LANDUSE LAND COVER CHANGE DETECTION, SOIL HEALTH ASSESSMENT AND SOCIO-ECONOMY IN NORTHEAST INDIA :

A REMOTE SENSING AND GIS APPROACH

(SUB-PROJECT UNDER NAIP-III)

NAIP-Publication No. 7

राकृनप
NAIP

Research Bulletin

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भाकृअनुप
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भाकृअनुप- पूक्ष
ICAR-RC-NEH

Citation

B.U. Choudhury, Pratibha T. Das, S.V. Ngachan, Mokidul Islam, Anup Das, B.C. Verma, K.P. Mohapatra, L. Nongkhlaw, Syed B. Islam, G.C. Munda. 2014. Landuse Land Cover Change Detection, Soil Health Assessment and Socio-economy in Northeast India: *A Remote Sensing and GIS Approach.* **Research Bulletin** , NAIP Publication No. 7. ICAR Research Complex for NEH Region, Umiam-793 103, Meghalaya, India. Pp. 1-53.

Published by

The Director
ICAR Research Complex for NEH Region,
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Telephone: 0364-2570257, Fax: 0364-2570363
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Year of Publication:June, 2014

ISBN: 13-978-81-920769-7-3

Sponsored by

NAIP Component –III, ICAR Research Complex for NEH Region, Umiam, Meghalaya

Designed and Printed at ***print21***, Ambikagirinagar, R.G.Baruah Road, Guwahati - 781 024,
E-mail: print21ghy@gmail.com

Preface

Landuse – land cover change (LULCC) has a great impact on soil health *vis-à-vis* sustainability of agricultural production and rural livelihood. In the frail landscape of Northeastern Region (NER) of India, rapid LULCC due to large scale deforestation, transformation to settle and temporary agricultures (slash and burn practices) and expansion of settlements are posing threat to agricultural production and environmental security in the region. Poor socio-economic condition, dominance of marginal and small farmers, subsistence farming, and risk prone low productive rainfed agriculture further compounded the uncertainties in sustaining agricultural productivity *vis-à-vis* food and rural livelihood security. In order to secure rural livelihood while sustaining natural resources, Indian Council of Agricultural Research formulated and implemented integrated farming system (IFS) through NAIP(component –III) during 2007-2014 in seven Planning Commission identified disadvantaged districts across the region. Generation of information on status of LULCC resulting due to implementation of different IFS interventions will help in location specific technological intervention for rural livelihood security.

Remote Sensing (RS) and Geographical Information System (GIS) offer the ability to detect the dynamics of LULCC, interlinking with spatial variability on soil health and socio-economic factors arising out of changing demands of increasing population. Considering these aspects, a sub-project under NAIP-III on "Landuse Change Detection on adoption of sustainable farming system and livelihood of rural poor : *A Remote Sensing and GIS Approach"*was undertaken during the period 2010-2013 in two of the seven NAIP-III sites located in the most disadvantaged districts of NER namely South Garo Hills, Meghalaya and Dhalai, Tripura. We assessed changes in LULC over a period of 6 years (2005 to 2011: before and after implementation of NAIP) using multi-date high resolution satellite data of IRS P6-LISS-IV sensor. Soil health assessment and suitability zone at spatial scale followed by multi-criteria spatial analysis of soil health attributes and agro-physical parameters in GIS environment and geo-statistical ratings of different variables were done at 1: 10,000 to 12,500 scales for crop intensification and future location specific sustainable soil health management. We also attempted geo-spatial analysis and interlinking the impact of socio-economic status (driving force) on LULCC pattern, land holding and distribution of different soil suitability zones across different income groups. The outcome of this attempt would be helpful in devising location specific adaptation strategies related to agricultural area diversification and crop intensification to ensure food and livelihood security of the inhabitants.

