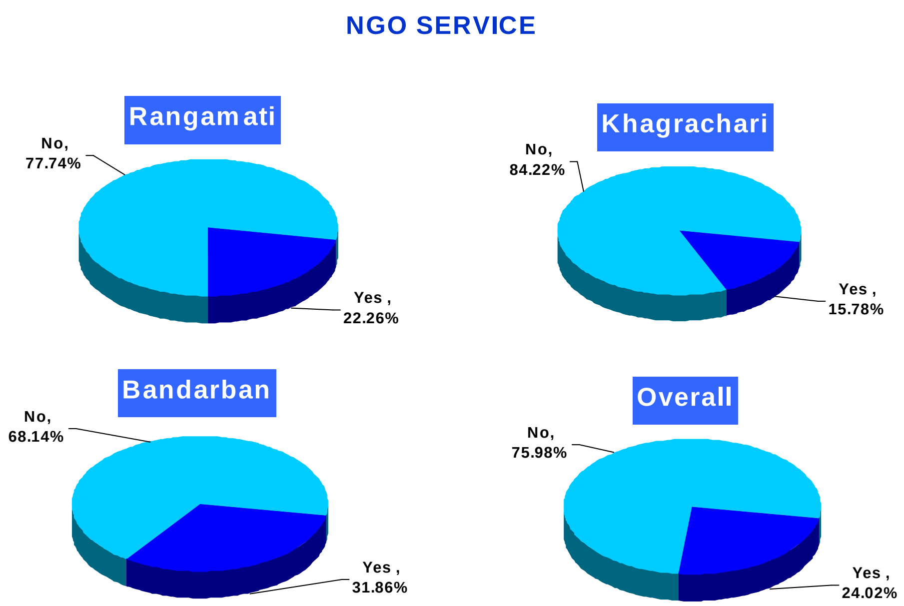


Fig. 21. Distribution of farm household by NGO service

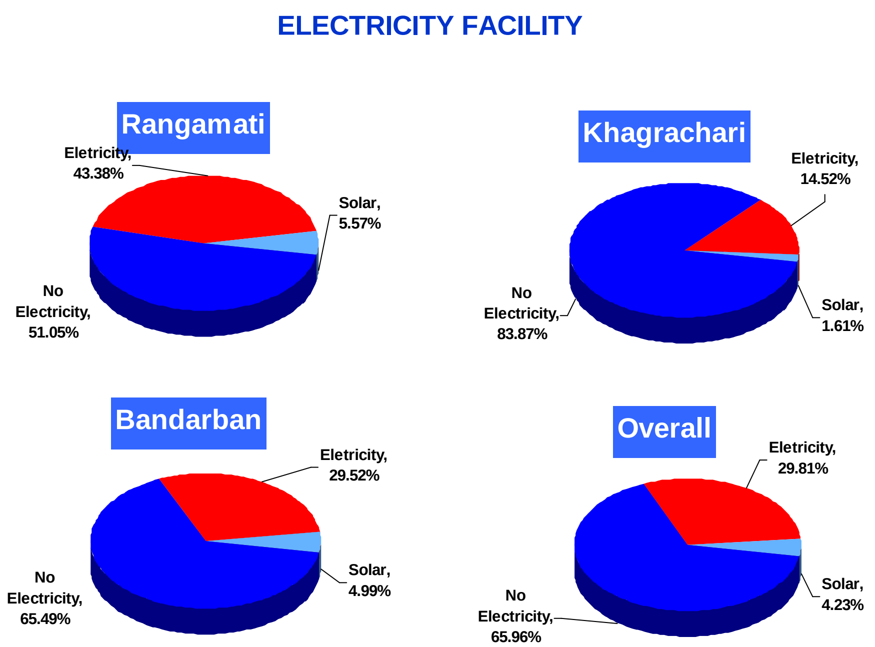


Fig. 22. Distribution of farm household by use of eletricity

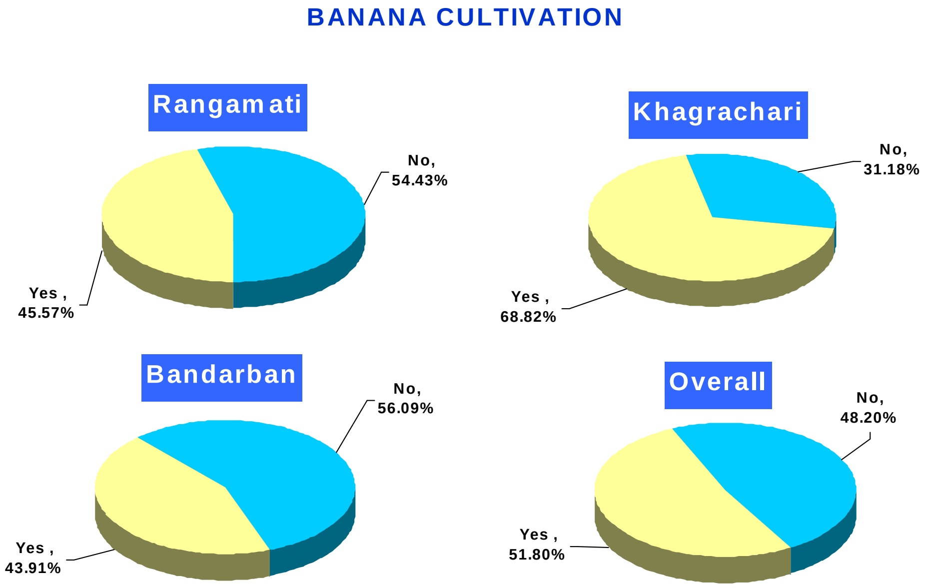


Fig. 23. Distribution of farm household by banana plantation

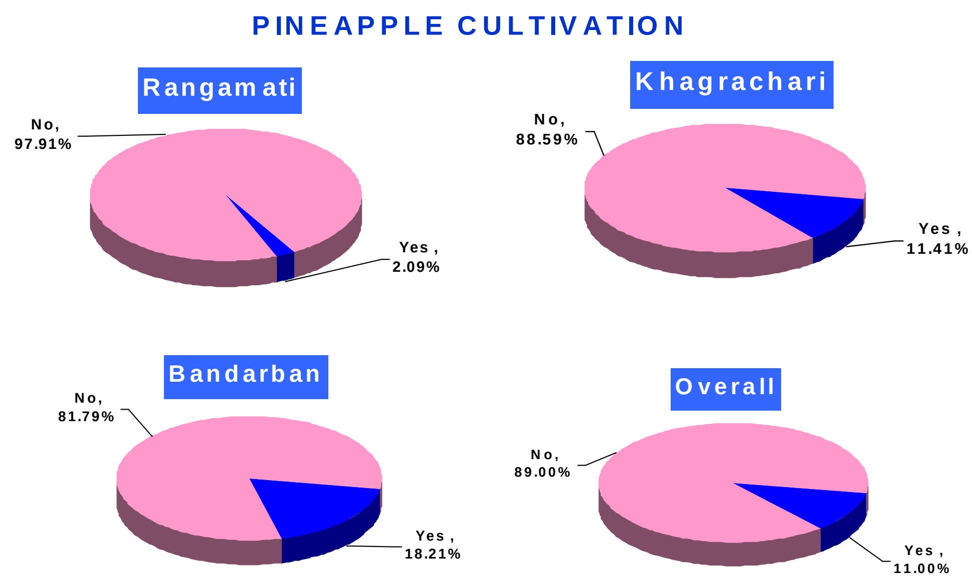


Fig. 24. Distribution of farm household by pineapple

According to the participants, this system may be sustainable if the *jhum* cultivators could permanently be settled in *jhum* land promoting terrace cultivation facilities of irrigation through rain water harvested in reservoir and other necessary inputs to be made available.

They further report that the *jhum* land is now being planted with teak, rubber, gamari, banana and is also being occupied with new settlement very fast. The participants report that types of plantation models with fruit and forest species are being tried. During the Focus Group Discussion the participants were divided into two groups regarding *jhum* cultivation. One group supports the gradual transition from *jhum* cultivation into fruits and forest species while other group supports the preservation of the *jhum* practice as a livelihood means of the *Adibashi* of the Chittagong Hill Tracts as their culture and heritage.

4.3 Principal components analysis

The results of principal components analysis of 27 villages of the Hill Tracts of Chittagong are in Table 5. A total of 18 selected variables transformed into 6 principal components of correlated variables whose eigenvalues are greater than 1. The principal component analysis allowed us to reduce the number of dimensions in the quantitative data by selecting the first 6 components of the principal components, which collectively explain 76.69% of the total variation. The loadings of the initial variables on the first component, explain 23.35% of the total variance. The second component is almost equally important as the first component, explaining 19.22% of the total variance. The importance of a variable on a principal component depends on its loading and the higher is loading, the greater is the importance of the variable in the component. It is observed that the most important variable in the first component is training and its influence is positive in the component. The other important variables which also exhibit positive influence on the first component are electricity, contact with NGO agents and informal micro credit. Household consumption (cost) is also an important variable for this component but its influence is negative. The second component is most negatively influenced by hill area followed by distance to market and upazila, but most positively influenced by education and religion. Hence, these are the important variables in the second component. Other components can similarly be interpreted.

4.4 Factor analysis

We have simply an idea about the determinants of the complicated agricultural systems exploring the results of principal component analysis. Factor analysis was conducted to discover if the observed variables can be explained in terms of a much smaller number variables called factors – covariance or correlation oriented method. Results of factor analysis of 27 villages of the Hill Tracts of Chittagong are shown in Table 6.

Table 5 Results of Principal Component Analysis

Variables	Estimated Component Loadings					
	C1	C2	C3	C4	C5	C6
Proportion of Buddhist farmers	-0.162	0.322	0.018	0.176	-0.193	0.339
Average years of schooling	0.084	0.359	0.165	0.082	0.167	0.114
Average distance to road (km)	-0.187	-0.141	-0.168	0.280	0.246	0.583
Average distance to local market (km)	0.116	-0.373	0.289	0.107	-0.060	-0.061
Average distance to upazila (km)	-0.012	-0.321	0.166	0.446	-0.199	0.040
Average annual off-farm income (Tk/HH)	0.206	0.288	0.036	0.294	-0.087	-0.038
Average annual consumption cost (Tk/HH)	-0.354	0.139	0.062	0.244	0.267	0.171
Average hill area (acre/HH)	0.116	-0.402	0.010	0.080	0.345	0.188
Average plain land (acre/HH)	-0.217	0.102	0.262	-0.290	0.191	0.047
Average jhum land (acre/HH)	0.199	-0.085	0.278	-0.388	-0.022	0.219
Proportion of HHs that used power tiller	-0.197	0.242	-0.016	0.026	0.474	-0.336
Proportion of HHs that attended in training program	0.405	0.144	0.254	0.008	0.037	0.010
Proportion of HHs that received formal micro credit	-0.184	0.209	0.190	-0.291	-0.29	0.360

					8	
Proportion of HHs that received informal micro credit	0.303	0.016	-0.491	-0.082	0.163	0.085
Proportion of HHs that received both formal and informal micro credit	0.173	0.233	-0.312	0.252	-0.360	-0.041
Proportion of HHs that had contact with extension agents	0.224	0.189	0.303	0.242	0.299	-0.141
Proportion of HHs that had contact with NGO agents	0.346	0.066	-0.270	-0.225	0.227	0.277
Proportion of HHs that had electricity	0.351	0.081	0.280	0.146	0.027	0.251
% of Variance	23.350	19.220	10.970	9.640	7.170	6.340
Cumulative % of variance	23.350	42.570	53.540	63.180	70.350	76.690

"HH" stands for household.

The factors may be institutional support, productive resources, distance to the market and service centers. Now, we make an attempt to interpret the results of factor analysis in terms of a much smaller number of components or factors as an extension of principal component analysis. Factor analysis extracts principal factors that explain much of the total variation. A total of 18 variables were used in the factor analysis whose descriptive statistics are presented in Table 1. Both principal factor and principal component methods of parameter estimation were used in this study, but principal factor method is widely used for factor analysis. Four factors extracted by principal factor method with eigenvalues more than 1 explain 77.21% of total variability, whereas principal component method extracts six factors with eigenvalues greater than 1 out of which four factors explain only 63.18% of total variability (Table 6). Hence, the factors extracted by principal factor method is considered. Thus, principal factor method is better than principal component method in explaining the total variability.

Table 6 Results of factor analysis

Variables	Estimated Factor Loadings[1]							
	Principal Factor Method				Principal Component Method			
	F1	F2	F3	F4	F1	F2	F3	F4
Proportion of Buddhist farmers		0.582				0.599		
Average years of schooling		0.639				0.667		
Average distance to road (km)								
Average distance to local market (km)		-0.673				-0.694		
Average distance to upazila (km)		-0.591		0.506		-0.598		0.587
Average annual off-farm income (Tk/HH)						0.535		
Average annual consumption cost (Tk/HH)	-0.711				-0.725			
Average hill area (acre/HH)		-0.736				-0.747		
Average plain land (acre/HH)								
Average jhum land (acre/HH)								-0.511
Proportion of HHs that used power tiller								
Proportion of HHs that attended in training program	0.842				0.830			
Proportion of HHs that received formal micro credit								
Proportion of HHs that received informal micro credit	0.629		-0.704		0.621		-0.691	
Proportion of HHs that received both formal and informal micro credit								
Proportion of HHs that had contact with extension agents								
Proportion of HHs that had contact with NGO agents	0.723				0.709			
Proportion of HHs that had electricity	0.711				0.720			

% of Variance	29.71	23.68	13.22	10.59	23.35	19.22	10.97	09.64
Cumulative % of variance	29.71	53.39	66.62	77.21	23.35	42.57	53.54	63.18

[1]Loadings >0.5 are displayed

Since the original loadings of the factor analysis are not readily interpretable, it is usual practice to rotate them until a simpler structure is achieved. Table 7 shows the results of factor analysis (rotated). All the variables are loaded unambiguously in the four factors. The important variables and their nature of the relationships with the factors can easily be visualized from Fig. 25. Three variables like 'distance to local market', 'distance to upazila' and 'hill area' have high negative loadings in the first factor, which explains about 16% of the total variance. The positive loading of 'religion' separates it from other clustered variables in this factor. Factor1 can be referred to as 'infrastructure development' as the variables are somehow associated with development. The second factor that explains about 15% of the total variance consists of the variables: 'training', 'extension service', 'electricity' and 'farmer's off-farm income' with high positive loadings. All the variables (except farmer's off-farm income) associated with service. Hence, we might call factor 2 as 'institutional service (training and extension)'. The third factor that explains about 13% of the total variance consists of the variables like 'formal-informal micro credit', 'informal micro credit' and 'NGO service' with moderate to high positive loadings and factor 3 can be referred to as 'micro credit and NGO service'. The fourth factor explains 10% of the total variance. The factor 4 consists of one variable 'jhum land' with high positive loading and one variable 'consumption cost' with moderate negative loading. We might call the factor 4 as 'availability of jhum land' separating the consumption cost variable. This implies that infrastructure factor, training and extension factor, micro credit and NGO service factor, and availability of jhum factor are affecting agricultural systems of uplands of the Hill Tracts of Chittagong and these factors must be considered for design and implementation of the sustainable development of uplands of the Hill Tracts of Chittagong.

Table 7 Results of factor analysis (rotated)

Variables	Estimated factor loadings[1]				Commu-nalities	Unique-ness
	F1	F2	F3	F4		
Proportion of Buddhist farmers	0.511				0.419	0.581
Average years of schooling					0.417	0.583
Average distance to road (km)					0.243	0.757
Average distance to local market (km)	-0.764				0.653	0.347
Average distance to upazila (km)	-0.729				0.745	0.255
Average annual off-farm income (Tk/HH)		0.629			0.507	0.493
Average annual consumption cost (Tk/HH)				-0.535	0.598	0.402
Average hill area (acre/HH)	-0.706				0.543	0.457
Average plain land (acre/HH)					0.334	0.666
Average jhum land (acre/HH)				0.620	0.435	0.565
Proportion of HHs that used power tiller					0.272	0.728
Proportion of HHs that attended in training program		0.844			0.987	0.013
Proportion of HHs that received formal micro credit					0.357	0.643
Proportion of HHs that received informal micro credit			0.989		1.01	-0.010
Proportion of HHs that received both formal and informal micro credit			0.506		0.477	0.523
Proportion of HHs that had contract with extension agents		0.663			0.446	0.554
Proportion of HHs that had contract with NGO agents			0.676		0.688	0.312
Proportion of HHs that had electricity		0.724			0.643	0.357
% of Variance	16.047	14.876	13.352	10.029		
Cumulative % of variance	16.047	30.923	44.276	54.305		

[1]Loadings >0.5 are displayed.

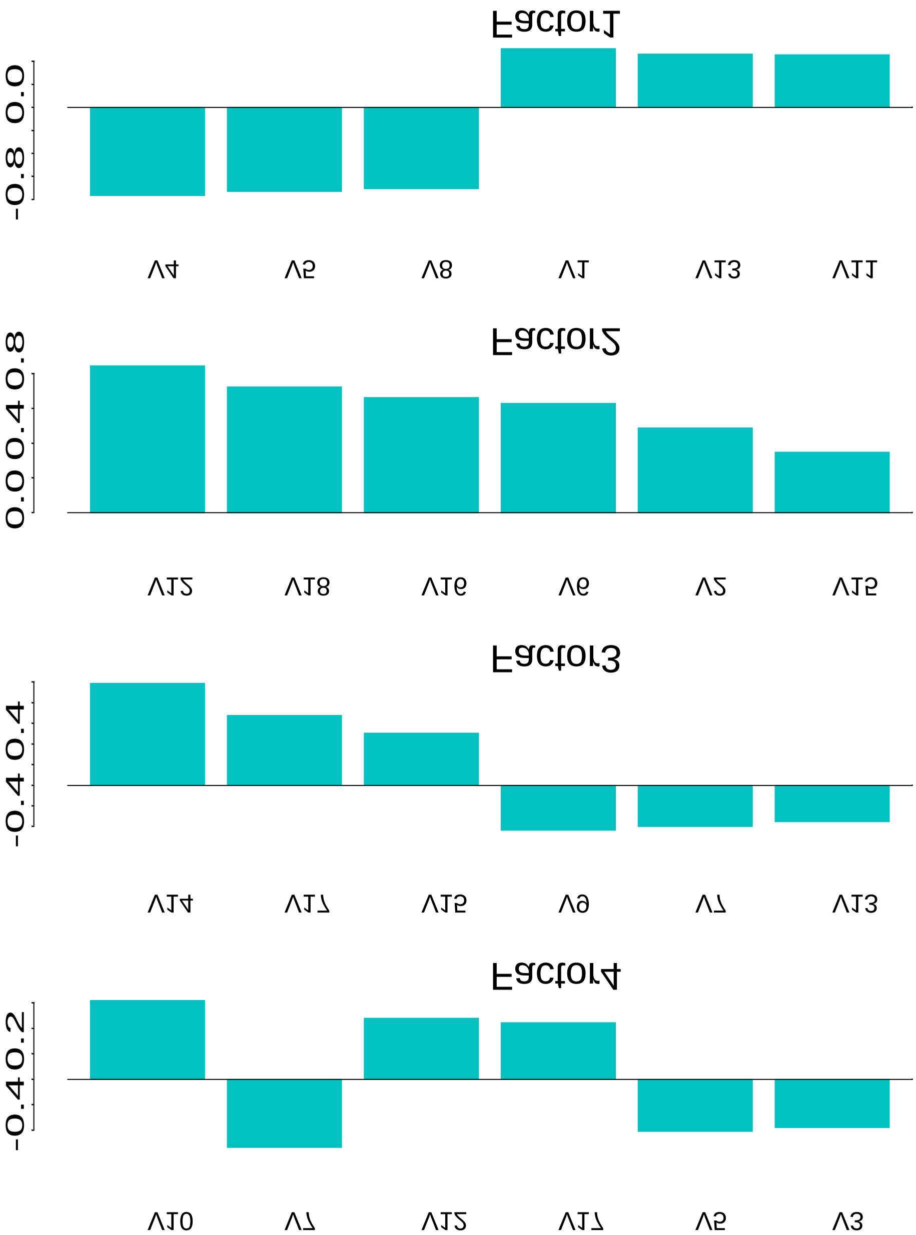
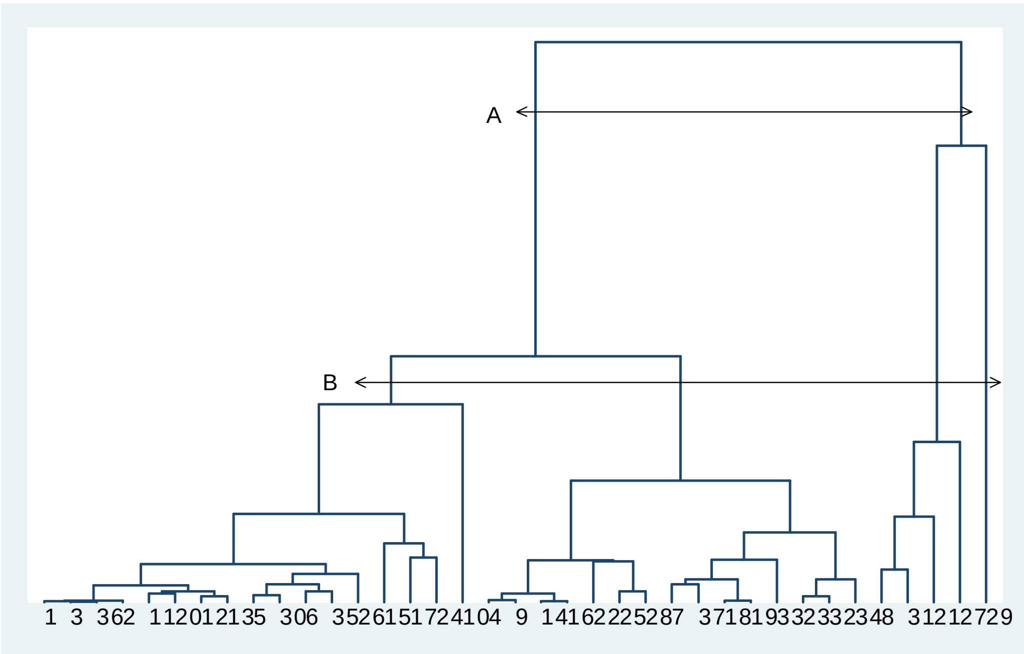


Fig 25. Bar diagrams showing the importance of the variables on the basis of the factor loadings

4.5 Cluster Analysis

Farming practices of each household is a unique farming system. Faming systems must be classified for efficient management of the plans and programs for sustainable development for food security. The cluster analysis has been performed to identify the types of farming systems in Chittagong Hill Tracts. The variables characterizing the systems are: area under shifting agriculture, horticulture, rice cultivation, annual cash crops, and average number of private trees per household, average number of fruit trees, average number of wood trees and average number of cattle, pigs, goats, poultry and household consumption. Fig. 26 shows the classification of the farming systems of a typical village in the Hill Tracts of Chittagong at cutting point B. The systems are classified as extensive, semi-intensive and intensive.