We offer our sincere thanks to the staffs of KVK, Tura for their co-operation and persistent help in periodic visits to the study site for social survey, ground truthing and soil sampling. We are also very much thankful to Sumerson, Amit Das, Christy Sangma, Swati

Biswas, Sam and Samik Chowdhury for their assistance in survey, collection and analysis of geo-referenced soil samples, socio-economic data base as well as other accessory information from Dhalai and South Garo Hills. We offer extolling thanks to our office staff and Mr. Victor for assisting in timely release of funds for carrying out the study smoothly. Financial assistance from NAIP-III for purchasing satellite data, GPS, ERDAS imagine software as well as periodic sampling is duly acknowledged.

Umiam, 2014 Authors

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EXECUTIVE SUMMARY

In the fragile ecosystems of Northeastern Region (NER) of India, more than 70% population depends on marginal input intensive, low productive, rainfed agricultural activities for their livelihood. Major chunk of the farmers are small and marginal in land holding and 40% of them lives in poverty. Multiple driving forces like poor socio-economic condition, dominance of marginal and small farmers, subsistence farming, complex, risk prone rainfed agriculture, increasing population pressure and age old cultural practices of cultivation resulted in unique pattern and rate of LULCC than rest of India.About 35% areas in the region are plain except Assam where plain is about 84.4% of its geographical area (GA). Nearly 15.7% GA is under cultivation; forest cover (open & dense) in the region varies from 40.2% (Assam) to 72.9% (Arunachal Pradesh). Area under shifting cultivation is 2.88% (0.754 Mha). Grassland occupies 6.06% GA while wastelands occupy 6.22% of GA. The region has 4.53% area under water bodies. The rural population in the region is facing multifarious problems which are threatening the sustainability of agricultural productivity, food grain, and livelihood *vis-a-vis* environmental security. In order to secure rural livelihood improvement through sustainable farming system approach,Indian Council of Agricultural Research (ICAR) with the financial aid fromWorld Bank formulated and implemented National Agricultural Innovation Project (NAIP) project (component–III) during 2007-2014 in seven Planning Commission identified most disadvantaged districts across North East India.

With the advent of geo-spatial tools (Remote Sensing and GIS), it is possible to detect the dynamics of LULCC, interlinking with spatial variability on soil health and socio-economic factors. We carried out analysis of LULCC for two of the seven NAIP project sites in the most disadvantaged districts of North East India i.e. South Garo Hills, Meghalaya and Dhalai, Tripura over a period of 6 years (2005 to 2011) using multi-date high resolution satellite data of IRS P6-LISS-IV images by visual interpretation technique. There were three clusters in two sites: Sibbari in South Garo Hills while Maracherra and Balaram in Dhalai. Sibbari cluster bordering to Bangladesh under Gasuapara development block, South Garo Hills comprised 11 villages with 505 marginal to small farming households, mostly dependent on agricultural activities for their livelihoods. In Dhalai district, two clusters namely Maracherra & Balaram were located 40 km away from each other. Cluster Balaram consisted of 6 villages while Maracherra consisted of 8 villages. An integrated assessment of driving forces (socio-economic factor) that affect the pattern and rate of LULCC and the consequences of that change on spatial variability of soil health were also determined. Spatial mapping of soil attributes at 1: 10,000 to 12,500 scales were done for both the sites. Following standard procedure, a composite spatial soil suitability index was developed using multi-criteria decision-making approach in Geographical Information Systems (GIS) and statistical weighing from the integration of spatial maps of different soil attributes and their distribution pattern across the study area.

Change detection from satellite data analyses in Sibbari cluster, South Garo Hills over the periods (before implementation of NAIP period-2005-06 and after implementation in 2011) reflected an increase in area under horticulture-plantation and water bodies, mostly village ponds/ fisheries. During the same period, significant chunk of area under dense forests were transformed into open forests and there was increase in rural settlements by 32.9% and wastelands by 1.6%. Therefore, a general trend experienced in the area was a decrease in forest covers (both dense & open) while settlements and wasteland revealed an increasing trend. Horticulture-plantation and pond based integrated landuse systems are encroaching slowly in marginal to sizeable areas in the cluster.

Total geographical area (TGA) in Maracherra cluster was 5050.9 hectare. Over a span of three years (2008 over 2005-06), LULC reflected considerable changes: area under settlement increased from 9.2 to 40.7% of TGA**.** Similarly, area under agriculture also increased from 23.0% to 27.6%. Horticulture and plantation also experienced an expansion from 7.5% to 13.7% in area. At the same time, area under wastelands decreased considerably from 10.0% to 5.0%. However, due to the increase in population pressure and subsequent increase in area under settlement by 31.5% of TGA, area under open forests were completely removed that reduced from a significant 31.8% in 2005-06 to almost negligible in 2008. Similarly, increase in horticulture and plantation as well as agricultural area also resulted in significant reduction in dense forests from 18.0% (in 2005-06) to 11.4% in 2008. The general trend in LULC change in Maracherra cluster was on the way to deforestation (evident from the decrease in forest areas), mostly driven by population pressure led increase in settlement areas. Balaram cluster had TGA of 6420.1 ha and the dominant land use systems were agriculture (36.4% TGA) followed by horticulture-plantation (19.72%), wastelands (15.1%), dense forests (13.59%) and settlement (13.15%). Shifting cultivation and water bodies occupied marginal areas. Change detection over a span of 3 years (2005-06 to 2008) reflected an increasing trend in areas under settlement, dense forest, shifting cultivation and water bodies while a decreasing trend was observed in areas under horticulture and plantation, wastelands and agriculture.

Majority of the soils (>90% of total agricultural area-TAA) in Sibbari cluster were coarse to medium in texture (sand content >50%), moderately acidic in reaction (pH>5.0) but low to medium (4-8 meq/100 g soil) in exchangeable bases and effective cation exchange capacity (ECEC: 5-8 meq/100 g soil). More than half of the TAA had higher exchangeable aluminium (Al^{3+}) content (1.0-1.5 meq/100 g soil) while one third area had relatively higher aluminium saturation (15-25%) in clay complexes. Majority (>96% of TAA) of the soils were very high in soil organic carbon (SOC: 1.5-2.5%), medium (200-300 kg ha^{-1}) in available nitrogen (N) and potash (K: 250-350 kg ha^{-1}) but deficient in available phosphorus (<=30 kg ha^{-1}). Available sulphur content in the soil was medium (20-40 kg ha^{-1}) to very high (40-60 kg ha^{-1}). In Maracherra cluster (Dhalai), soils were invariably coarser in texture with very high sand content (70 to 80%), moderate in clay content (20-30%), moderately acidic in reaction (pH>5.0), high in exchangeable aluminium(>1.0 meq/100 g soil) and low in exchangeable bases (Ca and Mg: <5 meq/100 g soils). Majority of the soils were moderate in SOC content (1.0-1.7%), low in available N (150-200 kg ha^{-1}), P (<= 20 kg ha^{-1}), K (<150 kg ha^{-1}) and S contents (<20 kg ha^{-1}). Soils of Balaram cluster (Dhalai) were coarser in texture (sand content: 40-90%), strong (pH<=5.0) to moderately (5.0<pH<5.7) acidic in reaction, low in exchangeable aluminium (<=1.0 meq/100 g soil) and very low in bases (3-5 meq/100 g soil). Soils were medium in organic carbon (SOC: 1.0-1.5%), very low (150-200 kg ha^{-1}) in available N, deficient in available P (<= 20 kg ha^{-1}), K (<=150 kg ha^{-1}) and S contents (<=15 kg ha^{-1}). Overall, soils under agricultural area in Maracherra and Balaram clusters of Dhalai district were low in soil fertility status (medium SOC, low available N, P, K and S). Thus, it demands selective ameliorative measures and periodic replenishment of plant nutrients both from organic and inorganic sources in balanced proportion for sustaining crops as well as land productivity *vis-à-vis* soil health and food security in the region.