Extensive Farming System | Semi-Intensive Farming System | Intensive Farming System

Fig. 26 Dendrogram for 37 farming systems of the village Shukarchhari Khamarpara in Rangamati district

Discriminant analysis was conducted for checking the accuracy of the classification of the farming systems. Table 8 shows the checking of the classification of the farming systems of a typical village in the Hill Tracts of Chittagong at cutting point B and it is evident that only one farm is misclassified i.e. classification error is 2.7%.

Table 8 Discriminant analysis for checking classification of the farming systems

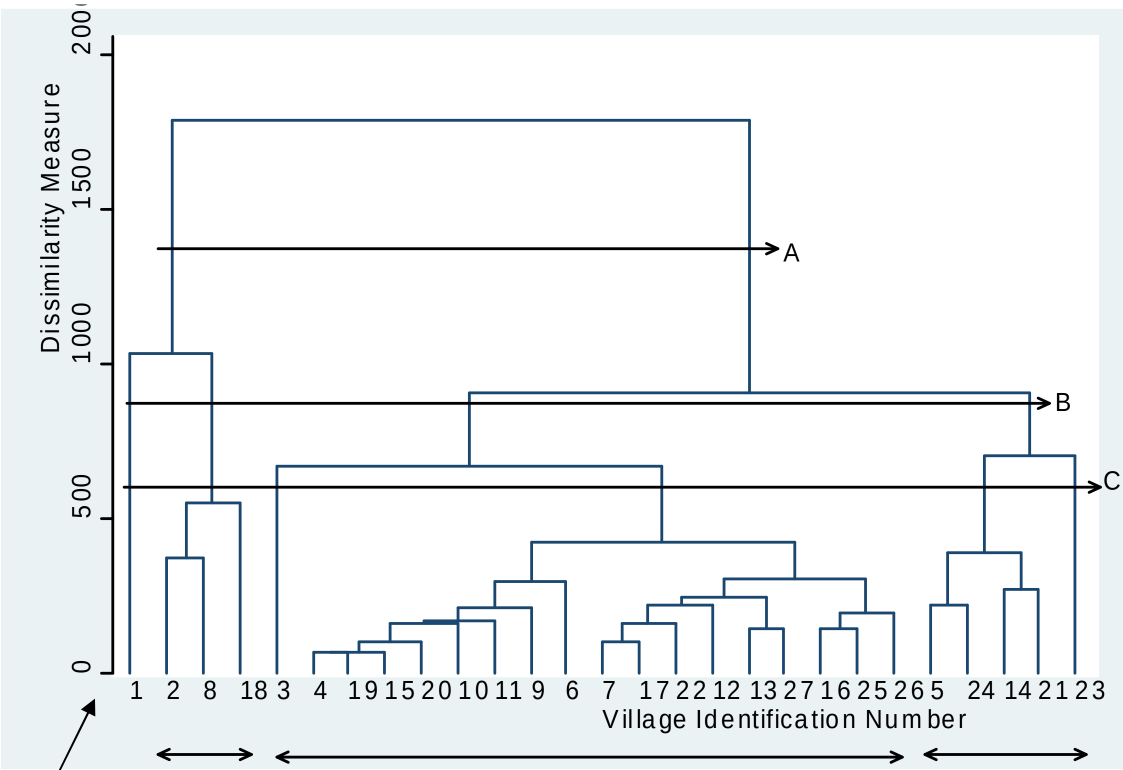
True classification	Classified by cluster analysis			Total
	Extensive	Semi-intensive	Intensive	
Extensive	16	1	0	17
Semi-intensive	0	15	0	15
Intensive	0	0	5	5
Total	16	16	5	37

The cluster analysis has also been performed to identify the types of agricultural systems in Chittagong Hill Tracts and the variables characterizing the systems are shown in Table 9. The classification is based on statistically homogeneous characteristics i.e. grouping of the similar characteristics of the agricultural systems and the characteristics considered in the classification are shown in Table 9. This analysis generates a set of solutions (Fig. 27). Observing different cutting points and their corresponding solutions we can see that at cutting point ‘A’ two clusters are formed while at cutting points ‘B’ and ‘C’ four and six clusters are formed respectively. After exploring the different cutting points and their corresponding solutions, four clusters associated with cutting point B seems to be realistic representation of Chittagong Hill Tracts and we can accept it as a meaningful classification. The validity of the classification has been tested using discriminant analysis (Aldenderfer and Blashfield, 1984a & 1984b) and this analysis exhibits that 100% of the objects are classified correctly (Table 10).The classified agricultural systems of 27 villages of the study area in Chittagong Hill Tracts are classified as extensive, semi-intensive, intensive and mixed. But one village out of 27 villages is classified as mixed since it manifested almost equally the entities of other three categories of the agricultural systems.

Table 9 Important characteristics of the patterns of agricultural systems in Chittagong Hill Tracts

Characteristics	Agricultural systems			
	Mixed n = 1	Extensive n = 5	Semi-intensive n = 18	Intensive n = 3
Area under shifting cultivation over hill area (%)	29	27(2.62)	20(3.08)	17(9.71)
Area under rice cultivation over plain land (%)	99	51.8(13.84)	81.06(2.74)	79(5.86)
Average forest area (acre/HH)	2.34	1.88(0.12)	1.09(0.080)	2.81(0.58)
Average horticulture area (acre/HH)	3.44	1.31(0.15)	1.25(0.18)	1.22(0.33)
Proportion of pineapple cultivators (%)	52	10(7.49)	12.44(4.73)	9.67(9.17)
Average number of banana trees per HH	294.35	391.69(133.61)	171.09(22.71)	240.51(90.86)
Average number of other fruit trees per HH	467.43	106.78(36.49)	136.43(35.77)	95.02(29.47)
Average number of timber trees per HH	3325	1495.85(90.82)	677.30(54.15)	2374.63(181.10)
Average number of cattle per HH	0.35	1.27(0.28)	1.04(0.14)	1.99(0.36)
Average number of goats per HH	2.04	0.89(0.18)	1.27((0.17)	0.70(0.15)
Average number of sheep per HH	0	0	0.05(0.04)	0
Average number of pigs per HH	0.83	0.44(0.07)	1.08(0.37)	0.85(0.42)
Average number of poultry per HH	4.22	7.96(1.67)	8.75(1.17)	13.05(4.96)

Figures in the parentheses stand for standard error



Mixed agric system	Intensive agric system	Semi-intensive agric system	Extensive agric system

Fig.27. Dendrogram for classifying agricultural systems of 27 villages in Chittagong Hill Tracts.

Discriminant analysis was conducted for checking the accuracy of the classification of the agricultural systems. Table 10 shows the checking of the classification of the agricultural systems of the Hill Tracts of Chittagong at cutting point B and it is evident that the classification error is zero.

Classification of Agricultural Systems

Agricultural systems of 27 villages of the study area in Chittagong Hill Tracts are classified as extensive, semi-intensive, intensive and mixed and the salient features of these agricultural systems are briefly discussed as follows:

Table 10 Discriminant analysis for checking classification of the agricultural systems of 27 villages

True class	Classified by cluster analysis				Total
	Mixed	Intensive	Semi-Intensive	Extensive	
Mixed	1	0	0	0	1
	(100.00)	(0.00)	(0.00)	(0.00)	(100.00)
Intensive	0	3	0	0	3
	(0.00)	(100.00)	(0.00)	(0.00)	(100.00)
Semi-Intensive	0	0	18	0	18
	(0.00)	(0.00)	(100.00)	(0.00)	(100.00)
Extensive	0	0	0	5	5
	(0.00)	(0.00)	(0.00)	(100.00)	(100.00)
Total	1	3	18	5	27
	(3.70)	(11.11)	(66.67)	(18.52)	(100.00)

Error rate = 0/37=0, i.e., accuracy= 100%

Extensive agricultural system: Shifting cultivation (jhum) is still widely practised in five villages of Chittagong Hill Tracts namely, Edenpara, Ruma upazila, Bandarban; Uchcha Kangail Chhari, Mohalchhari upazila, Khagrachhari; Khamarpara, Rangamati sadar, Bangailbaichcha and Baghachhari, Barkal upazila, Rangamati. It is evident from the Table 9 that 27% of the total hill areas (on an average) of these villages are used for jhum cultivation. Consumption oriented products like rice, maize, different types of vegetables, ginger, turmeric, local varieties of cotton and oilseeds are mainly produced in these villages. In jhum cultivation, inorganic fertilizers are rarely used. Hence, for maintaining soil fertility, the farmers have to find a new *jhum* land every year depending on its availability. In early days, a jhum land were kept fallow for 10-15 years, but now a days, it is kept fallow for 3-4 years due to poverty caused by population growth and environmental degradation. Banana cultivation is remarkable in this agricultural system, because of having a tradition of the farmers to plant banana after jhum cultivation. Fruits and horticultural crops are grown mainly for household's consumption. Livestock products are used to mitigate household's requirements. There is a scarcity of off-farm income in some of these villages due to poor road conditions and long distances from the roads, markets and upazilas.

Semi-intensive agricultural system: In eighteen out of twenty-seven selected villages of Chitagong Hill Tracts namely, Faruqpara, sadar upazila, Bethelpara and Kurangpara, Ruma upazila, Dakshin-Purba Palangpara and Nayapara, Alikadam upazila, Bandarban; Golabari, Nolsolara and Bograchhari, sadar upazila, Mohamanipara and Lamuchhari, Mohalchhari upazila, Duluchhari and Joy Durgapara, Dighinala upazila, Khagrachhari; Uluchhari and Tangchangya, sadar upazila, Kiyangpara, Barkal upazila, Mogbochhari, Karigarpara and Chhota Paglipara, Kaptai upazila, Rangamati, traditional intercropping practices are being gradually replaced by mono-culture of rice. Even the methods of cultivation are changing remarkably over time. In some of these villages, power tiller is used instead of traditional ploughing method. It is evident from the Table 9 that rice crop, cash crop (pineapple) along with other horticultural crops and livestock are the dominant components of this system.

Intensive agricultural system: Chemi Dolupara, sadar upazila, Monchapara, Alikam upazila, Bandarban and Netrojoypara, Dighinala upazila, Khagrachhari are the three among the twenty seven selected villages of Chittagong Hill Tracts in which market-oriented commercial agricultural products are produced. The area under shifting cultivation is the least (17%) over the hill area in these villages (Table 9). High-value cash crops such as commercial production of banana are more dominant than the traditional crops such as rice, maize and vegetables. Forestry and livestock are the most important components of this system (Table 9).

Mixed agricultural system: Mixed agricultural system is practised in Getsimanipara, sadar upazila, Bandarban. Jhum (shifting agriculture), plain land crops (mainly, rice), timber trees like teak and gammery, horticultural crops- high value cash crops such as pineapple, banana and other fruits, livestock, etc. are more or less equally dominant in this village (Table 9).

4.6 Food security and ecological footprint at upazila level

Major crop areas of nine upazilas in the Chittagong Hill Tract (CHT) are shown in Table 11. T. Aman is the major crop for all the upazilas except Ruma upazila. The area for Boro cultivation is lower than that of T. Aman area except Kaptai upazila. Among the nine upazilas, the highest area for Boro is in Dighinala (1914 ha) followed by Kaptai (1846 ha). The Boro area in the Ruma upazila is very negligible. The highest Jhum area is in Ruma (2000 ha) followed by Alikadam (920 ha) and Bandarban Sadar (850 ha) while the highest tobacco area is in Dighinala (1800 ha) followed by Alikadam (610 ha). There is no tobacco in Rangamati Sadar.

Table 11 Major crop areas in 2008-2009 of different upazilas

Sl. No.	Upazila	Total area (ha)	T. Aman area (ha)	Boro area (ha)	Jhum area (ha)	Tobacco area (ha)
1	Bandarban Sadar	50198	2648	1040	850	350
2	Alikadam	88615	1600	203	920	610
3	Ruma	61668	45	7	2000	81
4	Rangamati Sadar	54618	720	319	350	0
5	Barkal	76088	385	310	305	350
6	Kaptai	27336	1150	1846	340	40
7	Khagrachhari Sadar	29791	3550	1517	550	40
8	Mahalchhari	24864	3050	1400	405	31
9	Dighinala	69412	4760	1914	680	1800

The present status of population, food availability status, food self sufficiency ratio, contributions of crop production including tobacco, livestock, horticulture and forest products to food security, and environmental degradation in terms of ecological footprint of nine upazilas of the CHT of Bangladesh are estimated and these upazilas are Bandarban Sadar, Ali kadam, Ruma, Rangamati Sadar, Barkal, Kaptai, Khagrachhari Sadar, Mahalchhari and Dighinala. Fig. 28 shows the present levels of population in these nine upazilas. Dighinala (118307) has the largest population followed by Khagrachhari Sadar (116299) and Rangamati Sadar (114758) while Ruma (32120) has the lowest population level.

Fig. 29 shows the present production levels of rice production in the nine upazilas. Khagrachhari Sadar (27046 tons) and Mahalchhari (24606 tons) have the largest rice production among these nine upazilas. Rice productions of Khagrachhari Sadar are about 10% and 33% higher than Mahalchhari and Dighinala, respectively. Ruma (3186 tons) has the lowest level of rice production. Thus, Khagrachhari Sadar is rich in rice production but Ruma is poor in rice production having the lowest population level.

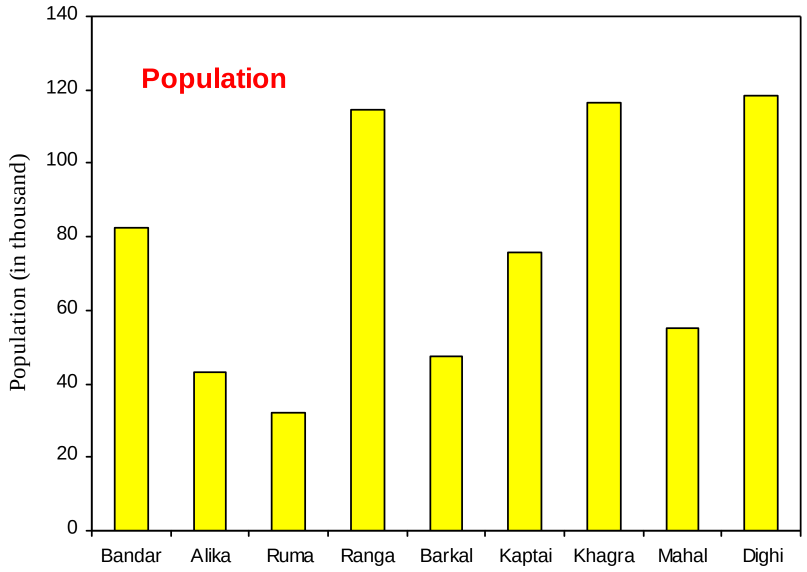


Fig. 28. Population in 2009 of different upazilas

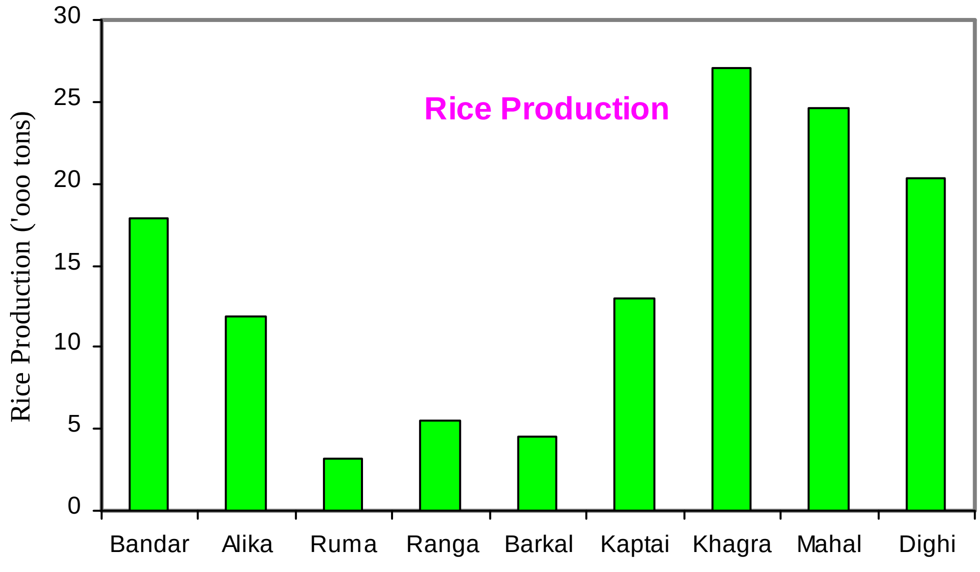


Fig. 29. Rice production of different upazilas

Fig. 30 shows the SSR (Self Sufficiency Ratio) of rice in the nine upazilas. Out of nine upazilas only Mahalchhari upazila is the self sufficient in rice and rests of eight upazilas are deficit in rice. Rangamati Sadar has the largest deficit (0.16).

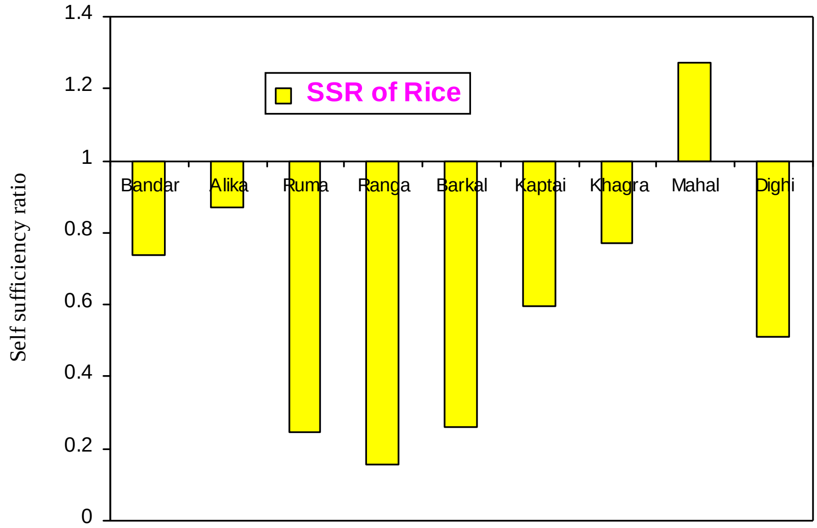


Fig. 30. Self sufficiency ratio of rice of different upazilas

Fig. 31 shows the food availability status in the nine upazilas. Bandarban Sadar (+37.10%), Alikadam (+141.03%), Ruma (+89.67%), Barkal (+6.52%), Kaptai (+8.71%), Khagrachhari Sadar (+5.04%), Mahalchhari (+51.19%) and Dighinala (+36.73%) have positive food security status and only Rangamati Sadar (-24.43%) have negative food availability status. This implies that Bandarban Sadar, Alikadam, Ruma, Barkal, Kaptai, Khagrachhari Sadar, Mahalchhari and Dighinala are food surplus and Rangamati Sadar is food deficit upazilas.

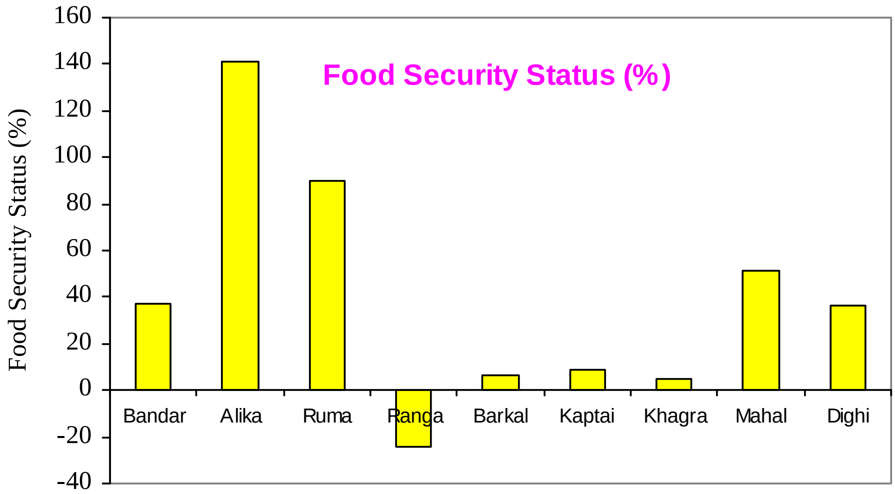


Fig.31. Food availability status of different upazilas

Fig. 32 shows the contributions of crop and horticulture to food availability in the nine upazilas. Mahalchhari (77%) has the largest contribution to food availability crop followed by Dighinala (64%) and Khagrachhari Sadar (59%) and these upazilas are crop dominated while Bandarban Sadar (18%) has the largest contribution to food availability from horticulture followed by Kaptai (16%) and Khagrachhari Sadar (16%).