Integration of multi-criteria decision-making approach in Geographical Information Systems (GIS) and statistical weighing/ratings of different variables (sand, silt, clay, bulk density, water retention –transmission based functions, pH, exchangeable aluminium, ex. acidity, aluminium saturation in ex. complexes, ex. bases, ECEC, N, P, K and S), a composite spatial soil suitability index was developed. Based on cumulative weighted rating score, four rating systems namely low, medium-low, medium-high and high were contrived. In-case of Sibbari cluster (South Garo Hills), of the total agricultural area (696.7 ha), nearly 50% area falls in medium-high category of soil suitability zones and can support intensive cultivation of atleast 2 nutrient exhaustive crops in a year. Soil suitability to crop intensification in the remaining 43.3% area falls under medium-low category and thus, can support less nutrient/ water exhaustive crops/ cropping systems (like vegetables/oilseeds-pulses). In Maracherra cluster, 45% agricultural area falls under medium-high soil suitability category, which can support crop intensification. However, more than 1/3rd agricultural area (>37% of TAA) falls under poor soil suitability class and needs soil health restoration approaches (external nutrient supplementation/in-situ resource conservation) for crop cultivation. In another 16.4% TAA, soils were medium-low in soil suitability for crop intensification thus, needs location specific soil health restoration approaches to increase intensification as well as land-crop productivity. Similar trend of significant area (>56% of TAA) under low to medium-low soil suitability falls in Balaram cluster. The cluster had only 40.6% area under medium-high soil suitability class. These areas can be exploited for crop intensification by growing 2-3 crops in a sequence round the year. Like Maracherra cluster, area under high soil suitability class was negligible (<2.5%). Overall, in Balaram cluster, more than 48% of the total agricultural area was not conducive for crop intensification in the existing conditions and needs periodic nutrient replenishment, integrated nutrient management with special emphasis on external nutrient supply at appropriate crop growth stages.

Primary data on household annual income at Sibbari cluster was collected randomly across 135 households and was extrapolated to represent the total households (505) of the cluster. Nearly 43% of the total households fall under low category income group (<Rs.60, 000/- annually) while 40% were in medium category (>60,000 to <1, 20,000) income group. Households with annual income > 1, 20,000/- were only 17%. Average agricultural land holding per household of high income group was 2.50 ha, which was 2.98 times higher than the low income group households (0.84 ha/household). Medium income group had 1.77 times higher land holding (1.49 ha/household) than low income group.

Integration of spatial multi-criteria soil suitability class in GIS along with geo-referenced household survey information and land holdings of Sibbari cluster, information on distribution of agricultural land under different soil suitability class among the three income groups (low, medium and high) were generated. Of the total 696.7 ha, low income group (43% of total household) had 26% of the land while medium income group (40% of the total household) had the highest land area (300.4 ha, 43.1% of the total). High income group represents only 17% of the total households, yet, agricultural land under them was almost double (>30% of the total agricultural land). Majority of the low to medium-low suitability soil areas belonged to low income group farmers while medium income group had major share in medium-low to medium–high soil suitability class areas. High income group had minimal share (3-5%) of land area under low to medium-low soil suitable zones. More than 90% agricultural land area (198.4 ha of 214.4 ha) of the high income group fall under high to medium-high in soil suitability for crop intensification. Higher income group households might have adopted periodic replenishment of soil nutrients, ameliorative measures, manuring and soil health restoration approaches, which helped in restoration of soil health. Another possible reason is less pressure on lands due to low crop intensification, less soil nutrient removal through crop uptake and cutting since they have higher average land holdings. In case of low income group, farmers were mostly marginal to small in land holding and resources, therefore, this group couldn’t adopt high input intensive cultivation. As a result, periodic replenishment of nutrients from external source was lacking. In addition, small land holding might have put extra-pressure on the lands for repeated cultivation with marginal external replenishment, nutrient removal through uptake and other forms of losses. Therefore, this study showed that soil fertility restoration had an indirect link to the owner’s resource status. Landuse type reflected a strong influence on spatial variability of soil properties across the study area while socio-economic condition of the farmers was one of the main driving forces behind deciding the pattern of land use /land cover change as well as soil health status.