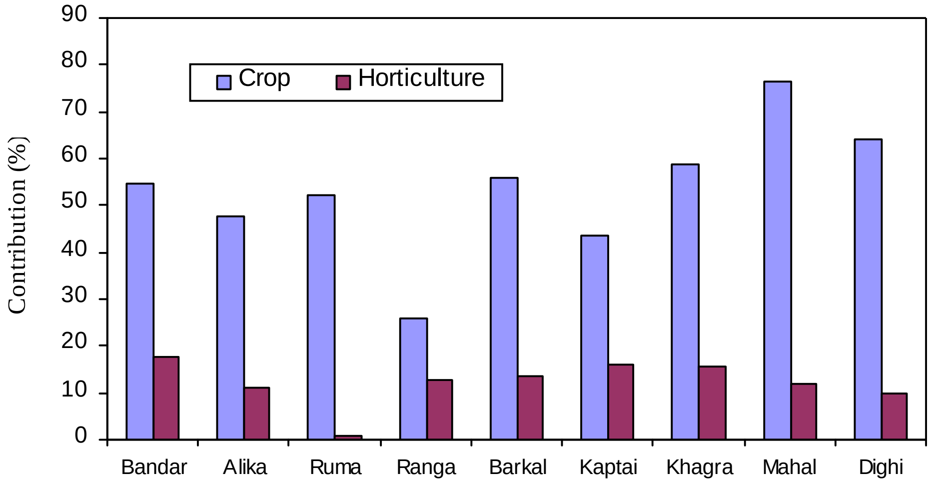
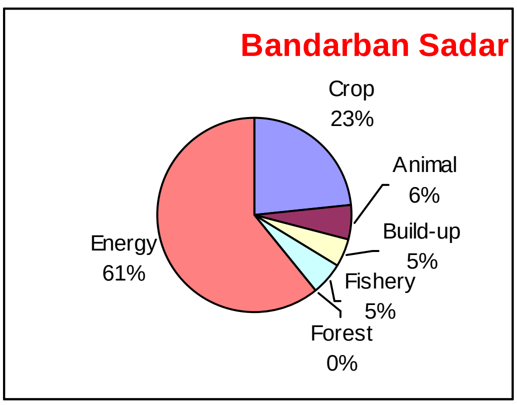
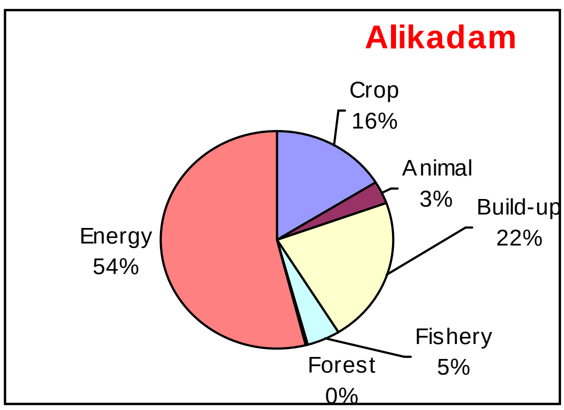


Fig. 32. Contributions of crop and horticulture to the food availability status of different upazilas

Fig. 33 shows the contributions to ecological footprint from different resources in the nine upazilas. For all these upazilas the contributions to ecological footprint from energy is 19-61%, from crop is 16-45%, and from build-up area is 4-22%. But the contribution from energy is the largest in Bandarban Sadar and it is 61%.





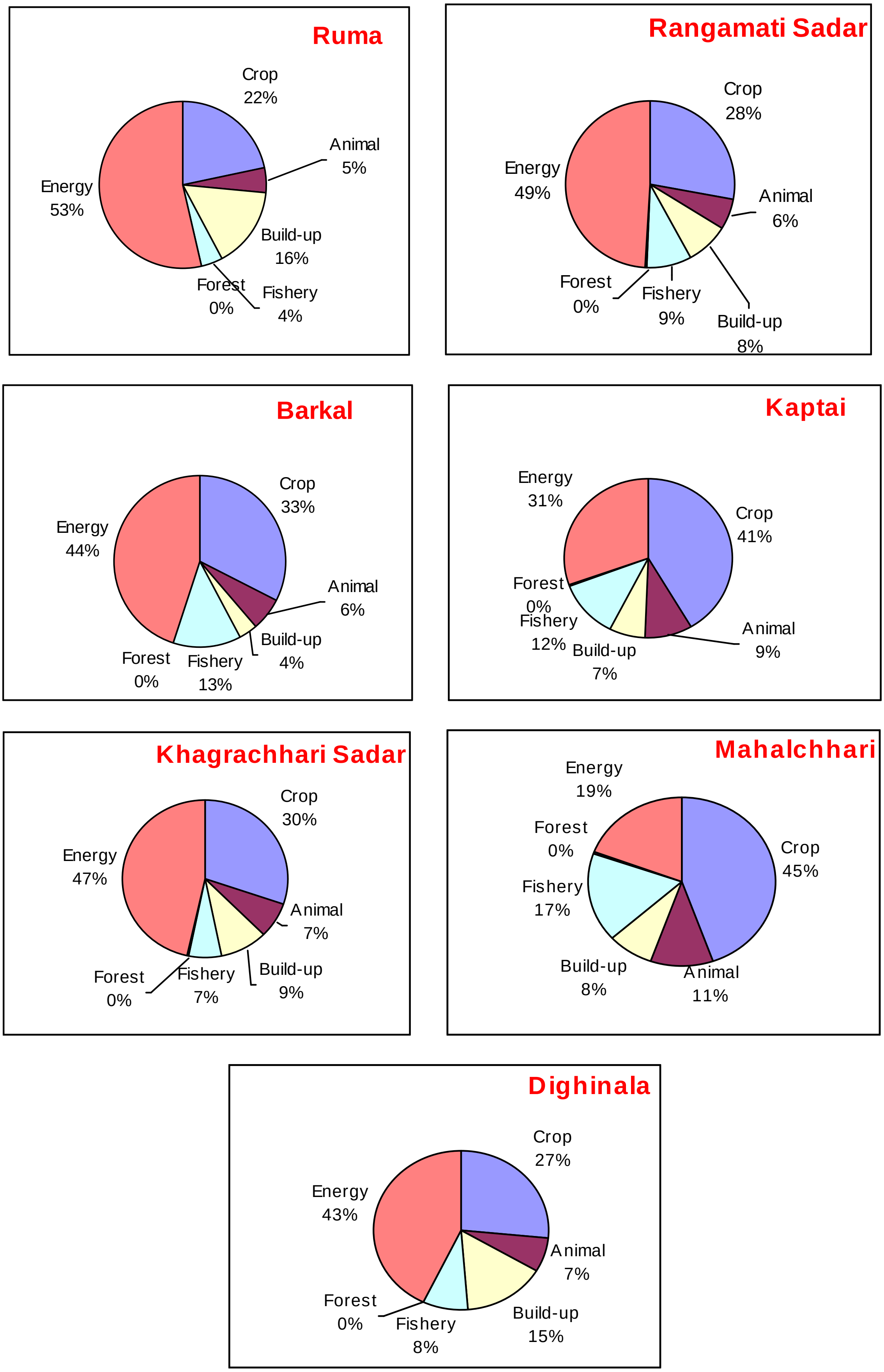


Fig.33. Percent ecological distribution of nine upazilas of CHT region

Fig. 34 shows the ecological footprint in the nine upazilas. The largest ecological footprint is at Alikadam (1.223 gha/cap) followed by Ruma (1.119 gha/cap) and the lowest ecological footprint is at Kaptai (0.426 gha/cap). This implies that Alikadam and Ruma have suffered serious environmental degradation and Kaptai is the least suffered upazila.

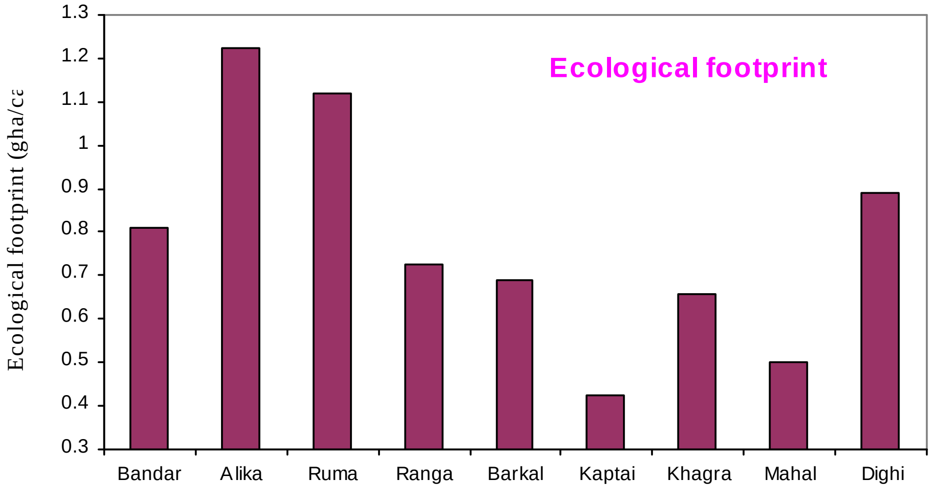


Fig. 34. Ecological footprint of different upazilas

Fig. 35 shows the biocapacity in the nine upazilas. Alikadam has the largest biocapacity (+1.145 gha/cap) and the lowest is at Ruma (+0.201 gha/cap).

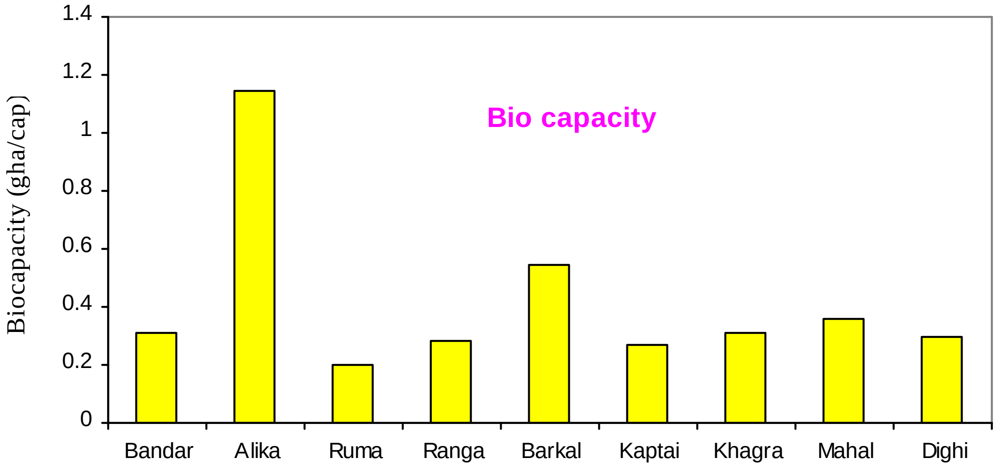


Fig. 35. Biological capacity of different upazilas

Fig.36 shows the ecological status in the nine upazilas. The ecological status of all the upazilas is negative that implies that these upazilas are facing environmental degradation. The ecological status of all the upazilas is deficit because a huge amount of wood is used in the kiln for tobacco processing in addition a large amount of leaves and trees are burned out for the cultivation of *Jhum*. Bala and Hossain (2010a) assessed the ecological status in the nine upazilas of the coastal zone of Bangladesh. They found that out of nine upazilas, two upazilas are ecologically surplus and the rest of five upazilas are ecologically deficit. Wackernagel *et al.* (1999) also reported that the ecological status for Bangladesh as a whole is -0.20 gha/cap. The ecological footprints of 52 countries of the world are shown in Table 12. The largest ecological surplus country among these 52 countries is New Zealand (+12.8) and the lowest ecological deficit country is Singapore (-6.8). The average ecological status (-0.2) of Bangladesh is marginally deficit, but the ecological status (-0.914) of Ruma is 4.5 times of the national average of Bangladesh and needs policy and programs to arrest the growth and reduce the degradation.

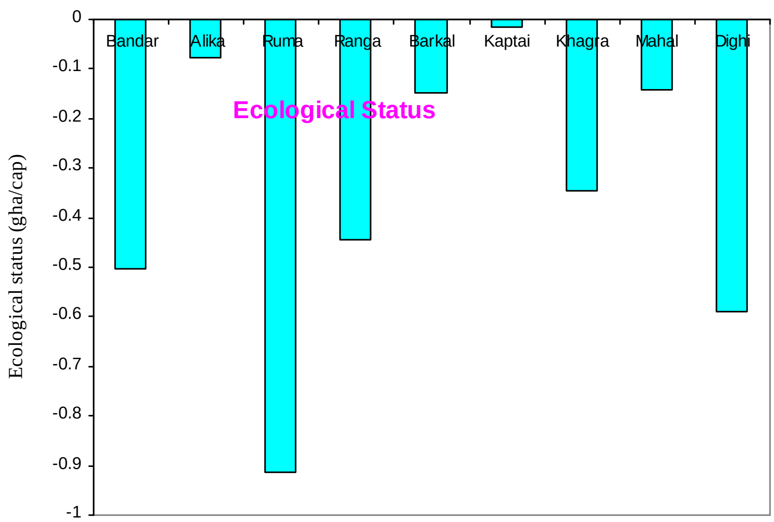


Fig.36. Ecological status of different upazilas

Table 12 Ecological footprint, bio-capacity and ecological status of 52 countries in the world

Sl No.	Country	Ecological footprint (ha/cap)	Available bio-capacity (ha/cap)	Ecological status (ha/cap)
1	<<Singapore>>	6.9	0.1	-6.8
2	<Hong Kong>	5.3	0	-5.1
3	<<Belgium> >	5	1.2	-3.8
4	<<Netherlands>>	5.3	1.7	-3.6

5	<<USA> >	10.3	6.7	-3.6
6	<<United Kingdom> >	5.2	1.7	-3.5
7	<<Germany> >	5.3	1.9	-3.4
8	<<Japan> >	4.3	0.9	-3.4
9	<<Switzerland> >	5	1.8	-3.2
10	<<Israel> >	3.4	0.3	-3.1
11	<<Italy> >	4.2	1.3	-2.9
12	<<Korea> >	3.4	0.5	-2.9
13	Greek	4.1	1.5	-2.6
14	<<Russian Federation> >	6	3.7	-2.3
15	Poland, Rep	4.1	2	-2.1
16	<<South Africa> >	3.2	1.3	-1.9
17	<<Jordan> >	1.9	0.1	-1.8
18	<<Spain> >	3.8	2.2	-1.6
19	<<Thailand> >	2.8	1.2	-1.6
20	<<Mexico> >	2.6	1.4	-1.2
21	<<Venezuela> >	3.8	2.7	-1.1
22	<<Austria> >	4.1	3.1	-1
23	<<Egypt> >	1.2	0.2	-1
24	<<Hungary> >	3.1	2.1	-1
25	<<Nigeria> >	1.5	0.6	-0.9
26	<<Portugal> >	3.8	2.9	-0.9
27	<<Turkey> >	2.1	1.3	-0.8
28	<<Denmark> >	5.9	5.2	-0.7
29	<<Philippines> >	1.5	0.9	-0.6
30	Czech Rep	4.5	4	-0.5
31	<<China> >	1.2	0.8	-0.4

32	<<Ethiopia> >	0.8	0.5	-0.3
33	<<India> >	0.8	0.5	-0.3
34	<<Pakistan> >	0.8	0.5	-0.3
35	<<Bangladesh> >	0.5	0.3	-0.2
36	<<Costa Rica> >	2.5	2.5	0
37	<<France> >	4.1	4.2	0.1
38	<<Norway> >	6.2	6.3	0.1
39	<<Malaysia> >	3.3	3.7	0.4
40	<<Ireland> >	5.9	6.5	0.6
41	<<Argentina> >	3.9	4.6	0.7
42	<<Chile> >	2.5	3.2	0.7
43	<<Sweden> >	5.9	7	1.1
44	<<Indonesia> >	1.4	2.6	1.2
45	<<Canada> >	7.7	9.6	1.9
46	<<Colombia> >	2	4.1	2.1
47	<<Finland> >	6	8.6	2.6
48	<<Brazil> >	3.1	6.7	3.6
49	<<Australia> >	9	14	5
50	<<Peru> >	1.6	7.7	6.1
51	<<New Zealand> >	7.6	20.4	12.8
52	<<Iceland> >	7.4	21.7	14.3
	World	2.8	2	-.0.8

Source: Adapted from Wackernagel *et al.* (1999)

The present status of food security, food self sufficiency ratio, contributions of crop production and tobacco to food security and environmental degradation in terms of ecological footprint in the nine upazilas of the CHT region of Bangladesh at a glance are given in Table 13.

Table 13 The present status of food availability and ecological status of nine upazilas of the CHT region of Bangladesh at a glance.

Name of Upazila	Contribution to food security (%)		Food self sufficiency Ratio SSR	Food availability status (%)	Ecological footprint (gha/cap)	Bio-capacity (gha/cap)	Ecological status (gha/cap)
	Crop	Horti					
Ruma	52	1	0.25	89.67	1.119	0.201	-0.914
Dighinala	64	10	0.51	36.73	0.890	0.300	-0.591
Bandarban	55	18	0.74	37.10	0.811	0.309	-0.503
Rangamati	26	13	0.16	-24.43	0.726	0.283	-0.444
Khagrachhari	59	16	0.77	5.04	0.656	0.310	-0.346
Barkal	56	14	0.26	6.52	0.691	0.543	-0.148
Mahalchhari	77	12	1.27	51.19	0.500	0.357	-0.143
Ali kadam	48	11	0.87	141.03	1.223	1.145	-0.078
Kaptai	44	16	0.60	8.71	0.426	0.268	-0.016

This research shows that the overall status of food availability at upazila levels is good for all the upazilas (5.04% to 141.03%) except Rangamati Sadar (-24.43) and the best is the Alikadam upazila (141.03%). Barkat et al. (2009) also reported that on the whole CHT people are more or less secured in relation to availability of food round the year. The environmental status in the CHT region is poor for all the upazilas. The environmental status in the CHT region has degraded mainly due to jhum and tobacco cultivation.

4.7 System Dynamics Model

An integrated and dynamic model was developed to predict food security and environmental loading for gradual transmission of jhum land into horticulture crops and teak plantation and crop land into tobacco cultivation using systems approach (Bala, 1998). Initial values and the parameters were estimated from the primary and secondary data. The sensitivity of the important parameters was also estimated. To build up confidence in the predictions of the model, various ways of validating a model such as comparing the model predictions with with historic data, cheching whether the model generates plausible behaviour and checking the quality of the parameter values were considered. The validated model was used for base line scenario and policy analysis.

Fig. 37 shows the simulated crop area and tobacco area, and *jhum* area and horticultural crop area and depleted forest area. Cropped area is converted into tobacco area at the rate of 1.7% while *jhum* area is converted into horticultural crop area at the rate of 0.035%. This causes the crop area to be fully converted into tobacco are within 110 years while *jhum* area into horticultural crops area within 95 years. More years are required to convert the crop area into tobacco area since crop area is very large compared to *jhum* area (present area under crop coverage is 6 times higher than the present area under *jhum* coverage). This policy of tobacco cultivation causes a total depletion of forest of 12 million tons within 150 years and this policy may lead to total depletion of the forest in the Hill Tracts of Chittagong.

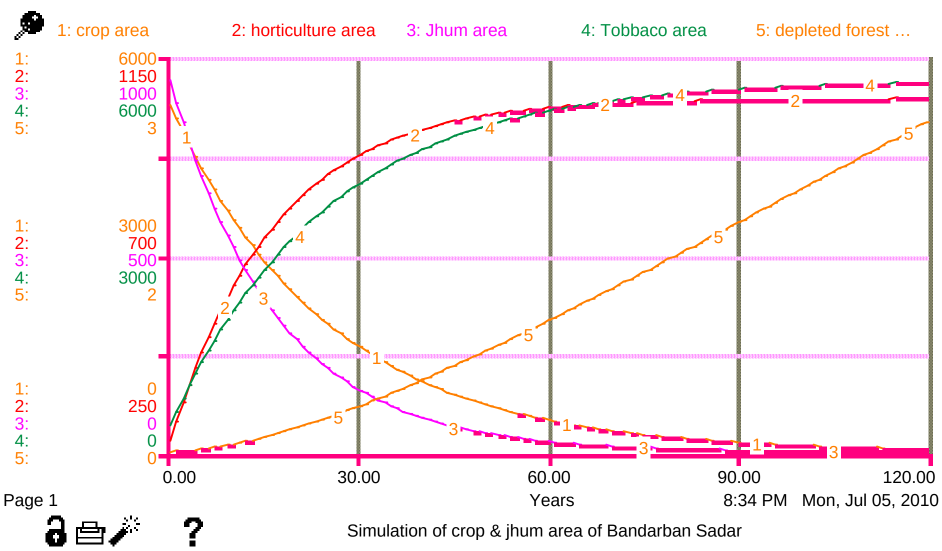


Fig. 37. Simulated crop, horticulture, j*hum*, tobacco & depleted forest areas of Bandarban sadar

Fig. 38 shows simulated population, food available, food requirement and food availability status in the Bandarban sadar upazila. Population increases from 90,443 in 2010 to 124538 in 2130. As a result the food requirements also increases and follows the pattern of population growth. The food availability increases till 95 years and becomes constant due to the fact that cropped area under different crops reaches the maximum limit. Since crop production becomes stagnant and the population increases, this results in a decrease in the food availability status.

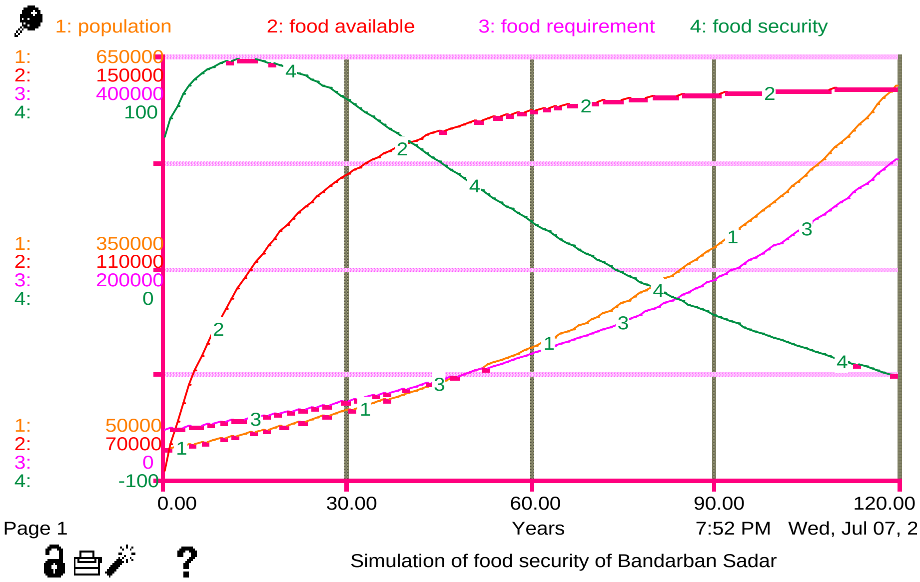


Fig. 38. Simulated food availability status of Bandarban sadar

Fig. 39 shows simulated soil erosion under present land use pattern and under the policy of gradual transition from *jhum* to horticulture. Soil erosion stops when all the *jhum* land is converted into horticulture crops within 95 years, but it continues without a policy to control it.