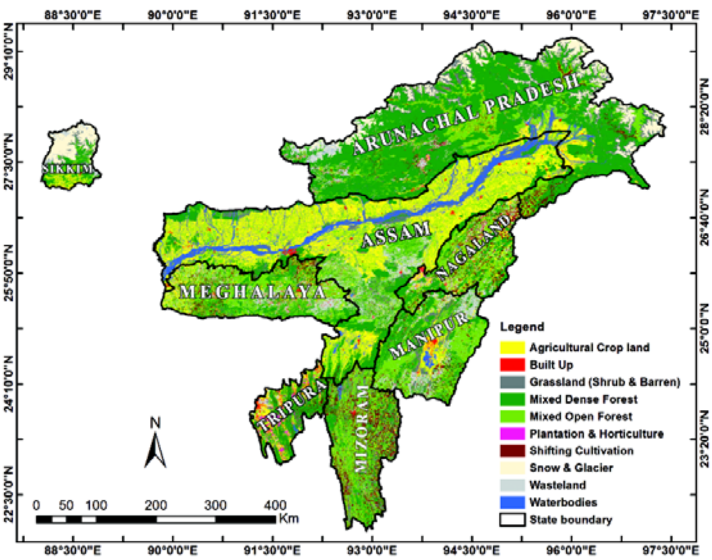
CHAPTER 1

INTRODUCTION

1.1 The region at a glance

The North eastern region (NER) of India representing an area of over 261000 km^2, by virtue of its geographic location and richness in bio-diversity, well supported by complimentary climatic factors, more particularly high rainfall for luxuriant phyto-biomass (both above and below ground) in the form of forests and allied sources of vegetation is a unique place in India (Chatterjee et al., 2006). The region experiences hot summer and cold winter. The temperature varies from as low as 0°C in Himalayan range (Sikkim) to 35°C in some parts of Tripura. The region falls under high rainfall zones, with Cherapunjee Plateau (Meghalaya) receiving over 11000 mm during monsoon season (June-September). The region is characterized by steep to very steep slopes in Meghalaya, Manipur, Nagaland and Sikkim and gentle slopes in the Assam valley. The topography, climate and vegetation have played a great role in the formation of a variety of soils in the region. These could broadly be put under Red and Yellow, Brown Hill, Old and Recent Alluvial and Terai soils (Patiram, 2007).

The landuse-land covers change (LULCC) in NER depicts a distinct pattern as compared to rest of the country. About 35% area in the region is plain except Assam where plain is about 84.4% of its geographical area (GA). Nearly 15.7% GA area is under cultivation; forest cover (open and dense) in the region varies from 40.2% (Assam) to 72.99% (Arunachal Pradesh) (NRSC, 2011). Area under shifting cultivation is 2.88% (0.754 Mha). Grasslands occupy 6.06% GA while wastelands occupy 6.22% of GA. The region has 4.53% area under water bodies (Table 1). The landuse pattern and distribution across 8 states of NER is presented in Table 1 and Map1.



Map 1. Landuse land cover pattern of Northeastern Region of India (NRSC, 2011).

Table 1: Remote sensing based land use pattern (2005-06) of Northeastern region of India

NER	Ar. Pradesh	Assam	Manipur	Meghalaya	Mizoram	Nagaland	Sikkim	Tripura	Grand Total
G. Area (M ha)	**8.30**	**7.79**	**2.22**	**2.24**	**2.10**	**1.65**	**0.70**	**1.02**	**26.02**
				Land use (% of Geographical area)					
Crop land	2.93	37.27	7.78	8.93	4.41	11.53	9.78	17.63	15.68
Built Up	0.46	0.71	1.69	3.73	0.82	2.23	0.24	8.22	1.37
Grassland	6.41	5.53	6.66	0.84	16.48	0.14	7.64	4.57	6.06
*D. Forest	58.06	15.80	28.94	25.06	19.81	26.73	26.05	46.04	33.49
O. Forest	14.93	24.40	35.63	42.52	44.36	37.64	10.38	9.24	25.44
PH	0.02	0.16	0.01	0.05	0.40	0.42	0.33	5.88	0.36
SC	1.83	0.30	2.79	3.33	12.46	9.08	0.00	2.44	2.88
Snow	9.51	0.00	0.00	0.00	0.00	0.00	36.74	0.00	3.98
Wasteland	3.92	4.58	14.58	13.98	0.19	11.08	8.04	4.89	6.22
Waterbody	1.94	11.25	1.92	1.56	1.08	1.15	0.79	1.09	4.53

*D. Forest: dense forest, O. Forest: open forest, PH: plantation and horticulture, SC: shifting cultivation (NRSC, 2011)

In the recent past, rapid LULCC due to large scale deforestation, transformation to temporary agricultural land through adoption of slash and burn (shifting cultivation) practices, conversion of natural forests/ grasslands into plantation/horticultural lands and other forms are mostly contributing to colossal loss of phytomass in the region (Choudhury *et al*., 2013). Burning of phytomass @ 8.5 million tonnes annually in shifting cultivation (Das *et al*., 2011) and farming along the steep slopes in high rainfall areas resulted in acceleration of soil erosion (>88 Mg ha^{-1} $year^{-1}$ soil loss), annual loss of organic C by 6.0 million tons and available plant nutrients (Ghosh *et al*., 2009). Out of the 4.0 million hectare net sown area of the region (Table 1), roughly 1.3 million hectare suffers from serious soil erosion problem. Presently, shifting cultivation and associated deforestation remains one of the largest degrading forces for the loss of forest cover and subsequent imbalance in aggredation-degradation cycle of land-soil and environmental resilience.Water scarcity and moisture stress induced intermittent droughts during peak crop growing season is another major challenge in sustaining crop productivity *vis-à-vis* food security in the low input intensive rainfed agriculture of the region.

1.2 Importance of landuse land covers change detection

The LULCC has a great bearing on soil health *vis-à-vis* sustainability of agricultural production, socio-economy and rural livelihood. In the fragile ecosystems of NER of India, multiple driving forces like poor socio-economic condition, dominance of marginal and small farmers, subsistence farming, complex, risk prone and low productive rainfed agriculture, increasing population pressure and age old cultural practices of cultivation resulted in rapid LULCC than rest of India. Understanding LULCC patterns, its interactions between human activities and natural phenomenon, impact on soil health and sustainability of land productivity are essential for sustainable management. LULCC has been recognized as an important driver of environmental change on all spatial and temporal scales and is emerging as a key environmental issue.

1.3 Integrated studies of LULCC, soil health and socio-economy

Geospatial tools like satellite remote sensing (RS) and geographic information system (GIS) in integration offers the ability to detect the dynamics of LULCC, interlink with spatial variability on soil health and socio-economic factors arising out of changing demands of increasing population. Remotely sensed data have been proven to be one of the best techniques for monitoring forest clearing, shifting cultivation, and land use conversion patterns. In integration with GIS, RS outputs particularly, LULCC with high accuracy has given a cutting edge in interlinking socio-economic surveys as well as other biophysical information gathering techniques, to bring about a better understanding of land use/cover dynamics and the factors that drive them (Quattrochi and Goodchild, 1997). Integrated analysis using these tools help in assessments of the proximate causes of LULCC, their effect on soil health and environmental constraints/opportunities associated with human activities (soil sustainability and zones of intensive cultivation) (Ehrlich et al., 1997).