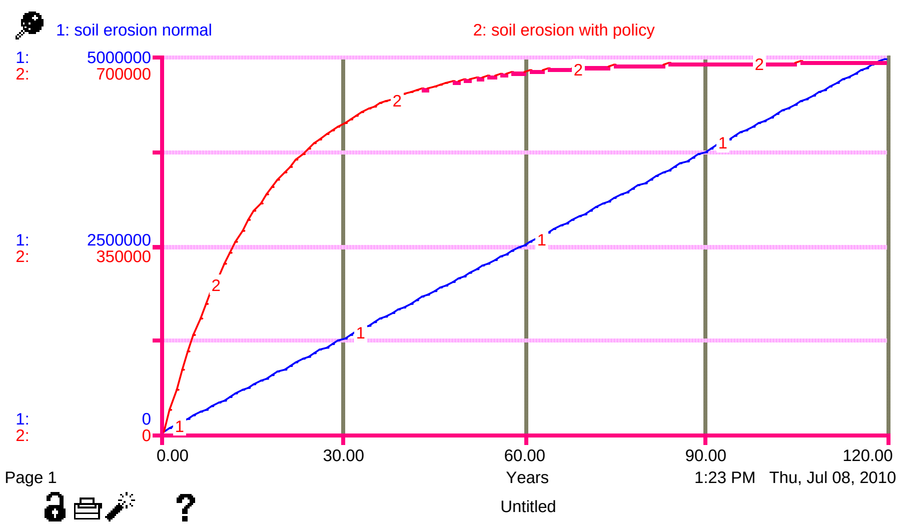


Fig. 39. Simulated soil erosion

Fig. 40 shows the simulated ecological footprint, ecological status, food availability status and biocapacity per capita in the Bandarban sadar upazila. Ecological foodprint initially increases slowly until 60 years and thereafter it increases exponentially with time and the biocapacity follows the similar pattern. Since ecological footprint is higher that of biocapacity, ecological status is negative and it becomes much prominent after 60 years. Food availability increases up to 15 years and then it decreases to zero within 71years.

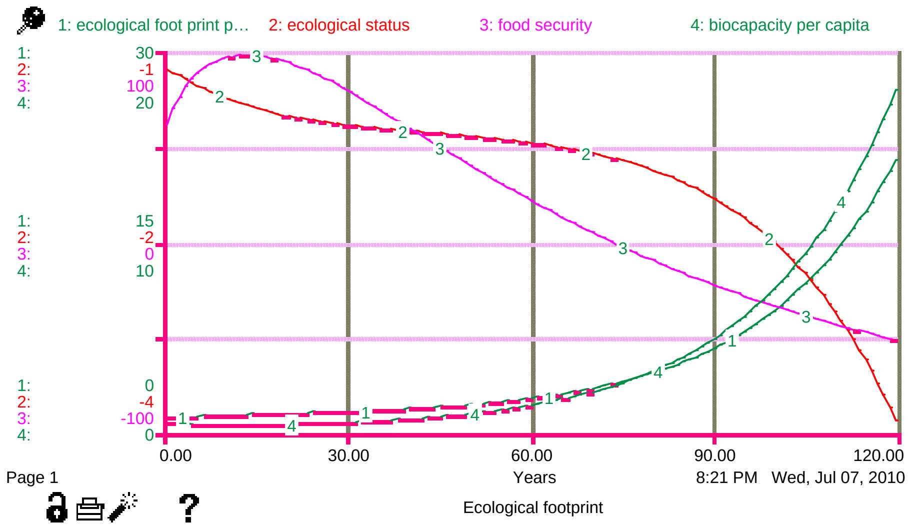


Fig. 40. Simulated ecological status of Bandarban sadar

Fig. 41 shows the simulated food availability status for (i) rice, tobacco and horticulture (normal), (ii) rice and horticulture (without tobacco) and (iii) rice and *jhum* only (without tobacco and horticulture). Food availability for rice and horticulture is slightly better than that of rice. Food availability for rice, tobacco and horticulture initially increases slowly with time and then becomes constant at a higher level than either rice and horticulture or rice and *jhum* only. But after 71 years the food requirement becomes higher than the food available whereas it is 19-25 years for other cases.

Fig. 42 shows the simulated food availability status for (i) crop, tobacco and horticulture (normal), (ii) rice and horticulture (without tobacco) and (iii) rice and *jhum* only (without tobacco and horticulture). All the cases the food availability status decreases in a similar pattern with time, but only difference is in the time when the food availability status reduces to zero. It is after 71years in case of rice, tobacco and horticulture cultivation, after 36 years in case of rice and horticulture and after 15 years in case of crop. The contribution of tobacco cultivation to food security increases to as high as 52% and then it reduces to 26%

at the end of the simulation period of 120 years. Hence, rice, tobacco and horticulture production is the best policy for food security followed by rice and horticulture

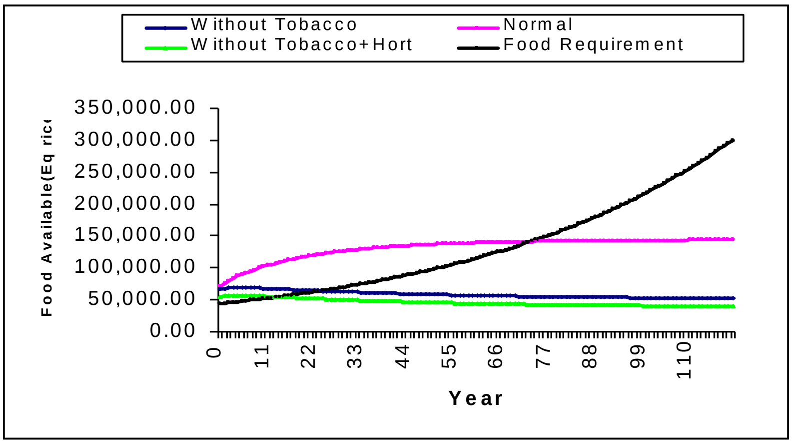


Fig. 41. Simulated food availability for different scenarios of land use patterns

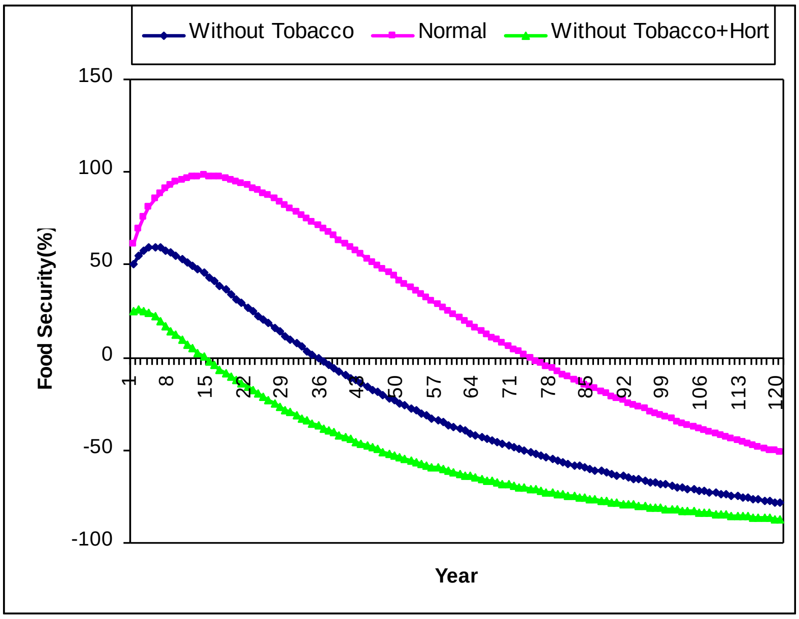


Fig. 42. Simulated food security for different scenarios of land use patterns.

Fig. 43 shows the simulated ecological footprint for (i) rice, tobacco and horticulture (normal), (ii) rice and horticulture (without tobacco) and (iii) rice only (without tobacco and horticulture). All the cases the ecological footprint i.e. environmental degradation increases initially slowly and after 70 years it increases rapidly, but during the early periods, environmental degradation under rice, tobacco and horticulture is dominant followed by rice only. The magnitudes of ecological footprint for rice and horticulture (without tobacco) and rice only (without tobacco and horticulture) are not significantly different and are almost same. Thus, any policy without tobacco is the best policy in terms of the reduction of environmental degradation.

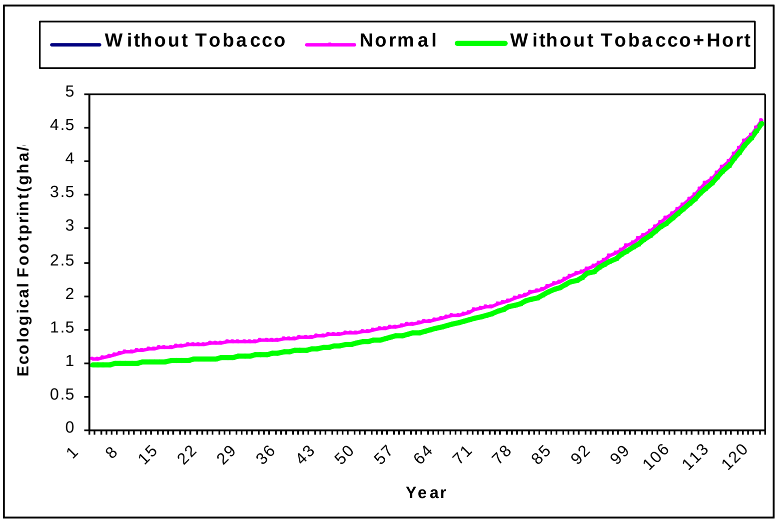


Fig. 43. Simulated environmental loading for different scenarios of land use patterns

4.8 Climate change

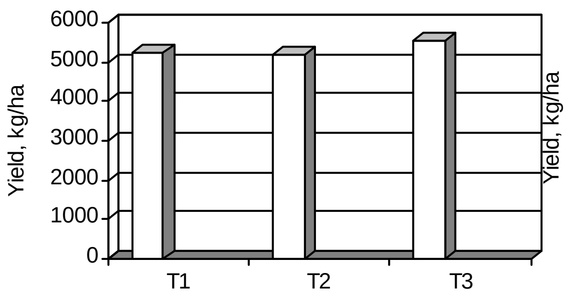
In general, historical weather data at least of 30 years are preferred to represent weather variability. Different climate change scenarios can then be assessed using these data records. The simplest approach is to assume a fixed climate change and to modify the data with a constant number, such as an increase or decrease of 1, 2, 3 ^{o}C etc. for temperature. Similarly, CO_2 can be changed with a certain percentage, such as an increase or decrease of 10, 20, 30%, etc. These changes are then applied to the crop simulation models.

The model was simulated to predict the yields of rice and maize for climate change scenarios of temperature, rainfall and CO_2 concentration. Treatments of climate change and their impacts on the yields of rice and maize are shown in Table 14. Fig. 44 shows the climate change impacts on the yields of rice and maize for three different treatments of climate change. The yield of rice decreases for treatment 2, but it increases for treatment 3. This is might be due to the fact that for +2°C of temperature change and +50 ppm of CO_2 change, the effect of temperature is dominant and it is negative while for +2°C of temperature change and +100 ppm of CO_2 change, the effect of CO_2 is dominant and it is positive i.e. the effect elevated CO_2 and increased rainfall makes for the negative effect on the rice yield due to temperature rise. The yield of maize increases for treatment 2 and 3. This might be due to the fact that maize is a C_4 plant and in C_4 plant the effect of CO_2 reduces the severity of the warmer air temperature. The climate change impacts on the yields of rice and maize are not significant. More recently Rosenzweig et al. (2010) reported preliminary outlook for effects of climate change on Bangladeshi rice and this study shows that aus crop is not strongly affected and aman crop simulations project highly consistent production increase.

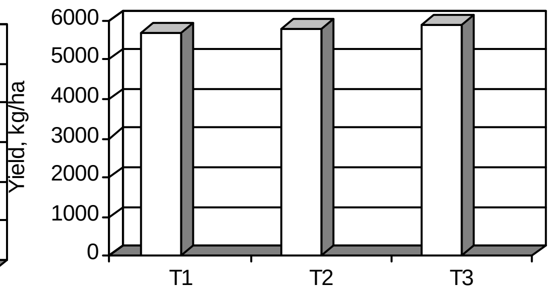
Table 14 Treatments for climate change impact on rice and maize

Treatment No.	Temperature change, °C		CO_2 change*	Rainfall change, %	Rice yield, kg/ha	Maize yield, kg/ha
	Maximum	Minimum				
1	0	0	0	0	5259.60	5692.40
2	2	2	50	+20	5191.80	5759.20
3	2	2	100	+30	5543.90	5869.50

*Reference CO_2 level is 340 ppm



Rice



Maize

Fig. 44. Climate change impacts on the yields of rice and maize for different treatments

Table 15 shows the climate change impacts on rice productions in Asia. The yield of rice increases with the increase of CO_2 concentration but decreases with the increases of temperature levels. The reduction of yield below the present level is predicted even for 1 ^oC temperature increase at the present level of CO_2 concentration and the reduction of yield increase for 4 ^oC increase of temperature and decrease of CO_2 concentration from 680 ppm to 340 ppm. These predictions are in good agreement with the predictions of the present study.

Table 15 Simulated potential yields of rice in Asia due to climate change

Model used and ambient CO_2 levels	Percentange change in mean potential rice yield in Asia resulting from air temperature increment of			
	0 ^oC	+ 1^oC	+ 2^oC	+ 4^oC
ORYZA1 Model				
340 ppm	0.00	- 7.25	- 14.18	- 31.00
1.5 × CO_2	23.31	12.29	5.60	- 15.66
2 × CO_2	36.39	26.42	16.76	- 6.99
SIMRIW Model				
340 ppm	0.00	- 4.58	- 9.81	- 26.15
1.5 × CO_2	12.99	7.81	1.89	- 16.58
2 × CO_2	23.92	18.23	11.74	- 8.54
Source: Matthows *et al.*, 1995, as reproduced in Lal *et al.*, 2001				

4.9 Multi agent system

Multi agent system model is used to simulate the interactions among the artificial actors of farmers, agricultural extension officer and NGO officer with the environment for assessing the sustainability of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong for gradual transition from *jhum* cultivation to horticultural crops. Fig. 45 shows the land use pattern in a typical village of Uchha Kangailchhari and about 23% of the land under *jhum* cultivation, 35% rice cultivation and 42% horticultural crops. This village has all three types of farming systems. off farm /nonfarm income is also considered in the computation of food security at household levels. Fig. 46 shows the present status of food security and only 43% of the households are food secure, 7% are conditionally food secures and 50% are food insecure. This indicates that significant food insecurity exists at household levels. Fig. 47 shows the simulated average food security indicator for a typical village of Uchha Kangailchhari in Mahalchhari upazila in the Khagrachhari district for a time horizon of 15 years. The average food security indicator is more or less in secured and it decreases with time, but the decrease is not substantial Multi agent system model with role playing games i.e. participatory approach at household level is essential for sustainable development of food security strategies and implementation of such strategies.

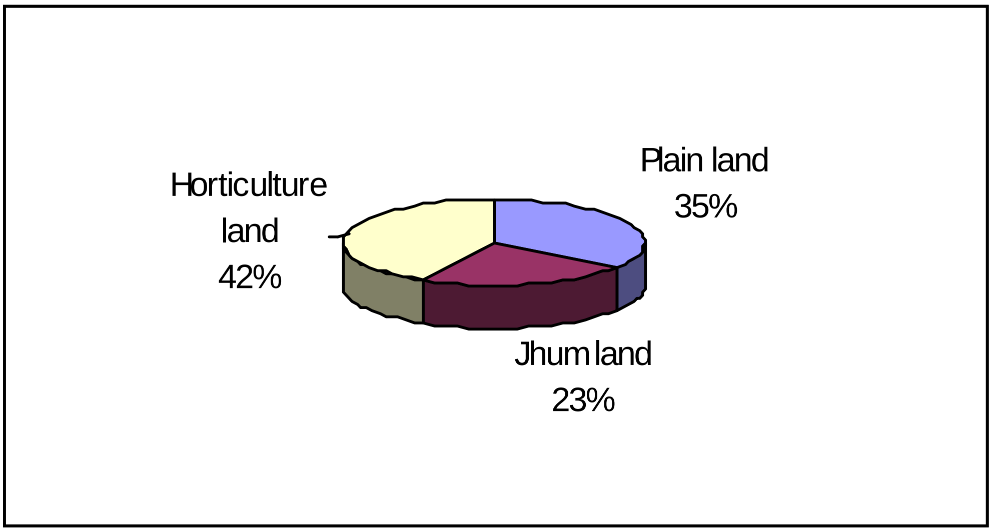


Fig. 45. Land use pattern in a typical village of Uchha Kangailchhari

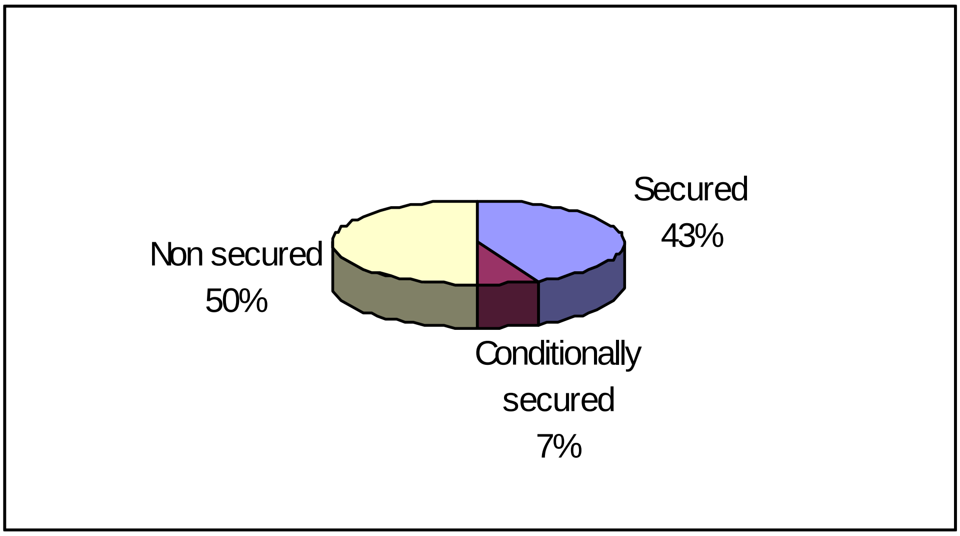


Fig. 46. Food security status in a typical village of Uchha Kangailchhari

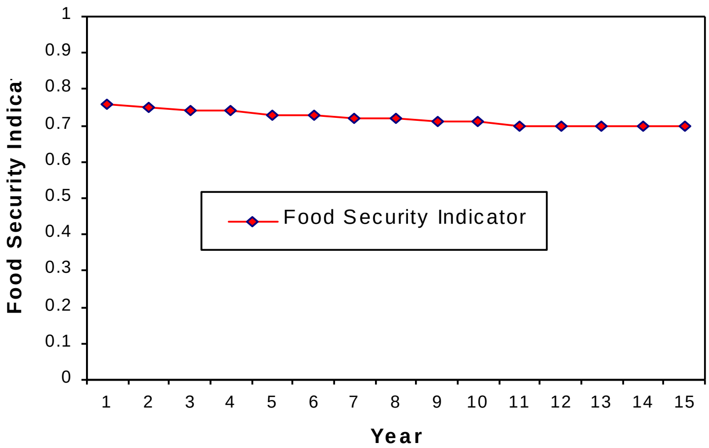


Fig. 47. Simulated food security indicator of a typical village of Uchha Kangailchhari

Potchanasin *et al.* (2008) reported the sustainability of farming systems at the village level in Thailand using multi agent systems approach and these results of the sustainability of a typical farming systems are similar to those predicted for the sustainability of a typical farming systems in the hilly areas of Chittagong Hill Tracts of Bangladesh.

5. KEY FINDINGS

Management of farming/agricultural systems of the Hill Tracts of Chittagong is highly complex and it is a formidable challenge to design and implement the policies for sustainable development. A total of 18 variables were selected to explain the total variability of the agricultural systems of the Hill Tracts of Chittagong based on experiences during field level studies and also the previous studies and the principal component analysis allowed us to reduce the number of dimensions in the quantitative data by selecting the first 6 components of the principal components, which collectively explained 76.69% of the total variation. The loadings of the initial variables on the first component of the principal components explained 23.35% of the variability.

Factor analysis was conducted to find the determinants of the agricultural systems of the Hill Tracts of Chittagong and the factor analysis may be considered as an extension of principal component analysis. Factor analysis was conducted to discover if the observed variables can be explained in terms of a much smaller number variables called factors – covariance or correlation oriented method and total of 18 observed variables can be explained by 4 factors, which explain 77.21% of total variability based on method of principal factors.

Since the original loadings of the factor analysis are not readily interpretable, it is usual practice to rotate them until a simpler structure is achieved. All the variables are loaded unambiguously in the four factors. Three variables, 'distance to local market', 'distance to upazila' and 'hill area', have high negative loadings in the first factor, which explains about 16% of the total variance. The positive loading of 'religion' separates it from other clustered variables in this factor. Factor1 can be referred to as 'infrastructure development' as the variables are somehow associated with development. The second factor that explains about 15% of the total variance consists of the variables: 'training', 'extension service', 'electricity' and 'farmer's off-farm income' with high positive loadings. All the variables (except farmer's off-farm income) are associated with service. So, factor 2 may be called 'institutional service (training and extension)'. The third factor that explains about 13% of the total variance consists of the variables like ‘formal-informal micro credit’, ‘informal micro credit’ and ‘NGO service’ with moderate to high positive loadings and factor 3 can be referred to as ‘micro credit and NGO service’. The fourth factor explains 10% of the total variance. The factor 4 consists of one variable ‘*jhum* land’ with high positive loading and one variable ‘consumption cost’ with moderate negative loading. We might call the factor 4 as ‘availability of *jhum* land’ separating the consumption cost variable. This implies that infrastructure factor, training and extension factor, micro credit and NGO service factor, and availability of *jhum* factor are affecting agricultural systems of uplands of the Hill Tracts of Chittagong and these factors must be considered for design and implementation of the sustainable development of uplands of the Hill Tracts of Chittagong.

Classification of the farming/agricultural systems of the Hill Tracts of Chittagong is essential for policy planning and its implementation for specific types of agricultural systems. Cluster analysis was conducted for solving classification problems and the variables characterizing the systems are selected. The selected variables were also used to classify the agricultural systems of 27 villages. The selected variables are area under shifting agriculture, horticulture, rice cultivation, annual cash crops, average number of private trees per household, average number of fruit trees, average number of wood trees and average number of cattle, pigs, goats, poultry and household consumption. The systems are classified as extensive, semi-intensive, intensive and mixed. But one village out of 27 villages is classified as mixed since it manifested almost equally the entities of other three categories of the agricultural systems. Discriminant analysis was conducted for checking the accuracy of the classification of the agricultural systems and the classification error was found to be zero.

Food availability status and environmental degradation in terms of ecological footprint of nine upazilas of three districts of the Hill Tracts of Chittagong were estimated. The overall status of food security at upazila level is good for all the upazilas (5.04% to 141.03%) except Rangamati Sadar (-24.43) and the best is the Alikadam upazila (141.03%). The environmental status in the CHT region is poor for all the upazilas. The environmental status in the CHT region has degraded mainly due to jhum and tobacco cultivation.

An integrated and dynamic model was developed to predict food security and environmental loading for gradual transmission of *jhum* land into horticulture crops and teak plantation and crop land into tobacco cultivation using systems approach. Food security status for gradual transition of *jhum* land into horticulture crops and teak plantation and crop land into tobacco cultivation is the best option for the food security. However, it is negative i.e. food deficit after 37 years and it is better with horticulture than that of *jhum* only. The ecological footprint is the highest for gradual transition of *jhum* land into horticulture crops and teak plantation and crop land into tobacco cultivation resulting the highest environmental loading. Considering both food security and environmental degradation in terms of ecological footprint the best option is gradual transition of *jhum* land into horticulture crops.

Climate change impacts on the yields of rice and maize in the Hill Tracts of Chittagong were assessed using crop growth simulation models. The climate change impact model was simulated to predict the yields of rice and maize for three different treatments of temperature, carbon dioxide and rainfall change of (+0°C, +0 ppm and +0% rainfall), (+2°C, +50 ppm and 20%) and (+2°C, +100 ppm and 30% rainfall). The yield of rice decreases for treatment 2, but it increases for treatment 3. The yield of maize increases for treatment 2 and 3 since maize is a C_4 plant. Climate change has little positive impacts on rice and maize production in the uplands of the Hill Tracts of Chittagong. The climate change impacts on the yields of rice and maize are not significant. More recently Rosenzweig *et al*. (2010) reported preliminary outlook for effects of climate change on Bangladeshi rice and this study shows that aus crop is not strongly affected and aman crop simulations project highly consistent production increase.

Multi agent system model was used to simulate the interactions among the artificial actors of farmers and agricultural extension with the environment for assessing the sustainability of the farming/agricultural systems of the uplands of the Hill Tracts of Chittagong for gradual transition from *jhum* cultivation to horticultural crops. The average food security indicator for a typical village of Mahalchhari in the Khagrachhari district was simulated for a time horizon of 15 years. The average food availability indicator is more or less secured and it decreases with time, but the decrease is not substantial. Thus, there exists food insecurity at household level in a typical village of Mahalchhari in the Khagrachhari district.

6. POLICY IMPLICATIONS AND RECOMMENDATION

Agricultural systems of the Hill Tracts of Chittagong are still traditional with marginal yield i.e. *jhum* cultivation resulting soil erosion and an expanding coverage of tobacco cultivation along banks of the hilly rivers which results in rapid depletion of the nearby reserve forests for kilning the tobacco. This traditional agriculture and expanding coverage of tobacco cultivation are the threats to the environment and this rapid expansion of tobacco cultivation may cause the total destruction of the reserve forests of the Hill Tracts of Chittagong within a short period of time. To study the determinants and patterns of agricultural systems, all the three districts of the Hill Tracts of Chittagong were studied at field level and information was collected using multistage stratified sample survey. Our findings suggest the following overall policy implications:

Overall policy implications

- Cluster analysis employed to classify the agricultural systems reveals that there exists three major systems: extensive, semi-intensive and intensive. The findings suggest that productive resource base, institutional supports available and access to market play important roles in the development of these different types of systems. It is recommended that plans and programs for socio-economic development and its implementation strategies at macro and micro levels for the Hill Tracts of Chittagong should be designed for these major three types of the agricultural systems for sustainable development.
- Findings of the multivariate analysis have important policy implications for promotion of environmentally sustainable and economically viable agricultural systems for socio-economic developments of the Hill Tracts of Chittagong. Uplands are confronted with problems of land degradation, deforestation and poverty. The factors affecting the agricultural systems of the Hill Tracts of Chittagong are infrastructure development for access to market and development of marketing channels for agro products, institutional service (training and extension), micro credit and gradual transition of the jhum land into horticultural crops and these factors are recommended for consideration for environmentally sustainable and economically viable agricultural systems for socio-economic development of the Hill Tracts of Chittagong.
- Findings of the macro and micro level simulated studies suggest that fruit trees with other horticultural crops to control soil erosion and landslides and banning of tobacco cultivation to avoid deforestation need promotion of environmentally sustainable and economically viable agricultural systems.
- Further study using multi agent system model with participatory approach for different policy interventions and management strategies at household levels for sustainable development is desirable.

7. AREA OF FURTHER RESEARCH

The overall status of food availability at upazila level is good for all the upazilas, but there exists food insecurity at household levels. Further studies should be carried out using a participatory approach modeling of multi agent system involving all the stakeholders for a successful sustainable development of the Hill Tracts of Chittagong.

A computer simulation based on system dynamics methodology is developed to provide an understanding of how things have changed with time and this approach has been adopted to simulate the highly complex agricultural systems of the Hill Tracts of Chittagong and also multi agent system model has been constructed to develop scenarios to increase the sustainability of the agricultural systems of the Hill Tracts of Chittagong at household levels. MAS model predicts that the household food security is not sustainable. Further study on strategies for sustainable development for household food security i.e. sustainable farming system is highly desirable.

Agent-based modeling is a means to explore, explain, and assess the complex interactions between ecosystems and human actions. These models are most frequently used to enhance our scientific understanding or to recommend corrective policy action such as farmers, extension workers or local administrators are usually only contacted at the time of primary data collection and are otherwise bypassed in the transfer of knowledge between the researcher and the policy maker. Still, those stakeholders are often directly affected by the new policies partly or fully based on the results of those models. This is a severe drawback since the quality of the model, the relevance of its assumptions, and the efficacy of its use could be improved by involving stakeholders more actively in the development, testing, and use of the model. Companion modeling (ComMod) has been developed as one such approach that seeks to enhance involvement in computer modeling, particularly in the field of natural resource management. ComMod is an approach that combines multi-agent systems (MAS) with participatory research. Further studies should be conducted to identify the policy options needed to increase the sustainability of the agricultural systems of the Hill Tracts of Chittagong at household levels using Companion Modelling (ComMod) approach combining the use of MAS models with role-playing games (RPG) which approach would facilitate collective decision-making in a socially heterogeneous community of small farmers of the Hill Tracts of Chittagong.

The forests of the Hill Tracts of Chittagong are one of largest carbon sinks in Bangladesh. Cutting cycles and climate change over the next 100 years are expected to have significant impacts on forest ecosystems of the Hill Tracts of Chittagong. The forestry community needs to know cutting cycles for sustainable yields and evaluate the long-term effects of climate change on forests and determine what the community might do now and in the future to respond to this threat. Management can influence the timing and direction of forest adaptation at selected locations, but in many situations society will have to adjust to how forests adapt. A high priority will be coping with and adapting to forest disturbance while maintaining the genetic diversity and resilience of forest ecosystems. Bala (2010) has adapted the gap model to simulate the mangrove forest growth of the sunderbans. Further research is needed on modeling of the forest of the Hill Tracts of Chittagong to address the cutting cycle for sustainable yield and also to assess the climate change impacts on the forests of the Hill Tracts of Chittagong to address the long-term effects of climate change on forests and its contribution to food security and environment.

8. CONCLUSIONS

Principal component analysis has been conducted to reduce the number of the dimensions in the collected data and a total of 18 selected variables have been transformed into 6 principal components to explain 76.69% of the total variability of the agricultural systems of the Hill Tracts of Chittagong.

Factor analysis was conducted to identify the determinants of the agricultural systems of the Hill Tracts of Chittagong and the 18 observed variables can be explained by 4 factors, which explain 77.21% of total variability based on the method of principal factors.

The original loadings of the factor analysis were rotated to make them interpretable. All the variables are loaded unambiguously in the four factors. Factor1 is referred to as 'infrastructure development' which explains about 16% of the total variance and the second factor that explains about 15% of the total variance and we call factor 2 as 'institutional service (training and extension)'. The third factor that explains about 13% of the total variance is referred to as 'micro credit and NGO service'. The fourth factor explains 10% of the total variance and the factor 4 is referred to as 'availability of jhum land'. These factors must be considered for design and implementation of the sustainable development policy and programs for socio-economic developments of the uplands of the Hill Tracts of Chittagong.

Farming/agricultural systems of the Hill Tracts of Chittagong must be classified for policy planning and its implementation for sustainable development. Cluster analysis was conducted to classify the agricultural systems of 27 villages in the Hill Tracts of Chittagong and the systems were classified as extensive, semi-intensive, intensive and mixed. But one village out of 27 villages is classified as mixed since it manifested almost equally the entities of other three categories of the agricultural systems. Discriminant analysis was conducted for checking the accuracy of the classification of the agricultural systems and the classification error was found to be zero i.e. classification exactly correct.

Food security and environmental degradation in terms of ecological footprint of nine upazilas of three districts of the Hill Tracts of Chittagong were determined. The overall status of food security at upazila level is good for all the upazilas (5.04% to 141.03%) except Rangamati Sadar (-24.43) and the best is the Alikadam upazila (141.03%). The environmental status in the CHT region is poor for all the upazilas. The environmental status in the CHT region has degraded mainly due to *jhum* and tobacco cultivation.

An integrated and dynamic model has developed to predict food security and environmental loading for gradual transition of *jhum* land into horticulture crops and teak plantation, and crop land into tobacco cultivation. Food security status for gradual transition of *jhum* land into horticulture crops and teak plantation and crop land into tobacco cultivation is the best option for the food security, but this causes the highest environmental loading resulting from tobacco cultivation. Considering both food security and environmental degradation in terms of ecological footprint the best option is gradual transition of jhum land into horticulture crops which provides moderate increase in the food security with a relatively lower environmental degradation in terms of ecological footprint.

Computer models to predict the climate change impacts on upland farming/agricultural systems have been developed and climate change impacts of three combinations of temperature, carbon dioxide and rainfall change of (+0, +0 and +0), (+2, +50 ppm and 20%) and (+2, +100 ppm and 30%) were assessed. The climate change impacts on the yields of rice and maize are not significant.

Structures of Multi agent systems modeling to predict food security and environmental degradation at household levels have also been designed and the dynamics of the upland farming systems and income per household are simulated using multi agent systems. The model can be simulated for different policy interventions and management strategies.

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APPENDICES

Appendix-A: Questionnaire for primary data collection from farmers

Management of Agricultural Systems of the Uplands of Chittagong Hill Tracts for Sustainable Food Security

Questionnaire for Individual Farmers

Sl. No. [ ] Date [ ]

Farm size category

Marginal (0.05-0.49 ac)	Small (0.5-2.49 ac)	Medium (2.5-7.49 ac)	Large(7.5 ac & above)

1. Village information

Name	Union	Upazila	District	Altitude	Age of settlement	Existence of school

2. Head of the household

Tribal			Non-tribal	Religion	Age	Education	Years of schooling	Profession
Chakma	Marma	Others (specify)						

3. Address of the household

Father's name	Electrified (Y/N)	Distance from			Time to reach the main road
		Main road	Market	Upazila	

4. Family details of the household

No. of family members	No. of. male	No. of female	No. of children	Earning members	Sources of income	Off-farm income	Yearly income (Tk.)	Yearly expenditure (Tk.)

5. Land distribution and land type

Distribution	Area (ha/ac/ big)	Land type (ha/ac/bigha)			Almost Flat (ha/ac/bigha)				Fallow period (year)
		Very steep	Steep	Moderate Steep	High	Medium	Low	Others	
Homestead									
Cropped area									
Horticulture									
Forest									
Aquaculture									
Others									
Total									

6. Soil type

Distribution	Water retaining capacity (ha/ac/bigha)			Soil fertility (ha/ac/bigha)			Soil erosion (ton/ac/yr)
	0-1 day	1-3 day	above 3 days	Good	Not so good	poor	
Homestead							

Cropped area							
Horticulture							
Forest							
Aquaculture							
Others							
Total							

7. Crop information

A. General Crop

Crop	Area (ha/ac/ big)	Fallow period (month/yr)	Main product (md/big)	By product (md/big)	No. of irrigation	Irrigation Cost (Tk/bigha)	Price of grain (Tk/md)	Price of straw (Tk/md)

B. Fertilizer and Pesticides

Crop	Area (big)	Fertilizer								Pesticides	
		Urea		TSP		MP					
		Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)

8. Horticulture

A. Horticultural Crop

Name	Area (ha/ac/ bigha)	Fallow period (month /yr)	No. of irriga tion	Cost of irrigation (Tk/bigha)	No. of trees or plants	No. of harvested trees/plant/ yr	Yield/p lants (kg)	Price of fruit (Tk/no. /kg)	Gross return (Tk.)

B. Fertilizer and Pesticides

Crop	Area (big)	Fertilizer								Pesticides	
		Urea		TSP		MP					
		Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)

9. Cultivation

Mode of cultivation		Methods of cultivation		Fuel consumption (liter)	Man-days used
Shifting (ha/ac/bigha)	Normal (ha/ac/bigha)	Traditional (ha/ac/bigha)	Power tiller (ha/ac/bigha)		

10. Timber Tree

Name	Area (ha/ac/bigha)	No. of trees	Average age (years)	Amount of timbers (cft)	Price of timber (Tk/cft)	Net return (Tk.)

11. Fuel Tree

Name	Area (ha/ac/bigha)	No. of trees	Average age (years)	Amount of wood Mds	Price of wood (Tk/mds)	Net return (Tk.)

12. Livestock and Poultry

	Cattle			Goat			Sheep		Pig		Poultry	Duck
Item	Male	Female	Calf	Male	Female	Calf	Sheep	Calf	Pig	Calf		
No.												
Meat												
Milk												

Egg												

13. Aquaculture

Name of fish	Area (ac/ha)	Yield (ton/ac)	Production (ton)	Price (Tk/kg)	Cost (Tk./ac)	Gross return (Tk.)	Net return (Tk.)

14. Energy consumption for cooking (Mds/month)

Fire wood	Leaf	Straw	Tree branches	Herbs	Shurbs	Jute sticks	Cowdung cake		

15. Electricity consumption

Item	No.	Average consumption (kwh/month)	Total consumption (kwh/month)	Total consumption (kwh/year)
Domestic				
Irrigation				
Total				

16. Micro credit

Source of credit	Type of credit		Amount	interest rate
	Formal	Informal		

17. Extension services

Types of extension services	Training		Do yourself material	Frequency of visit	irregular range of visit
	yes	no			
DAE					
NGO					

18. Daily/Monthly food consumption (kg)

Item	No. of meal/day	Rice	Wheat	Potato	Fish	Meat	Milk	Oil	Egg	Pul ses	Veg	Spi

Amount											
Price											
Total											

19. Sustainability indicator

Farm Income/year (Tk)	Household		
	Capital (Tk)	Income (Tk)	Saving (Tk)

...

Signature of the interviewer

Appendix-B: Questionnaire for secondary data collection from different sources

Management of Agricultural Systems of the Uplands of Chittagong Hill Tracts for Sustainable Food Security

Information to be collected from secondary sources

Name of Upazila		Name of District	

1. Population information

Total population	Male	Female	No. of Children	M/F ratio	Birth rate	Death rate	Family size	

2. Household information

No. of household	Non-farm household	Number of farm holding				
		Total	Marginal	Small	Medium	Large

3. Area related information

a. Total area of upazila (ac/ha)	
b. Water bodies area (ac/ha)	
c. Total household area (ac/ha)	
d. Total cultivated land area (ac/ha)	
e. Total Jhum area (ac/ha)	
f. Crop land area (ac/ha)	
g. Fallow land area (ac/ha)	
h. Irrigated land area (ac/ha)	
i. Forest area (ac/ha)	
j. Aqua cultural land area (ac/ha)	
k. Roads and highways area (ac/ha)	
l. Market area (ac/ha)	
m. Cropping intensity (%)	

4. Year wise area

Year	Crop area (ac/ha)	Jhum area (ac/ha)	Horticulture crop area (ac/ha)	Forest Area (ac/ha)	Aquaculture Area (ac/ha)	Total Area (ac/ha)

5. Cropping pattern:

Sl. No.	Cropping pattern	Area	Percentage (%)

6. Crop information

A. Crop

Crop	Area (ac/ha)	Main product (t/ac/ha)	By product (t/ac/ha)	No. of irrigation	Cost/ha (Tk.)	Price of grain(Tk.)	Price of straw(Tk.)

B. Fertilizer and pesticides

Crop	Area (ha)	Fertilizer								Pesticides	
		Urea		TSP		MP					
		Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)

7. Horticulture

A. Crop

Name	Area (ha/ac/bigha)	No. of trees/ plant	No. of harvested plant/yr	Yield/plant (kg)	Price of fruit (Tk/no./kg)	Gross return (Tk.)

B. Fertilizer and Pesticides

Crop	Area (big)	Fertilizer								Pesticides	
		Urea		TSP		MP					
		Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)	Amount (Kg)	Price (Tk.)

8. Timber Tree

Name	Area (ha/ac/bigha)	No. of trees	Average age (years)	Amount of timbers (cft)	Price of timber (Tk/cft)	Net return (Tk.)

9. Fuel Tree

Name	Area	No. of	Average	Amount of	Price of	Net return

	(ha/ac/bigha)	trees	age (years)	wood Mds	wood (Tk/mds)	(Tk.)

10. Livestock and Poultry

	Cattle			Goat			Sheep		Pig		Poultry	Duck
	Male	Female	Calf	Male	Female	Calf	Sheep	Calf	Pig	Calf		
No.												
Meat												
Milk												
Egg												

11. Aquaculture

Name of fish	Area (ac/ha)	Yield (ton/ac)	Production (ton)	Price (Tk/kg)	Cost (Tk./ac)	Gross income (Tk.)	Net return (Tk.)

11. Information needed to compute Food Security and Ecological Footprint

Category	Existing Area (ac/ha)	Yield (t/ac/ha)	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Footprint component (ha/capita)
A. Crop							
B. Animal Product							
Poultry Meat							
Poultry Egg							
Dairy Meat							
Dairy Milk							
C. Fishery							

D. Forestry							
Fruit tree							
Timber							

E. Build-up Area:

- Transportation:

i) Length of road (km): ii) Average width (km): iii) Total Area (ac/ha):

Mode	No.	Average Area (ac/ha)	Total Area (ac/ha)
Housing			
Industry			
Market			
Others			
Total			

F. Energy:

(a) Cultivation

No. of PT	Area cultivated by PT (ac/ha)	Operating hrs/day	Average no. of passes	Field capacity (ac/ha/hr)	Fuel consumption (lit/hr)	Total fuel (lit)

(b) Irrigation

No. of STW	Irrigated land (ac/ha)	No. of irrig/ season	Ave time/irrigation/ha (hr)	Fuel consumption (lit/hr)	Total fuel (lit)

(c) Threshing and Milling

Item	No.	Total operating days	Average operating hrs/day	Fuel consumption (lit/hr)	Total fuel (lit)
Power thresher					
Mill					

(d) Transportation

Mode	No. of vehicles	Avg. distance (km/day)	Average hrs/day	Fuel consumption (lit/hr)	Total fuel (lit)
Bus					
Track					

Tempo/motor vehicle					
PT/Tractor					
Motor boat					

(f) Electricity

Heads	No.	Average consumption (kwh/month)	Total consumption (kwh/month)	Total consumption (kwh/year)
Domestic				
Commercial				
Industrial				
Irrigation				
Total				

(g) Cooking fuel energy (Mds/month)

Heads	No.	Fire wood	Leave	Straw	Tree branches	Jute sticks	Cowdung cake	Herbs	Shrubs
Households									
Brick Kiln									
Market									
Total									

...

Signature of the interviewer

Appendix-C: Database in Excel for computation of food security and ecological footprint in the nine upazilas of Bandarban Sadar, Ali kadam, Ruma, Rangamati Sadar, Barkal, Kaptai, Khagrachhari Sadar, Mahalchhari and Dighinala.