1.4 Project background and objectives

In North Eastern Region (NER) of India, more than 70 percent of the population depends on low input intensive, low productive, rainfed agricultural activities for their livelihood. Major chunk of the farmers have small and marginal land holdings and 40% of them lives under poverty. Over the years, rural population is facing multifarious problems which are threatening the sustainability of agricultural productivity, food grain, livelihood *vis-a-vis* environmental security. In order to secure rural livelihood improvement through sustainable farming system approach, Indian Council of Agricultural Research (ICAR) with the financial aid fromWorld Bank formulated and implemented National Agricultural Innovation Project (NAIP) project (component –III) during 2007-2014 in Planning Commission identified seven disadvantaged districts across North East India. These were Upper Subansiri (Arunachal Pradesh), Tamenglong (Manipur), South Garo Hills (Meghalaya), Saiha (Mizoram), Mon (Nagaland), North Sikkim (Sikkim) and Dhalai (Tripura). In this project (NAIP, Component – III), other major activities undertaken were technological interventions for sustainable natural resource management, productivity and profitability enhancement, building support systems and institutions.

Several site specific technological interventions like integrated farming system approaches including intervention of plantation and horticulture, agro-forestry for rehabilitation of degraded land resource, fish based integrated system, soil health restoration through resource conserving technologies (input intensification, integrated crop management, zero tillage etc.) were adopted during the project period. Therefore, the present investigation was formulated with a hypothesis that these technological interventions would bring change in landuse land cover (LULC) in those areas. Considering these aspects, a sub-project under NAIP-III on "*Landuse Change Detection on adoption of sustainable farming system and livelihood of rural poor: A Remote Sensing and GIS Approach*" was under taken during the period 2010-2013 in two of the seven NAIP-III sites located in the most disadvantaged districts of NER namely South Garo Hills, Meghalaya and Dhalai, Tripura (Map 2). Using remote sensing and GIS technology, LULC change detection from multi-date fine resolution satellite data (IRS-P6-LISS-IV, 5.8 m) was done over a period of six years 2005-2011; 2005 was considered as before implementation period of project while 2011 was considered as after implementation. Soil health assessment at spatial scale followed by multi-criteria spatial soil suitability zone for crop intensification and future location specific technological intervention was also done.

The outcome of this study would give a new dimension to the initiatives on agricultural area diversification, and crop intensification, restoration of soil health and land productivity, food and livelihood security of the rural poor.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study area description

Of the seven most disadvantaged districts identified for implementation of NAIP-III component at ICAR Research Complex for NEH Region, two namely South Garo Hills (Meghalaya) (Map 2) and Dhalai (Tripura) (Map 3) were selected for the present study. Details are described below-

A. South Garo Hills (Meghalaya)

South Garo Hills district is one of the most backward districts; lies in the southern part of NE state of Meghalaya (between 25°10' - 25°35'N latitudes and 90°15 - 91°10' E longitude) with district headquarters at Baghmara. It covers an area of 1887 sq. km and is bounded in the North by East Garo Hills, in the East by the West Khasi Hills district, in the West by West Garo Hills district and in the South by Bangladesh. Administratively, South Garo Hills District is divided into four community development blocks namely Baghmara, Rongara, Chokpot and Gasuapara.

Gasuapara development Block covers an area of 28,289 hectare with 165 villages, having 4195 households and 30,127 populations. Of the 165 villages, only 52 villages (32%) are electrified. Average literacy in the block is 51% and female: male ratio is 907:1000. Major occupation of the inhabitants is agriculture. Sites for technological interventions under NAIP component-III were selected in 11 villages bordering to Bangladesh under Gasuapara development Block, known as Sibbari cluster (Map 2). Sibbari cluster covers 505 households and majority of them are marginal to small farmers, mostly dependent on agricultural activities for their livelihoods (Table 2). Mean elevation of Sibbari cluster varies from 11-32 meter above msl.