FOOD SECURITY CALCULATION

Name of Upazila: Bandarban sadar **District:** Bandarban

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)

Aus(U)	90	3.75	337.5	12500	4218750	160.7143
Aus(L)	850	1.985	1687.25	12500	21090625	803.4524
Aman(U)	2549	4.095	10438.16	13750	143524631	5467.605
Aman(L)	99	2.625	259.875	13750	3573281.3	136.125
Boro(U)	970	4.8	4656	15000	69840000	2660.571
Boro(H)	70	6.32	442.4	15000	6636000	252.8
Wheat	0.85	2	1.7	15000	25500	0.971429
Potato	146	18	2628	15000	39420000	1501.714
S. Potato	50	15	750	10000	7500000	285.7143
Musterd	40	1	40	50000	2000000	76.19048
G. Nut	65	1.847	120.055	40000	4802200	182.941
Maize	125	4.2	525	16000	8400000	320
Win Veg	560	21.02	11771.2	12000	141254400	5381.12
Chilli	71	1.39	98.69	40000	3947600	150.3848
Onion	6	9	54	14000	756000	28.8
Garlic	1	5	5	40000	200000	7.619048
Dania	12	1	12	40000	480000	18.28571
Musur	2	1	2	80000	160000	6.095238
Chola	2	1.75	3.5	30000	105000	4
Muskalai	3	1	3	40000	120000	4.571429
Mung	3	1.33	3.99	80000	319200	12.16
Motor	18	1.5	27	25000	675000	25.71429
Arhar	5	1.2	6	22000	132000	5.028571
Felon	7	1	7	40000	280000	10.66667
Sugercane	45	40	1800	8000	14400000	548.5714
Til	40	1	40	30000	1200000	45.71429
Sum Veg	380	12.27	4662.6	12000	55951200	2131.474
Ginger	300	12	3600	40000	144000000	5485.714
Termaric	450	1.4	630	50000	31500000	1200
Tobacco	350	2.07	724.5	130000	94185000	3588
Total	7309.85					30502.72

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	93	28.05	46.8	110000	5148000	196.114286
Fish farm	13	19	42	120000	5040000	192
Galda	3	1	0.15	450000	67500	2.57142857
Fish+Rice	4	0.5	0.3	95000	28500	1.08571429
Creek	30	22	28	110000	3080000	117.333333
Chara	55	38	47	110000	5170000	196.952381
Canal	7	75	1	95000	95000	3.61904762
River	1	300	6	160000	960000	36.5714286
Total		483.55	171.25			746.247619

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income(Tk.)	Equi rice (ton)
	Meat		1099	150000	1.6E+08	6280
	Milk		1556	30000	4.7E+07	1778.29
	Egg('000 No.)		1500	5000	7500000	285.714
Total					2.2E+08	8344

D. Forestry						
i) Fruit production						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango	36400	520	2600	30000	78000000	2971.43
Jackfruit(No)	136633	577	2692666	30	80779980	3077.33
Lichi(No)	2700	54	540000	1.2	648000	24.6857
Banana	520000	520	4160	10000	41600000	1584.76
Papaya	196200	218	1453	6000	8718000	332.114
Coconut(No)	25360	317	134000	20	2680000	102.095
Nut(No)	7200	36	720000	1	720000	27.4286
Pineapple	1.6E+07	407	2170	8000	17360000	661.333
Watermelon	40000	10	200	12000	2400000	91.4286
Orange	13200	44	440	35000	15400000	586.667
Lemon		30	75	10000	750000	28.5714
Guava	16700	75	430	12000	5160000	196.571
Amra	700	4	70	10000	700000	26.3158
Kamranga	250	2	18	5000	90000	3.38346
Bar	8000	50	350	12000	4200000	157.895
Jam	500	15	25	7000	175000	6.57895
Amlaki	510	3	50	11000	550000	20.6767
Olive	500	10	25	6000	150000	5.6391
Bell	200	1	20	8000	160000	6.01504
Chailta	400	12	12	5000	60000	2.25564
Zambura		10	4	6000	24000	0.90226
Others		29	409	6000	2454000	92.2556
Total		2944	4099177			10006.34

ii) Non-fruit production				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	148000	600	88800000	3382.8571

Firewood (mt)	104000	750	78000000	2971.4286
Total			166800000	6354.2857

	Food Security Status Calculation			
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
55953.58844	40812.14139	82398	1.3710	37.10

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Bandarban sadar **District:** Bandarban

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha	Populat ion	Footprint component (gha/cap)
		Crop						
Rice	11881	4055	0	15936	3.75	2.8	82398	0.1444074
Wheat	2	987	0	989	2.62	2.8	82398	0.0128273
Potato	3378	0	895	2483	16.47	2.8	82398	0.005123
Pulses	53	95	0	148	0.837	2.8	82398	0.0060087
Vegetable	16434	0	11802	4632	18	2.8	82398	0.0087445
Oils	160	332	0	492	2.24	2.8	82398	0.0074638
Spices	4400	0	3933	467	14.17	2.8	82398	0.0011199
Tea	0	17	0	17	0.56	2.8	82398	0.0010316
Sugar	180	150	0	330	6.82	2.8	82398	0.0016443
Sub-total								0.1883705
		Animal						
Meat	1099	0	101	998	0.457	1.1	82398	0.0291535
Egg	88	132	0	220	0.304	1.1	82398	0.0096611
Milk	1556	0	1202	354	0.52	1.1	82398	0.0090882
Sub-total								0.0479027
		Fishery						
Fish	171	737	0	908	0.05	0.2	82398	0.0440787
Sub-total								0.0440787
		Forest						
Fruit	15407	200	14368	1236	18	1.1	82398	0.0009167
Sub-total								0.0009167

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
3332	0.33	2.8	82398	0.0373646

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr)	Equivalence factor (gha/ha)	Population	Footprint component (gha/cap)
Fire wood	90231	15.4	1389557	59	1.1	82398	0.314413
Twigs	9152	15.4	140940.8	59	1.1	82398	0.0318905
Diesel (litre)	1671726	0.038	63525.59	71	1.1	82398	0.0119445
Petrol (litre)	109774	0.034	3732.316	71	1.1	82398	0.0007018
Kerosine (litre)	355200	0.037	13142.4	71	1.1	82398	0.0024711
Electricity (kwh)	13600000	0.0036	48960	1000	1.1	82398	0.0006536
Coal (ton)	14000	27	378000	55	1.1	82398	0.0917498
Wood (tobacco)	11200	15.4	172480	59	1.1	82398	0.0390268
Total							0.4928509

		FOOTPRINT SUMMERY					
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	7310	0.654	2.8	82398	0.16246	0.1883705	
Animal	27.48	150.84	1.1	82398	0.05534	0.0479027	-0.5028401
Build-up	3331	0.654	2.8	82398	0.07403	0.0373646	
Fishery	483	7.08	0.2	82398	0.0083	0.0440787	
Forest	13073	0.29	1.1	82398	0.05061	0.0009167	
Energy						0.492851	
Total					0.35073	0.8114842	
	Available BC (-12% for Biodiversity)				0.30864		

FOOD SECURITY CALCULATION

Name of Upazila: Alikadam **District:** Bandarban

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	360	4.05	1458	12500	18225000	694.2857
Aus(L)	920	2.23	2051.6	12500	25645000	976.9524
Aman(U)	1590	4.53	7202.7	13750	99037125	3772.843

Aman(L)	10	2.4	24	13750	330000	12.57143
Boro(U)	93	4.09	380.37	15000	5705550	217.3543
Boro(H)	110	6.6	726	15000	10890000	414.8571
Wheat	0	2	0	15000	0	0
Potato	110	20	2200	15000	33000000	1257.143
S. Potato	0	12	0	10000	0	0
Musterd	25	1	25	50000	1250000	47.61905
G. Nut	15	1.6	24	40000	960000	36.57143
Maize	21	6.6	138.6	16000	2217600	84.48
Win Veg	590	17.05	10059.5	12000	120714000	4598.629
Chilli	95	1.45	137.75	40000	5510000	209.9048
Onion	4	6	24	14000	336000	12.8
Garlic	3	6.3	18.9	40000	756000	28.8
Coriander	0	1.2	0	40000	0	0
Musur	2	1	2	80000	160000	6.095238
Chola	3	1	3	30000	90000	3.428571
Muskalai	4	1	4	40000	160000	6.095238
Mung	10	0.8	8	80000	640000	24.38095
Motor	15	1.06	15.9	25000	397500	15.14286
Arhar	0	1.2	0	22000	0	0
Felon	30	1.2	36	40000	1440000	54.85714
Sugercane	10	40	400	8000	3200000	121.9048
Til	150	0.96	144	30000	4320000	164.5714
Sum Veg	315	14.05	4425.75	12000	53109000	2023.2
Ginger	180	12	2160	40000	86400000	3291.429
Termaric	310	2.8	868	50000	43400000	1653.333
Tobacco	610	1.56	951.6	130000	123708000	4712.686
Total	5585					24441.934

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	316	42.46	82	100000	8200000	312.380952
Fish farm	40	10.42	0	100000	0	0
Galda	3	0	0	450000	0	0
Fish+Rice	4	0	0	95000	0	0
Creek	90	0	0	90000	0	0
Chara	20	25	1.75	100000	175000	6.66666667
Canal	2	200	2	95000	190000	7.23809524
River	1	445	25	160000	4000000	152.380952
Total		722.88	110.75			478.666667

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		910	150000	1.4E+08	5200
	Milk		955	30000	2.9E+07	1091.43
	Egg('000 No.)		1060	5000	5300000	201.905
Total					1.7E+08	6493.33

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango		147	1176	30000	35280000	1344
Jackfruit		170	950	8000	7600000	289.524
Lichi		20	80	20000	1600000	60.9524
Banana		360	1250	10000	12500000	476.19
Papaya		35	1540	6000	9240000	352
Coconut		75	425	15000	6375000	242.857
Nut		60	1540	25000	38500000	1466.67
Pineapple		76	425	8000	3400000	129.524
Watermelon		5	200	12000	2400000	91.4286
Orange		0	0	35000	0	0
Lemon		150	525	10000	5250000	200
Guava		70	612	12000	7344000	279.771
Amra		20	1054	10000	10540000	396.241
Kamranga		0	0	5000	0	0
Bar		25	200	12000	2400000	90.2256
Jam		17	45	7000	315000	11.8421
Amlaki		0	0	11000	0	0
Olive		0	0	6000	0	0
Bell		0	0	8000	0	0
Jambura		6	24	5000	120000	4.51128
Others		110	825	6000	4950000	186.09

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)

Timber (cft)	363000	600	217800000	8297.1429
Firewood (mt)	315000	500	157500000	6000
Total			375300000	14297.143

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
51332.9012	21297.6197	42999	2.4103	141.03

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Ali Kadam **District:** Bandarban

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha	Population	Footprint component (gha/cap)
Rice	7895	1156	0	9051	3.75	2.8	42999	0.1571683
Wheat	0	215	0	215	2.62	2.8	42999	0.0053436
Potato	2200	0	1175	1025	16.47	2.8	42999	0.0040526
Pulses	69	93	0	162	0.837	2.8	42999	0.0126034
Vegetables	14484	0	12521	1963	18	2.8	42999	0.0071015
Oils	49	218	0	267	2.24	2.8	42999	0.0077618
Spices	3208	0	2973	235	14.17	2.8	42999	0.0010799
Tea	0	9	0	9	0.56	2.8	42999	0.0010465
Sugar	40	32	0	172	6.82	2.8	42999	0.0016423
Sub-total								0.1978
		Animal						
Meat	910	0	554	356	0.457	1.1	42999	0.0199282
Egg	62	32	0	94	0.304	1.1	42999	0.0079102
Milk	955	0	724	231	0.52	1.1	42999	0.0113643
Sub-total								0.0392027
		Fishery						
Fish	111	534	0	645	0.05	0.2	42999	0.0600014
Sub-total								0.0600014
		Forest						
Fruit	13662	190	13207	645	18	1.1	42999	0.0009167
Sub-total								0.0009167

E. Build-up Area:

Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
4103	0.99	2.8	42999	0.26450652

F. Energy							
Name	Amount consumed (ton)	Conver sion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr	Equiva lence factor (gha/ha	Populat ion	Footprint component (gha/capita)
Fire wood	61650	15.4	949410	59	1.1	42999	0.4116576
Twigs	7042	15.4	108446.8	59	1.1	42999	0.0470218
Diesel (litre)	412800	0.038	15686.4	71	1.1	42999	0.005652
Petrol (litre)	36000	0.034	1224	71	1.1	42999	0.000441
Kerosine (litre)	249600	0.037	9235.2	71	1.1	42999	0.0033275
Electricity (kwh)	3548547	0.0036	12774.77	1000	1.1	42999	0.0003268
Coal (ton)	3900	27	105300	55	1.1	42999	0.0489779
Wood (tobacco)	21376	15.4	329190.4	59	1.1	42999	0.1427347
Total	4340915						0.660139235

FOOTPRINT SUMMERY							
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	5585	0.653	2.8	42999	0.23748	0.1978	
Animal	22.75	150.84	1.1	42999	0.08779	0.0392027	-0.0779124
Build-up	4103	0.653	2.8	42999	0.17447	0.2645065	
Fishery	723	3.63	0.2	42999	0.01221	0.0600014	
Forest	68826	0.448	1.1	42999	0.7888	0.0009167	
Energy						0.6601392	
Total					1.30074	1.2225665	
	Available BC (-12% for Biodiversity)				1.14465		

FOOD SECURITY CALCULATION

Name of Upazila: Ruma **District:** Bandarban

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	0	3.6	0	12500	0	0

Aus(L)	2,000	1.5	3000	12500	37500000	1428.571
Aman(U)	30	4.07	122.1	13750	1678875	63.95714
Aman(L)	15	2.4	36	13750	495000	18.85714
Boro(U)	7	4	28	15000	420000	16
Boro(H)	0	6.9	0	15000	0	0
Wheat	0	2	0	15000	0	0
Potato	80	15	1200	15000	18000000	685.7143
S. Potato	15	15	225	10000	2250000	85.71429
Musterd	50	1	50	50000	2500000	95.2381
G. Nut	80	15	1200	40000	48000000	1828.571
Maize	0	3	0	16000	0	0
Win Veg	250	17	4250	12000	51000000	1942.857
Chilli	0	1	0	40000	0	0
Onion	0	6	0	14000	0	0
Garlic	0	3	0	40000	0	0
Coriander	0	1.2	0	40000	0	0
Musur	0	0.8	0	80000	0	0
Chola	0	1.75	0	30000	0	0
Muskalai	0	1	0	40000	0	0
Mung	0	0.85	0	80000	0	0
Motor	30	1	30	25000	750000	28.57143
Arhar	5	1	5	22000	110000	4.190476
Felon	50	1.2	60	40000	2400000	91.42857
Sugercane	0	40	0	8000	0	0
Til	200	1.2	240	30000	7200000	274.2857
Sum Veg	200	15	3000	12000	36000000	1371.429
Ginger	350	12	4200	40000	168000000	6400
Termaric	280	1.4	392	50000	19600000	746.6667
Tobacco	81	1.562	126.522	130000	16447860	626.5851
Total	3723					15708.638

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	4	1	1.9	120000	228000	8.68571429
Fish farm	1	0.89	0.5	100000	50000	1.9047619
Galda	3	0	0	450000	0	0

Fish+Rice	4	0	0	95000	0	0
Creek	90	0	0	90000	0	0
Chara	55	0	0	110000	0	0
Canal	1	21	2	95000	190000	7.23809524
River	1	100	5	160000	800000	30.4761905
Total		122.89	9.4			48.3047619

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		561	150000	8.4E+07	3205.71
	Milk		865	30000	2.6E+07	988.571
	Egg ('000 No.)		952	5000	4760000	181.333
Total					1.1E+08	4375.62

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango		65	20	30000	600000	22.8571
Jackfruit		450	23	8000	184000	7.00952
Lichi		0	0	20000	0	0
Banana		245	25	10000	250000	9.52381
Papaya		25	15	6000	90000	3.42857
Coconut		0	0	15000	0	0
Nut		0	0	25000	0	0
Pineapple		850	15	8000	120000	4.57143
Watermelon		0	0	12000	0	0
Orange		100	18	35000	630000	24
Lemon		325	1.5	10000	15000	0.57143
Guava		0	0	12000	0	0
Amra		0	0	10000	0	0
Kamranga		0	0	5000	0	0
Bar		0	0	12000	0	0
Jam		0	0	7000	0	0
Amlaki		22	8	11000	88000	3.30827
Olive		0	0	6000	0	0
Bell		150	14	8000	112000	4.21053

Jambura		15	20	5000	100000	3.7594
Others		29	409	6000	2454000	92.2556

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	280000	550	154000000	5866.6667
Firewood (mt)	210000	500	105000000	4000
Total			259000000	9866.6667

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
30174.72374	15909.1966	32120	1.8967	89.67

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Ruma **District:** Bandarban

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Population	Footprint component (gha/cap)
Rice	2124	6463	0	8587	3.75	2.8	32120	0.1996148
Wheat	0	161	0	161	2.62	2.8	32120	0.0053568
Potato	1425	0	822	603	16.47	2.8	32120	0.0031916
Pulses	95	19	0	114	0.837	2.8	32120	0.011873
Vegetables	7250	0	5135	2115	18	2.8	32120	0.0102428
Oils	1250	0	1020	230	2.24	2.8	32120	0.0089508
Spices	5642	0	5522	120	14.17	2.8	32120	0.0007382
Tea	0	7	0	7	0.56	2.8	32120	0.0010897
Sugar	0	128	0	128	6.82	2.8	32120	0.0016361
Sub-total								0.2426939
		Animal						
Meat	561	0	56	505	0.457	1.1	32120	0.0378436
Egg	56	45	0	101	0.304	1.1	32120	0.011378
Milk	865	0	801	64	0.52	1.1	32120	0.004215
Sub-total								0.0534365
		Fishery						
Fish	10	354	0	364	0.05	0.2	32120	0.04533

Sub-total								0.04533
		Forest						
Fruit	568	90	136	482	18	1.1	32120	0.000917
Sub-total								0.000917

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
2050	0.99	2.8	32120	0.17691781

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	50317	15.4	774881.8	59	1.1	32120	0.4497805
Twigs	7952	15.4	122460.8	59	1.1	32120	0.0710824
Diesel (litre)	275400	0.038	10465.2	71	1.1	32120	0.0050478
Petrol (litre)	32850	0.034	1116.9	71	1.1	32120	0.0005387
Kerosine (litre)	149952	0.037	5548.224	71	1.1	32120	0.0026762
Electricity (kwh)	800000	0.0036	2880	1000	1.1	32120	9.863E-05
Coal (ton)	2700	27	72900	55	1.1	32120	0.0453923
Wood (tobacco)	2591	15.4	39901.4	55	1.1	32120	0.0248452
Total	1321762						0.599461758

FOOTPRINT SUMMERY							
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	3723	0.264	2.8	32120	0.08568	0.2426939	
Animal	14	150.84	1.1	32120	0.07232	0.0534365	-0.917339
Build-up	2050	0.264	2.8	32120	0.04718	0.1769178	
Fishery	123	1.53	0.2	32120	0.00117	0.04533	
Forest	47680	0.0138	1.1	32120	0.02253	0.000917	
Energy						0.5994618	
Total					0.22888	1.118757	
	Available BC (-12% for Biodiversity)				0.20142		

FOOD SECURITY CALCULATION

Name of Upazila: Rangamati sadar **District:** Rangamati

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	100	3.6	360	12500	4500000	171.4286
Aus(L)	250	1.86	465	12500	5812500	221.4286
Aman(U)	700	4.17	2919	13750	40136250	1529
Aman(L)	20	2.4	48	13750	660000	25.14286
Boro(U)	247	4.98	1230.06	15000	18450900	702.8914
Boro(H)	72	6.9	496.8	15000	7452000	283.8857
Wheat	0	2	0	15000	0	0
Potato	30	9	270	15000	4050000	154.2857
S. Potato	50	12	600	10000	6000000	228.5714
Musterd	60	0.95	57	50000	2850000	108.5714
G. Nut	2	1.2	2.4	40000	96000	3.657143
Maize	57	3	171	16000	2736000	104.2286
Win Veg	157	9.172	1440.004	12000	17280048	658.2875
Chilli	46	1	46	40000	1840000	70.09524
Onion	6	6	36	14000	504000	19.2
Garlic	5	3	15	40000	600000	22.85714
Coriander	8	1.2	9.6	40000	384000	14.62857
Musur	8	0.8	6.4	80000	512000	19.50476
Chola	0	1.75	0	30000	0	0
Muskalai	0	1	0	40000	0	0
Mung	15	0.85	12.75	80000	1020000	38.85714
Motor	15	0.85	12.75	25000	318750	12.14286
Arhar	0	1.2	0	22000	0	0
Felon	0	1	0	40000	0	0
Sugercane	20	40	800	8000	6400000	243.8095
Til	30	0.8	24	30000	720000	27.42857
Sum Veg	100	10	1000	12000	12000000	457.1429
Ginger	300	12	3600	40000	144000000	5485.714
Termaric	200	1.4	280	50000	14000000	533.3333
Tobacco	0	0	0	0	0	0
Total	2498					11136.093

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	44	23.33	36.3	90000	3267000	124.457143
Fish farm	40	10.42	106	100000	10600000	403.809524
Galda	3	0	0	450000	0	0
Fish+Rice	4	0	0	95000	0	0
Creek	90	40	114	90000	10260000	390.857143
Chara	55	0	0	110000	0	0
Canal	7	0	0	95000	0	0
River	1	0	0	160000	0	0
Total		73.75	256.3			919.12381

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		1951	150000	2.9E+08	11148.6
	Milk		2802	30000	8.4E+07	3202.29
	Egg ('000 No.)		4129	5000	2.1E+07	786.476
Total					4E+08	15137.3

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango	16400	230	500	30000	15000000	571.429
Jackfruit	35000	500	1050	8000	8400000	320
Lichi	4000	50	300	20000	6000000	228.571
Banana	25000	250	750	10000	7500000	285.714
Papaya	60000	45	2100	6000	12600000	480
Coconut	5000	75	150	15000	2250000	85.7143
Nut	10000	50	100	25000	2500000	95.2381
Pineapple	2E+07	600	9000	8000	72000000	2742.86
Watermelon		5	200	12000	2400000	91.4286
Orange	600	5	45	35000	1575000	60
Lemon	8000	50	160	10000	1600000	60.9524
Guava	16700	75	430	12000	5160000	196.571
Amra	700	4	70	10000	700000	26.3158

Kamranga	250	2	18	5000	90000	3.38346
Bar	8000	50	350	12000	4200000	157.895
Jam	500	15	25	7000	175000	6.57895
Amlaki	510	3	50	11000	550000	20.6767
Olive	500	10	25	6000	150000	5.6391
Bell	200	1	20	8000	160000	6.01504
Jamrul	400	12	12	5000	60000	2.25564
Others		29	409	6000	2454000	92.2556
		2061	15764			5539.491

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	263000	600	157800000	6011.4286
Firewood (mt)	147466	750	110599500	4213.3143
Total			268399500	10224.743

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
42956.78449	56840.21119	114758	0.7557	-24.43

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Rangamati sadar **District:** Rangamati

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Population	Footprint component (gha/cap)
Rice	3680	19678	0	23358	3.75	2.8	114758	0.1519776
Wheat	0	1377	0	1377	2.62	2.8	114758	0.0128235
Potato	870	1876	0	2746	16.47	2.8	114758	0.004068
Pulses	32	355	0	387	0.837	2.8	114758	0.0112813
Vegetables	2440	4177	0	6617	18	2.8	114758	0.0089694
Oils	60	851	0	911	2.24	2.8	114758	0.0099231
Spices	3986	0	3409	577	14.17	2.8	114758	0.0009935
Tea	0	23	0	23	0.56	2.8	114758	0.0010021
Sugar	86	379	0	459	6.82	2.8	114758	0.0016421
Sub-total								0.2026806
		Animal						

Meat	1951	0	606	1345	0.457	1.1	114758	0.0282108
Egg	24	319	0	343	0.304	1.1	114758	0.0108151
Milk	2802	0	2510	292	0.52	1.1	114758	0.0053826
Sub-total								0.0444085
		Fishery						
Fish	257	1590	0	1846	0.05	0.2	114758	0.0643441
Sub-total								0.0643441
		Forest						
Fruit	15760	185	14228	1721	18	1.1	114758	0.0009165
Sub-total								0.0009165

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
2347	0.99	2.8	114758	0.0566922

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	117120	15.4	1803648	59	1.1	114758	0.2930282
Twigs	12210	15.4	188034	59	1.1	114758	0.0305488
Diesel (litre)	2800000	0.038	106400	71	1.1	114758	0.0143646
Petrol (litre)	1113250	0.034	37850.5	71	1.1	114758	0.00511
Kerosine (litre)	255500	0.037	9453.5	71	1.1	114758	0.0012763
Electricity (kwh)	30000000	0.0036	108000	1000	1.1	114758	0.0010352
Coal (ton)	2500	27	67500	55	1.1	114758	0.0117639
Wood (tobacco)	0	12.23	0	59	1.1	114758	0
Total							0.357127031

FOOTPRINT SUMMERY

Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	7210	0.67	2.8	114758	0.11787	0.2026806	
Animal	48.77	150.84	1.1	114758	0.07051	0.0444085	-0.443535318
Build-up	2346	0.67	2.8	114758	0.03835	0.0566922	
Fishery	73.75	69.5	0.2	114758	0.00893	0.0643441	
Forest	21040	0.424	1.1	114758	0.08551	0.0009165	

Energy						0.357127	
Total					0.32117	0.7261689	
	Available BC (-12% for Biodiversity)				0.28263		

FOOD SECURITY CALCULATION

Name of Upazila: Barkal **District:** Rangamati

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	200	3.3	660	12500	8250000	314.2857
Aus(L)	365	1.92	700.8	12500	8760000	333.7143
Aman(U)	355	3.67	1302.85	13750	17914188	682.4452
Aman(L)	30	2.4	72	13750	990000	37.71429
Boro(U)	275	5.52	1518	15000	22770000	867.4286
Boro(H)	35	7.75	271.25	15000	4068750	155
Wheat	0	2	0	15000	0	0
Potato	20	12	240	15000	3600000	137.1429
S. Potato	25	6.24	156	10000	1560000	59.42857
Musterd	18	1.1	19.8	50000	990000	37.71429
G. Nut	2	3.6	7.2	40000	288000	10.97143
Maize	42	2.25	94.5	16000	1512000	57.6
Win Veg	325	12.51	4065.75	12000	48789000	1858.629
Chilli	15	3.53	52.95	40000	2118000	80.68571
Onion	5	6	30	14000	420000	16
Garlic	2	5	10	40000	400000	15.2381
Coriander	3	2	6	40000	240000	9.142857
Musur	3	0.95	2.85	80000	228000	8.685714
Chola	4	1.5	6	30000	180000	6.857143
Muskalai	0	1	0	40000	0	0
Mung	3	1.67	5.01	80000	400800	15.26857
Motor	10	1.1	11	25000	275000	10.47619
Arhar	0	1.2	0	22000	0	0
Felon	12	1	12	40000	480000	18.28571
Sugercane	18	45	810	8000	6480000	246.8571
Til	55	1	55	30000	1650000	62.85714
Sum Veg	118	15.79	1863.22	12000	22358640	851.7577
Ginger	210	12	2520	40000	100800000	3840
Termaric	250	1.4	350	50000	17500000	666.6667
Tobacco	350	2.1	735	130000	95550000	3640
Total	2750					14040.852

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	0	23.33		90000	0	0
Fish farm	40	10.42		100000	0	0
Galda	3	1		450000	0	0
Fish+Rice	4	0.5		95000	0	0
Creek	90	40		90000	0	0
Chara	55	38		110000	0	0
Canal	7	75		95000	0	0
River	1	300	120	160000	19200000	731.428571
Total		488.25	120			731.428571

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		628	150000	9.4E+07	3588.57
	Milk		837	30000	2.5E+07	956.571
	Egg ('000 No.)		2999	5000	1.5E+07	571.238
Total					1.3E+08	5116.38

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango		9	95	30000	2850000	108.571
Jackfruit		37	277	8000	2216000	84.419
Lichi		4	7	20000	140000	5.33333
Banana		1526	7630	10000	76300000	2906.67
Papaya		45	410	6000	2460000	93.7143
Coconut		7	47	15000	705000	26.8571
Nut		5	7	25000	175000	6.66667
Pineapple		4.5	6.8	8000	54400	2.07238
Watermelon		0	0	12000	0	0
Orange		1.1	5.2	35000	182000	6.93333
Lemon		4	6.5	10000	65000	2.47619
Guava		10	13	12000	156000	5.94286
Amra		0	0	10000	0	0
Kamranga		0	0	5000	0	0

Bar		0	0	12000	0	0
Jam		0	0	7000	0	0
Amlaki		8.5	19	11000	209000	7.85714
Olive		0	0	6000	0	0
Bell		0	0	8000	0	0
Jamrul		0	0	5000	0	0
Others		35	450	6000	2700000	101.504
		1696.1	8973.5			3359.014

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	16800	500	8400000	320
Firewood (mt)	68675	600	41205000	1569.7143
Total			49605000	1889.7143

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
25137.39052	23597.81612	47643	1.0652	6.52

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Barkal **District :** Rangamati

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Population	Footprint component (gha/cap)
Rice	3017	8574	0	11591	3.75	2.8	47643	0.1816555
Wheat	0	238	0	238	2.62	2.8	47643	0.0053387
Potato	396	583	0	979	16.47	2.8	47643	0.0034934
Pulses	37	84	0	121	0.837	2.8	47643	0.0084961
Vegetables	5929	0	2942	2987	18	2.8	47643	0.0097526
Oils	27	455	0	482	2.24	2.8	47643	0.0126461
Spices	2969	0	2775	194	14.17	2.8	47643	0.0008046
Tea	0	10	0	10	0.56	2.8	47643	0.0010495
Sugar	81	110	0	191	6.82	2.8	47643	0.0016459
Sub-total								0.2248825
		Animal						
Meat	628	0	24	652	0.457	1.1	47643	0.0329401
Egg	176	0	128	48	0.304	1.1	47643	0.0036455

Milk	837	0	715	122	0.52	1.1	47643	0.0054169
Sub-total								0.0420025
		Fishery						
Fish	120	925	0	1045	0.05	0.2	47643	0.0877359
Sub-total								0.0877359
		Forest						
Fruit	8973	175	8434	714	18	1.1	47643	0.0009158
Sub-total								0.0009158

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
425	0.99	2.8	47643	0.02472766

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	39337	15.4	605789.8	59	1.1	47643	0.2370629
Twigs	4175	15.4	64295	59	1.1	47643	0.0251605
Diesel (litre)	37160	0.038	1412.08	71	1.1	47643	0.0004592
Petrol (litre)	0	0.034	0	71	1.1	47643	0
Kerosine (litre)	157212	0.037	5816.844	71	1.1	47643	0.0018916
Electricity (kwh)	302950	0.0036	1090.62	1000	1.1	47643	2.518E-05
Coal (ton)	0	27	0	55	1.1	47643	0
Wood (tobacco)	9600	12.23	117408	59	1.1	47643	0.0459451
Total							0.310544387

FOOTPRINT SUMMERY							
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	2750	0.61	2.8	47643	0.09859	0.2248825	
Animal	15.7	150.84	1.1	47643	0.05468	0.0420025	-0.1479282
Build-up	424	0.61	2.8	47643	0.0152	0.0247277	
Fishery	488	4.92	0.2	47643	0.01008	0.0877359	
Forest	64800	0.293	1.1	47643	0.43837	0.0009158	
Energy						0.3105444	
Total					0.61691	0.6908087	
127080	Available BC (-12% for Biodiversity)				0.54288		

FOOD SECURITY CALCULATION

Name of Upazila: Kaptai **District :** Rangamati

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	12	3.6	43.2	12500	540000	20.57143
Aus(L)	340	1.69	574.6	12500	7182500	273.619
Aman(U)	1130	4.31	4870.3	13750	66966625	2551.11
Aman(L)	20	2.55	51	13750	701250	26.71429
Boro(U)	1831	3.98	7287.38	15000	109310700	4164.217
Boro(H)	15	6.6	99	15000	1485000	56.57143
Wheat	0	0	0	15000	0	0
Potato	31	10.48	324.88	15000	4873200	185.6457
S. Potato	0	0	0	10000	0	0
Musterd	8	1.2	9.6	50000	480000	18.28571
G. Nut	1	2	2	40000	80000	3.047619
Maize	14.5	3.64	52.78	16000	844480	32.17067
Win Veg	135	22	2970	12000	35640000	1357.714
Chilli	38	1.5	57	40000	2280000	86.85714
Onion	2.5	6	15	14000	210000	8
Garlic	1.5	3	4.5	40000	180000	6.857143
Coriander	0	1.2	0	40000	0	0
Musur	1	0.8	0.8	80000	64000	2.438095
Chola	0	1.75	0	30000	0	0
Muskalai	0	1	0	40000	0	0
Mung	0	0.85	0	80000	0	0
Motor	0	0.85	0	25000	0	0
Arhar	0	1.2	0	22000	0	0
Felon	11	2.5	27.5	40000	1100000	41.90476
Sugercane	10	50	500	8000	4000000	152.381
Til	27	0.8	21.6	30000	648000	24.68571
Sum Veg	169	16	2704	12000	32448000	1236.114
Ginger	350	12	4200	40000	168000000	6400
Termaric	300	1.5	450	50000	22500000	857.1429
Tobacco	40	1.56	62.4	130000	8112000	309.0286
Total	4487.5					17815.076

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	215	15	26.34	90000	2370600	90.3085714
Fish farm	40	0	0	100000	0	0
Galda	3	0	0	450000	0	0
Fish+Rice	4	0	0	95000	0	0
Creek	90	6	19	90000	1710000	65.1428571
Chara	55	0	0	110000	0	0
Lake	1	2243	683.4	95000	64923000	2473.25714
River	1	120	5.3	160000	848000	32.3047619
Total		2384	734.04			2661.01333

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		846	150000	1.3E+08	4834.29
	Milk		910	30000	2.7E+07	1040
	Egg('000 No.)		1622	5000	8110000	308.952
Total					1.6E+08	6183.24

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango		268	540	30000	16200000	617.143
Jackfruit		488	1075	8000	8600000	327.619
Lichi		146	2106	20000	42120000	1604.57
Banana		530	1900	10000	19000000	723.81
Papaya		102	900	6000	5400000	205.714
Coconut		42	370	15000	5550000	211.429
Nut		31	744	25000	18600000	708.571
Pineapple		10.5	350	8000	2800000	106.667
Watermelon		0	0	12000	0	0
Orange		0	0	35000	0	0
Lemon		122	350	10000	3500000	133.333
Guava		165	1935	12000	23220000	884.571
Amra		10	440	10000	4400000	165.414
Kamranga		0	0	5000	0	0

Bar		69	600	12000	7200000	270.677
Jam		36	660	7000	4620000	173.684
Jambura		20	460	5000	2300000	86.4662
Others		242	1694	6000	10164000	382.105
		2281.5	14124			6601.774

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	215000	550	118250000	4504.7619
Firewood (mt)	135000	600	81000000	3085.7143
Total			199250000	7590.4762

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
40851.57844	37577.30444	75867	1.0871	8.71

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Kapatai **District :** Rangamati

Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Population	Footprint component (gha/cap)
Rice	8617	5817	0	14434	3.75	2.8	75867	0.1420563
Wheat	0	379	0	379	2.62	2.8	75867	0.0053388
Potato	325	592	0	917	16.47	2.8	75867	0.0020549
Pulses	1	200	0	201	0.837	2.8	75867	0.0088629
Vegetables	5674	0	1852	3822	18	2.8	75867	0.0078365
Oils	12	455	0	467	2.24	2.8	75867	0.0076944
Spices	4726	0	4277	449	14.17	2.8	75867	0.0011694
Tea	0	15	0	15	0.56	2.8	75867	0.0009886
Sugar	50	253	0	303	6.82	2.8	75867	0.0016397
Sub-total								0.1776415
		Animal						
Meat	846	0	164	682	0.457	1.1	75867	0.0216375
Egg	95	41	0	136	0.304	1.1	75867	0.0064864

Milk	910	0	588	322	0.52	1.1	75867	0.0089783
Sub-total								0.0371022
		Fishery						
Fish	2509	600	1604	929	0.05	0.2	75867	0.0489805
Sub-total								0.0489805
		Forest						
Fruit	14369	150	13381	1138	18	1.1	75867	0.0009167
Sub-total								0.0009167

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
833	0.99	2.8	75867	0.03043584

F. Energy							
Name	Amount consumed (ton)	Conversi on factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr	Equivale nce factor (gha/ha)	Populat ion	Footprint component (gha/capita)
Fire wood	21636	15.4	333194.4	59	1.1	75867	0.0818814
Twigs	4057	15.4	62477.8	59	1.1	75867	0.0153537
Diesel (litre)	2220000	0.038	84360	71	1.1	75867	0.0172273
Petrol (litre)	129600	0.034	4406.4	71	1.1	75867	0.0008998
Kerosine (litre)	1402555	0.037	51894.54	71	1.1	75867	0.0105975
Electricity (kwh)	6600000	0.0036	23760	1000	1.1	75867	0.0003445
Coal (ton)	0	27	0	55	1.1	75867	0
Wood (tobacco)	1408	12.23	17219.84	59	1.1	75867	0.0042317
Total	10379256						0.130536032

FOOTPRINT SUMMERY							
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	4488	0.656	2.8	75867	0.10866	0.1776415	
Animal	21.15	150.84	1.1	75867	0.04626	0.0371022	-0.1573352
Build-up	833	0.656	2.8	75867	0.02017	0.0304358	
Fishery	2384	6.15	0.2	75867	0.03865	0.0489805	
Forest	18324	0.343	1.1	75867	0.09113	0.0009167	
Energy						0.130536	
Total					0.30486	0.4256127	
	Available BC (-12% for Biodiversity)				0.26828		

FOOD SECURITY CALCULATION

Name of Upazila: Khagrachari sadar **District:** Khagrachari

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	380	3.675	1396.5	12500	17456250	665
Aus(L)	280	1.875	525	12500	6562500	250
Aman(U)	3300	4.605	15196.5	13750	208951875	7960.071
Aman(L)	250	3.264	816	13750	11220000	427.4286
Boro(U)	1247	5.74	7157.78	15000	107366700	4090.16
Boro(H)	270	7.24	1954.8	15000	29322000	1117.029
Maize	300	3.75	1125	15000	16875000	642.8571
Potato	100	13.9	1390	15000	20850000	794.2857
S. Potato	150	10.87	1630.5	8000	13044000	496.9143
Musur	7	1	7	80000	560000	21.33333
Khesari	1	1	1	70000	70000	2.666667
Mung	8	1	8	80000	640000	24.38095
Motor	15	1.5	22.5	25000	562500	21.42857
Musterd	140	1.02	142.8	40000	5712000	217.6
Til	45	1	45	30000	1350000	51.42857
G. Nut	4	1.55	6.2	40000	248000	9.447619
Onion	10	8	80	14000	1120000	42.66667
Garlic	8	4	32	40000	1280000	48.7619
Ginger	290	12.24	3549.6	40000	141984000	5408.914
Termaric	900	1.33	1197	50000	59850000	2280
Chilli	101	1	101	40000	4040000	153.9048
Dania	25	1	25	40000	1000000	38.09524
Sugercane	150	46	6900	8000	55200000	2102.857
Win Veg	850	17	14450	10000	144500000	5504.762
Sum Veg	500	12	6000	12000	72000000	2742.857
Tobacco	40	1.8	72	130000	9360000	356.5714

B. Fish						
Category	No.	Area (ac)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	404	146.2	87.72	110000	9649200	367.588571
Fish farm	20	30	3	130000	390000	14.8571429
Galda	0	0	0	0	0	0
Fish+Rice	0	0	0	0	0	0

Creek	45	68.8	41.28	110000	4540800	172.982857
Chara	7	70	3.5	110000	385000	14.6666667
Canal	0	0	0	0	0	0
River	1	130	32	140000	4480000	170.666667
Total		445	167.5			740.761905

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		851	150000	1.3E+08	4862.86
	Milk		1061	30000	3.2E+07	1212.57
	Egg ('000 No.)		4139	5000	2.1E+07	788.381
Total					1.8E+08	6863.81

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Jackfruit		482	4820	10000	48200000	1836.19
Mango		210	3200	30000	96000000	3657.14
Banana		340	4420	10000	44200000	1683.81
Lichi		170	425	20000	8500000	323.81
Guava		100	450	12000	5400000	205.714
Pineapple		75	750	8000	6000000	228.571
Orange		10	55	35000	1925000	73.3333
Amra		7	56	10000	560000	21.3333
Kamranga		5	25	5000	125000	4.7619
Papaya		55	385	6000	2310000	88
Bar		15	52.5	12000	630000	24
Jam		1	2	7000	14000	0.53333
Amlaki		5	10	11000	110000	4.13534
Olive		5	15	6000	90000	3.38346
Watermelon		50	1250	10000	12500000	469.925
Bell		6	90	8000	720000	27.0677
Chalta		2	26	5000	130000	4.88722
Lemon		50	125	10000	1250000	46.9925
Coconut		60	150	15000	2250000	84.5865
Jambura		10	4	6000	24000	0.90226
Others		292	2920	6000	17520000	658.647
		1950	19230.5			

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	192000	600	115200000	4388.5714
Firewood (mt)	125733	750	94299750	3592.3714
Total			209499750	7980.9429

Food Security Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
60504.66251	57603.4762	116299	1.0504	5.04

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Khagrachari sadar **District:** Khagrachari

ECOLOGICAL FOOTPRINT CALCULATION								
Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consu mption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Populati on	Footprint component (gha/cap)
Rice	18031	5210	0	23241	3.75	2.8	116299	0.1492126
Wheat	0	1396	0	1396	2.62	2.8	116299	0.0128282
Potato	3021	0	1002	2019	16.47	2.8	116299	0.0029514
Pulses	39	459	0	498	0.837	2.8	116299	0.0143247
Vegetables	20450	0	14057	6393	18	2.8	116299	0.0085509
Oils	149	537	0	686	2.24	2.8	116299	0.0073732
Spices	4985	0	4105	880	14.17	2.8	116299	0.0014952
Tea	0	23	0	23	0.56	2.8	116299	0.0009888
Sugar	690	0	225	465	6.82	2.8	116299	0.0016415
Sub-total								0.1993667
		Animal						
Meat	851	234	0	1085	0.457	1.1	116299	0.0224559
Egg	243	0	75	168	0.304	1.1	116299	0.005227
Milk	1061	0	12	1049	0.52	1.1	116299	0.0190805
Sub-total								0.0467633
		Fishery						
Fish	445	843	0	1288	0.05	0.2	116299	0.0442996
Sub-total								0.0442996
		Forest						
Fruit	19230	210	17696	1744	18	1.1	116299	0.0009164
Sub-total								0.0009164

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
2522	0.99	2.8	116299	0.06011216

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	96773	15.4	1490304	59	1.1	116299	0.2389129
Twigs	9023	15.4	138954.2	59	1.1	116299	0.022276
Diesel (litre)	1671726	0.038	63525.59	71	1.1	116299	0.0084627
Petrol (litre)	109774	0.034	3732.316	71	1.1	116299	0.0004972
Kerosine (litre)	355200	0.037	13142.4	71	1.1	116299	0.0017508
Electricity (kwh)	13600000	0.0036	48960	1000	1.1	116299	0.0004631
Coal (ton)	6400	27	172800	55	1.1	116299	0.0297165
Wood (tobacco)	1408	12.23	17219.84	55	1.1	116299	0.0029613
Total							0.305040416

FOOTPRINT SUMMERY							
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	9371	0.8	2.8	116299	0.18049	0.1993667	
Animal	21.27	150.84	1.1	116299	0.03035	0.0467633	-0.3460247
Build-up	2522	0.8	2.8	116299	0.04858	0.0601122	
Fishery	445	7.52	0.2	116299	0.00575	0.0442996	
Forest	16940	0.547	1.1	116299	0.08764	0.0009164	
Energy						0.3050404	
Total					0.35281	0.6564986	
	Available BC (-12% for Biodiversity)				0.31047		

FOOD SECURITY CALCULATION

Name of Upazila: Mahalchari **District:** Khagrachari

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus(U)	355	3.74	1327.7	12500	16596250	632.2381
Aus(L)	150	2.1	315	12500	3937500	150
Aman(U)	2900	4.49	13021	13750	179038750	6820.524
Aman(L)	150	3.28	492	13750	6765000	257.7143
Boro(U)	600	4.87	2922	15000	43830000	1669.714
Boro(H)	800	8.16	6528	15000	97920000	3730.286
Wheat	3	2.67	8.01	15000	120150	4.577143
Potato	35	13.48	471.8	15000	7077000	269.6
S. Potato	150	15	2250	10000	22500000	857.1429
Musterd	100	0.9	90	50000	4500000	171.4286
G. Nut	5	1.8	9	40000	360000	13.71429
Maize	170	5.75	977.5	16000	15640000	595.8095
Win Veg	970	16	15520	12000	186240000	7094.857
Chilli	154	1.5	231	40000	9240000	352
Onion	10	6.46	64.6	14000	904400	34.45333
Garlic	8	6	48	40000	1920000	73.14286
Coriander	10	1.5	15	40000	600000	22.85714
Musur	8	1	8	80000	640000	24.38095
Khesari	1	1	1	30000	30000	1.142857
Muskalai	2	1	2	40000	80000	3.047619
Mung	8	0.875	7	80000	560000	21.33333
Motor	8	1	8	25000	200000	7.619048
Arhar	20	1	20	22000	440000	16.7619
Felon	0	1	0	40000	0	0
Sugercane	0	40	0	8000	0	0
Til	0	0.8	0	30000	0	0
Sum Veg	256	12	3072	12000	36864000	1404.343
Ginger	300	12.5	3750	40000	150000000	5714.286
Termaric	250	3	750	50000	37500000	1428.571
Tobacco	31	1.7	52.7	130000	6851000	260.9905
Total	7454					31632.535

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	50	10	32.5	90000	2925000	111.428571
Fish farm	40	10.42	0	100000	0	0
Galda	3	0	0	450000	0	0
Fish+Rice	4	0	0	95000	0	0
Creek	366	6	4.2	120	504	0.0192
Chara	55	0	0	110000	0	0
Canal	7	0	0	95000	0	0
River	1	100	37	160000	5920000	225.52381
Total		126.42	73.7			336.971581

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		256	150000	3.8E+07	1462.86
	Milk		353	30000	1.1E+07	403.429
	Egg ('000 No.)		1040	5000	5200000	198.095
Total					5.4E+07	2064.38

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango		109	950	30000	28500000	1085.71
Jackfruit		340	2545	8000	20360000	775.619
Lichi		45	247	20000	4940000	188.19
Banana		800	2945	10000	29450000	1121.9
Papaya		70	2210	6000	13260000	505.143
Coconut		20	120	15000	1800000	68.5714
Nut		19	65	25000	1625000	61.9048
Pineapple		174	1825	8000	14600000	556.19
Watermelon		0	0	12000	0	0
Orange		0	0	35000	0	0
Lemon		26	95	10000	950000	36.1905
Guava		75	430	12000	5160000	196.571
Amra		10	175	10000	1750000	65.7895
Kamranga		0	45	5000	225000	8.45865

Bar		30	210	12000	2520000	94.7368
Jam		25	42	7000	294000	11.0526
Amlaki		0	0	11000	0	0
Olive		0	0	6000	0	0
Bell		0	0	8000	0	0
Jambura		30	150	5000	750000	28.1955
Others		60	480	6000	2880000	108.271
		1833	12534			4912.504

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	66000	550	36300000	1382.8571
Firewood (mt)	42700	600	25620000	976
Total			61920000	2358.8571

Food Security Status Calculation				
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
41305.24867	27320.5285	55159	1.5119	51.19

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Mahalchari **District:** Khagrachari

ECOLOGICAL FOOTPRINT CALCULATION								
Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consu mption (ton)	Global yield (t/ha)	Equiva factor (gha/ha)	Popul ation	Footprint component (gha/cap)
Rice	16404	0	3552	12852	3.75	2.8	55159	0.1739727
Wheat	8	268	0	276	2.62	2.8	55159	0.0053475
Potato	2722	0	1227	1495	16.47	2.8	55159	0.0046078
Pulses	46	139	0	185	0.837	2.8	55159	0.0112199
Vegetables	18592	0	14793	3799	18	2.8	55159	0.0107137
Oils	99	484	0	583	2.24	2.8	55159	0.0132118
Spices	4859	0	4570	289	14.17	2.8	55159	0.0010353
Tea	0	11	0	11	0.56	2.8	55159	0.0009971
Sugar	0	220	0	220	6.82	2.8	55159	0.0016375
Sub-total								0.2227432
		Animal						

Meat	256	460	0	716	0.457	1.1	55159	0.0312445
Egg	61	138	0	199	0.304	1.1	55159	0.0130544
Milk	353	0	90	263	0.52	1.1	55159	0.0100862
Sub-total								0.0543851
		Fishery						
Fish	74	1113	0	1187	0.05	0.2	55159	0.0860784
Sub-total								0.0860784
		Forest						
Fruit	12534	190	12344	827	18	1.1	55159	0.0009162
Sub-total								0.0009162

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
799	0.99	2.8	55159	0.04015352

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	4233	15.4	65188.2	59	1.1	55159	0.022034
Twigs	8162	15.4	125694.8	59	1.1	55159	0.0424856
Diesel (litre)	720000	0.038	27360	71	1.1	55159	0.0076848
Petrol (litre)	33600	0.034	1142.4	71	1.1	55159	0.0003209
Kerosine (litre)	132000	0.037	4884	71	1.1	55159	0.0013718
Electricity (kwh)	2523048	0.0036	9082.973	1000	1.1	55159	0.0001811
Coal (ton)	1400	27	37800	55	1.1	55159	0.0137058
Wood (tobacco)	1091	12.23	13342.93	32	1.1	55159	0.0083153
Total							0.096099352

		FOOTPRINT SUMMERY					
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	7454	0.844	2.8	55159	0.31935	0.2227432	
Animal	6.5	150.84	1.1	55159	0.01955	0.0543851	-0.143389
Build-up	798	0.844	2.8	55159	0.03419	0.0401535	
Fishery	126	11.66	0.2	55159	0.00533	0.0860784	
Forest	3595	0.38	1.1	55159	0.02724	0.0009162	

Energy						0.0960994	
Total					0.40567	0.5003758	
	Available BC (-12% for Biodiversity)				0.35699		

FOOD SECURITY CALCULATION

Name of Upazila: Dighinala **District:** Khagrachari

A. Crop						
Crop	Area (ha)	Yield (t/ha)	Production (ton)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Aus	680	2.14	1455.2	12500	18190000	692.9524
Aman	4760	2.36	11233.6	13750	154462000	5884.267
Boro(U)	1914	4.02	7694.28	15000	115414200	4396.731
Wheat	3	2.4	7.2	15000	108000	4.114286
Potato	100	16.5	1650	15000	24750000	942.8571
S. Potato	200	15	3000	10000	30000000	1142.857
Musterd	90	1	90	50000	4500000	171.4286
G. Nut	3	1.8	5.4	40000	216000	8.228571
Maize	300	6.5	1950	16000	31200000	1188.571
Win Veg	700	16	11200	12000	134400000	5120
Chilli	150	1.5	225	40000	9000000	342.8571
Onion	8	6.5	52	14000	728000	27.73333
Garlic	7	6	42	40000	1680000	64
Coriander	15	1.2	18	40000	720000	27.42857
Musur	8	1	8	80000	640000	24.38095
Chola	0	1.75	0	30000	0	0
Muskalai	2	1	2	40000	80000	3.047619
Mung	8	1	8	80000	640000	24.38095
Motor	10	1	10	25000	250000	9.52381
Arhar	20	1	20	22000	440000	16.7619
Felon	0	1	0	40000	0	0
Sugercane	80	48	3840	8000	30720000	1170.286
Til	23	0.86	19.78	30000	593400	22.60571
Sum Veg	609	16.69	10164.21	12000	121970520	4646.496
Ginger	300	12.5	3750	40000	150000000	5714.286
Termaric	500	3	1500	50000	75000000	2857.143
Tobacco	1800	1.9	3420	130000	444600000	16937.14
Total	4936					51440.081

B. Fish						
Category	No.	Area (ha)	Production (ton)	Price (Tk./ ton)	Gross income (Tk.)	Equi rice (ton)
Pond	905	110	98	90000	8820000	336
Fish+Rice	52	19	12.7	95000	1206500	45.9619048
Creek	28	7	7.5	90000	675000	25.7142857

River	1	124	11	160000	1760000	67.047619
Others	5	4	3.5	1100000	3850000	146.666667
Total		264	132.7			621.390476

C. Animal						
	Category	Area (ha)	Production (ton/No.)	Price (Tk./ton/No.)	Gross income (Tk.)	Equi rice (ton)
	Meat		1191	150000	1.8E+08	6805.71
	Milk		1535	30000	4.6E+07	1754.29
	Egg('000 No.)		6369	5000	3.2E+07	1213.14
Total					2.6E+08	9773.14

D. Forestry						
i) Fruit Tree						
Name	No.	Area (ha)	Production (ton/No.)	Price (Tk./ton)	Gross income (Tk.)	Equi rice (ton)
Mango	18000	219	1350	30000	40500000	1542.86
Jackfruit	22000	278	6600	8000	52800000	2011.43
Lichi	6500	100	390	20000	7800000	297.143
Banana	760000	380	836	10000	8360000	318.476
Papaya	100000	80	800	6000	4800000	182.857
Coconut	10400	80	624	15000	9360000	356.571
Nut	500000	100	120	25000	3000000	114.286
Pineapple	3000000	120	2160	8000	17280000	658.286
Orange	32000	80	480	35000	16800000	640
Lemon	11000	110	550	10000	5500000	209.524
Guava	40000	100	110	12000	1320000	50.2857
Bar	8000	20	280	12000	3360000	126.316
Amlaki	12000	30	144	11000	1584000	59.5489
Bell	5000	40	160	8000	1280000	48.1203
Jamrul	400	12	12	5000	60000	2.25564
Others		428	6048	6000	36288000	1364.21
Total						7982.165

ii) Non-fruit Tree: Wood				
Category	Quantity	Price (Tk./cft/ton)	Gross income (Tk.)	Equi rice (ton)
Timber (cft)	230000	550	126500000	4819.0476
Firewood (mt)	240000	600	144000000	5485.7143
Total			270500000	10304.762

	Food Security Status Calculation			
Food Available Equivalent rice (ton)	Food Requirement Equivalent rice (ton)	Population	Food Security ratio	Food Security status (%)
80121.54141	58598.04864	118307	1.3673	36.73

ECOLOGICAL FOOTPRINT CALCULATION

Name of Upazila: Dighinala **District:** Khagrachari

		ECOLOGICAL FOOTPRINT CALCULATION						
Category	Production (ton)	Inside supply (ton)	Outside supply (ton)	Consumption (ton)	Global yield (t/ha)	Equiva factor (gha/ha	Population	Footprint component (gha/cap)
Rice	13588	12924	0	26512	3.75	2.8	118307	0.1673242
Wheat	7	585	0	592	2.62	2.8	118307	0.0053477
Potato	4650	0	692	3358	16.47	2.8	118307	0.0048254
Pulses	48	455	0	503	0.837	2.8	118307	0.014223
Vegetables	21364	0	10044	11320	18	2.8	118307	0.0148841
Oils	95	955	0	1050	2.24	2.8	118307	0.011094
Spices	5587	0	4715	872	14.17	2.8	118307	0.0014564
Tea	0	24	0	424	0.56	2.8	118307	0.0179195
Sugar	384	89	0	473	6.82	2.8	118307	0.0016414
Sub-total								0.2387158
		Animal						
Meat	1191	166	0	1357	0.457	1.1	118307	0.0276087
Egg	375	0	47	328	0.304	1.1	118307	0.0100319
Milk	1535	0	399	1136	0.52	1.1	118307	0.0203122
Sub-total								0.0579528
		Fishery						
Fish	133	1991	0	2124	0.05	0.2	118307	0.0718132
Sub-total								0.0718132
		Forest						
Fruit	20664	180	19069	1775	18	1.1	118307	0.0009169
Sub-total								0.0009169

E. Build-up Area:				
Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
5882	0.99	2.8	118307	0.13781859

F. Energy							
Name	Amount consumed (ton)	Conversion factor	Amount consumed (GJ/year)	Global average (GJ/ha/yr)	Equivalence factor (gha/ha)	Population	Footprint component (gha/capita)
Fire wood	92687	15.4	1427380	59	1.1	118307	0.2249416
Twigs	8995	15.4	138523	59	1.1	118307	0.0218299
Diesel (litre)	2400263	0.038	91209.99	71	1.1	118307	0.0119445
Petrol (litre)	157613	0.034	5358.842	71	1.1	118307	0.0007018
Kerosine (litre)	383168	0.037	14177.22	71	1.1	118307	0.0018566
Electricity (kwh)	3479940	0.0036	12527.78	1000	1.1	118307	0.0001165
Coal (ton)	0	27	0	55	1.1	118307	0
Wood (tobacco)	63360	12.23	774892.8	59	1.1	118307	0.1221158
Total	6586026						0.383506608

			FOOTPRINT SUMMERY				
Category	Existing Area (ha)	Yield factor (crop)	Equivalence factor (gha/ha)	Population	Bio-capacity (gha/cap)	Ecological Footprint (gha/capita)	Ecological Status (gha/capita)
Crop	4936	0.471	2.8	118307	0.05502	0.2387158	
Animal	29.77	150.84	1.1	118307	0.04175	0.0579528	-0.5910781
Build-up	5882	0.471	2.8	118307	0.06557	0.1378186	
Fishery	264	20.73	0.2	118307	0.00925	0.0718132	
Forest	34472	0.527	1.1	118307	0.16891	0.0009169	
Energy						0.3835066	
Total					0.34051	0.8907238	
	Available BC (-12% for Biodiversity)				0.29965		

Appendix- D.

Equations for food security and ecological footprint model

Biocapacity sector
biocapacity_for_animal = animal_area*equivalence_factor_for_animal*yield_factor_for_animal
biocapacity_for_buildup_area = buildup_area*equivalence_factor_for_crop*yield_factor_for_crop
biocapacity_for_fish = fish_area*yield_factor_for_fish*equivalence_factor_for_fish
biocapacity_for_forest=
    (forest_area+horticulture_area)*equivalence_factor_for_forest*yield_factor_for_forest
biocapacity_for_jhum = Jhum_area*equivalence_factor_for_crop*yield_factor_for_crop
biocapacity_for_non_jhum = crop_area*equivalence_factor_for_crop*yield_factor_for_crop
biocapacity_per_capita = (total_biocapacity-.12*total_biocapacity)/population
ecological_status = biocapacity_per_capita-ecological_foot_print_per_capita
total_biocapacity=
    biocapacity_for_animal+biocapacity_for_buildup_area+biocapacity_for_jhum+biocapacity_for_fish+biocapacity_for_forest+biocapacity_for_non_jhum
yield_factor_for_animal = 151
yield_factor_for_crop = .99
yield_factor_for_fish = .227
yield_factor_for_forest = .8
Ecological footprint sector
buildup_area(t) = buildup_area(t - dt) + (buildup_area_growth_rate) * dt
INIT buildup_area = 3331

INFLOWS:
buildup_area_growth_rate = buildup_area*build_up_growth_factor
animal_consumption = population*per_capita_animal_consumption
build_up_growth_factor = .06
ecological_footprint_for_animal=
    (animal_consumption/global_average_of_animal_consumption)*equivalence_factor_for_animal/population
ecological_footprint_for_build_up_area=
    buildup_area*yield_factor_for_crop*equivalence_factor_for_non_rice/population
ecological_footprint_for_energy=
    ((energy_consumption/global_average_of_energy_consumption)*equivalence_factor_for_energy)/population
ecological_footprint_for_fish=
    ((fish_consumption/global_yield_for_fish)*equivalence_factor_for_fish)/population
ecological_footprint_for_forest=
    (forest_consumption*equivalence_factor_for_forest)/global_average_of_forest_consumption/population
ecological_footprint_for_non_rice=
    (non_rice_consumption*equivalence_factor_for_non_rice)/global_average_of_non_rice_consumption/population
ecological_footprint_for_rice=
    ((rice_consumption/global_yield_for_crop)*equivalence_factor_for_crop)/population
ecological_foot_print_per_capita=
    ecological_footprint_for_animal+ecological_footprint_for_build_up_area+ecological_footprint_for_energy+ecological_footprint_for_fish+ecological_footprint_for_forest+ecological_footprint_for_non_rice+ecological_footprint_for_rice
energy_consumption=
    (population*energy_consumption_per_capita)+energy_consumption_for_tobaco_curing
energy_consumption_for_tobaco_curing = fuelwood_for_curing*heatihg_value_of_fuelwood
energy_consumption_per_capita = 7.0

equivalence_factor_for_animal = 1.1
equivalence_factor_for_crop = 2.8
equivalence_factor_for_energy = 1.10
equivalence_factor_for_fish = 0.20
equivalence_factor_for_forest = 1.1
equivalence_factor_for_non_rice = 2.8
fish_consumption = population*fish_consumption_per_capita
fish_consumption_per_capita = .09
forest_consumption = population*forest_consumption_per_capita
forest_consumption_per_capita = .09
global_average_of_animal_consumption = .452
global_average_of_energy_consumption = 49.92
global_average_of_forest_consumption = 18
global_average_of_non_rice_consumption = 8.63
global_yield_for_crop = 3.75
global_yield_for_fish = .05
heatihg_value_of_fuelwood = 15.4
non_rice_consumption = population*non_rice_consumption_per_capita
non_rice_consumption_per_capita = .3
per_capita_animal_consumption = .03
rice_consumption = population*rice_consumption_per_capita
rice_consumption_per_capita = .305

Food security sector
animal_area(t) = animal_area(t - dt) + (animal_growth_rate) * dt
INIT animal_area = 22.68

INFLOWS:
animal_growth_rate = animal_area*animal_growth_fraction
crop_area(t) = crop_area(t - dt) + (- Tobbaco_area_growth_rate) * dt
INIT crop_area = 5259

OUTFLOWS:
Tobbaco_area_growth_rate = crop_area*tobbaco_area_growth_fraction
depleted_forest_area(t) = depleted_forest_area(t - dt) + (forest_clear_rate) * dt
INIT depleted_forest_area = 0

INFLOWS:
forest_clear_rate = felling_rate/forest_stock_per_unit_area
Depleted_forest_stock(t) = Depleted_forest_stock(t - dt) + (felling_rate) * dt
INIT Depleted_forest_stock = 9611

INFLOWS:
felling_rate = No_of_tobbaco_kilns/fuelwood_for_a_kiln
forest_area(t) = forest_area(t - dt) + (land_transfer_rate_for_forest - forest_clear_rate) * dt
INIT forest_area = 13072

INFLOWS:
land_transfer_rate_for_forest = Jhum_area*transfer_fraction_for_forest
OUTFLOWS:
forest_clear_rate = felling_rate/forest_stock_per_unit_area
Forest_stock(t) = Forest_stock(t - dt) + (forest_regeneration_rate - felling_rate) * dt
INIT Forest_stock = 961100

INFLOWS:

forest_regeneration_rate = Forest_stock*regeneration_fraction
OUTFLOWS:
felling_rate = No_of_tobbaco_kilns/fuelwood_for_a_kiln
horticulture_area(t) = horticulture_area(t - dt) + (land_transfer_rate_for_hort) * dt
INIT horticulture_area = 273.3

INFLOWS:
land_transfer_rate_for_hort = Jhum_area*transfer_fraction_for_hort
Jhum_area(t) = Jhum_area(t - dt) + (- land_transfer_rate_for_hort - land_transfer_rate_for_forest) * dt
INIT Jhum_area = 940

OUTFLOWS:
land_transfer_rate_for_hort = Jhum_area*transfer_fraction_for_hort
land_transfer_rate_for_forest = Jhum_area*transfer_fraction_for_forest
No_of_tobbaco_kilns(t) = No_of_tobbaco_kilns(t - dt) + (kiln_growth_rate - kiln_depreciation_rate) * dt
INIT No_of_tobbaco_kilns = 363.64

INFLOWS:
kiln_growth_rate = (desired_no_of_kilns-No_of_tobbaco_kilns)/kiln_ad_time
OUTFLOWS:
kiln_depreciation_rate = No_of_tobbaco_kilns/kiln_average_life
population(t) = population(t - dt) + (population_growth) * dt
INIT population = 88998

INFLOWS:
population_growth = population*population_growth_factor
soil_erosion_normal(t) = soil_erosion_normal(t - dt) + (soil_erosion_g_rate) * dt
INIT soil_erosion_normal = 0

INFLOWS:
soil_erosion_g_rate = ini_jhum*soil_erosion_factor
soil_erosion_with_policy(t) = soil_erosion_with_policy(t - dt) + (soil_erosion_rate) * dt
INIT soil_erosion_with_policy = 0

INFLOWS:
soil_erosion_rate = Jhum_area*soil_erosion_factor
Tobbaco_area(t) = Tobbaco_area(t - dt) + (Tobbaco_area_growth_rate) * dt
INIT Tobbaco_area = 400

INFLOWS:
Tobbaco_area_growth_rate = crop_area*tobbaco_area_growth_fraction
animal_growth_fraction = 0.0012
area__planted_for_a_kiln = 1.1
desired_no_of_kilns = Tobbaco_area/area__planted_for_a_kiln
equivalence_factor_non_jhum = 0.53
equivalent_factor_fish = 4.358
equivalent_factor_horticulture = 2.8
equi_factor_for_jhum = 0.52
eq_factor_for_tobacco = 4.95
fish_area = 483.55
fish_production = fish_area*fish_yield
fish_yield = .355

food_available = food_from_animal+food_from_fish+food_from_forest+food_from_horticulture+food_from_jhum_area+food_from_non_jhum+food_from_tobbaco
food_from_animal = animal_area*food_from_animal_normal
food_from_animal_normal = 350
food_from_fish = equivalent_factor_fish*fish_production
food_from_forest = forest_area*food_from_forest_normal
food_from_forest_normal = 1.985
food_from_horticulture = horticulture_production*equivalent_factor_horticulture
food_from_jhum_area = Jhum_area*jhum_yield*equi_factor_for_jhum
food_from_non_jhum = equivalence_factor_non_jhum*non_jhum_production
food_from_tobbaco = tobaco_production*eq_factor_for_tobacco
food_per_capita = 0.001357
food_requirement = population*food_per_capita*no_of_days
food_security = ((food_available-food_requirement)/food_requirement)*100
forest_stock_per_unit_area = 5600
fuelwood_for_a_kiln = 32
fuelwood_for_curing = No_of_tobbaco_kilns*fuelwood_for_a_kiln
horticulture_production = horticulture_area*horticulture_yield
horticulture_yield = 14.99
ini_jhum = 940
jhum_yield = jhum_yield_normal*jhum_ecological_foot_print_multiplier
jhum_yield_normal = 2.153
kiln_ad_time = 1
kiln_average_life = 10
non_jhum_production = crop_area*non_jhum_yield*cropping_intensity_multiplier
non_jhum_yield = 6.33
no_of_days = 365
population_growth_factor = .016
regeneration_fraction = .02
soil_erosion_factor = 44
tobaco_production = Tobbaco_area*yield_of_tobacco
tobbaco_area_growth_fraction = 0.04
transfer_fraction_for_forest = .010
transfer_fraction_for_hort = .05
yield_of_tobacco = 2.272
cropping_intensity = GRAPH (TIME)
(0.00, 1.26), (1.00, 1.52), (2.00, 1.70), (3.00, 1.87), (4.00, 2.02), (5.00, 2.09), (6.00, 2.13), (7.00, 2.14), (8.00, 2.16), (9.00, 2.19), (10.0, 2.22), (11.0, 2.24), (12.0, 2.26)
cropping_intensity_multiplier = GRAPH (cropping_intensity)
(1.00, 1.00), (1.20, 1.08), (1.40, 1.14), (1.60, 1.22), (1.80, 1.28), (2.00, 1.32), (2.20, 1.36), (2.40, 1.38), (2.60, 1.41), (2.80, 1.43), (3.00, 1.45)
jhum_ecological_foot_print_multiplier = GRAPH (ecological_footprint_for_rice)
(0.00, 1.00), (0.3, 0.965), (0.6, 0.94), (0.9, 0.925), (1.20, 0.9), (1.50, 0.87), (1.80, 0.845), (2.10, 0.815), (2.40, 0.8), (2.70, 0.765), (3.00, 0.73)

Not in a sector