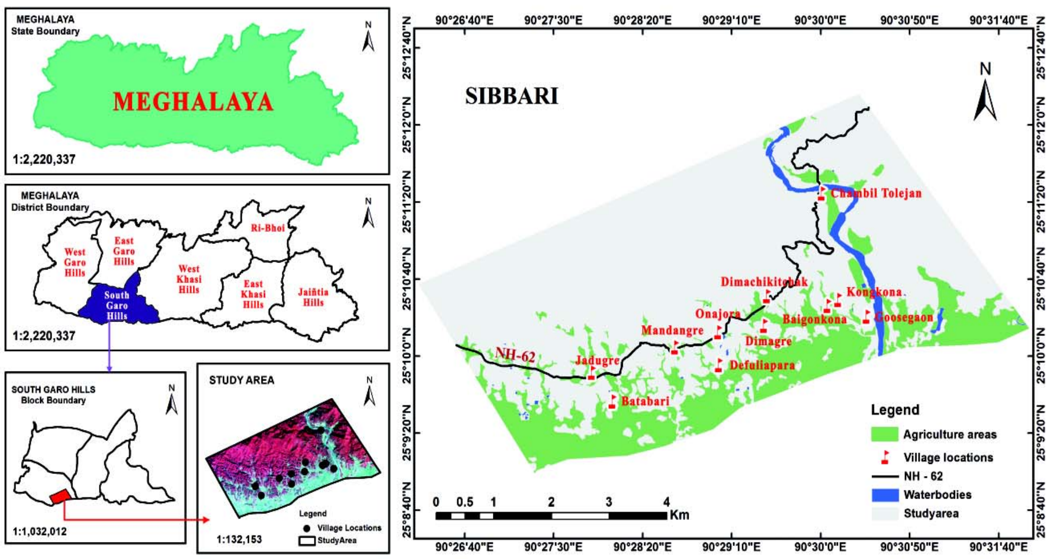
Climate, soil and landuse pattern

The study area (Sibbari cluster, Gasuapara development block) is characterized by warm summer and cold winter with low precipitation. Agro-climatologically, the Gasuapara Development block, consisting Sibbari cluster, falls under Subtropical (hill and valley) zone with annual rainfall of 2000 mm mean maximum temperature of 33°C and minimum temperature of 17°C. Soils of the region are lateritic and alluvial in nature. Rainfed lowland rice is the dominant crop grown in the region followed by vegetables and oilseeds.

Landuse pattern derived from the LULC map developed by the NRSC from multi-date satellite data (IRS-P6-LISS-III) (NRSC,2011) reflected that during 2005-06, the state

Table 2: Cluster of 11 villages and number of household of study area (Sibbari cluster, South Garo Hills)

Sl.No.	Village	Latitude (N)	Longitude (E)	Elevation (m)	House holds (No)
1	Jadugre	25.164245	90.464333	20	36
2	Mandangre	25.167900	90.477317	27	43
3	Defuliapara	25.165333	90.484150	28	54
4	Onajora	25.170100	90.484033	24	16
5	Dimagre	25.171016	90.491173	31	54
6	Dimachikitchak	25.175278	90.491670	32	36
7	ChambilTolejan	25.190094	90.500223	19	31
8	Baigonkona	25.174744	90.502762	11	95
9	Kongkona	25.173904	90.501111	17	36
10	Goosegaon	25.172350	90.507183	14	64
11	Batabari	25.160085	90.467559	15	40



Map 2: Location of the study area at Gasuapara (NAIP cluster at Sibbari), South Garo Hills, Meghalaya

Meghalaya had 67.63% area under dense and open forest cover while agriculture (settled) was practiced in meager 8.85% area. Shifting cultivation was practiced in 3.34% area. The state had nearly one sixth area (14.86%) under wasteland (including scrubs) (Fig.1a). On the contrary to the state, South Garo Hills district had more than 75.87% area under forest cover where mixed dense forest (canopy density >40%) occupied 41.14% area and the remaining 34.7% area was under mixed open forest (canopy density <40%). Next to forest, the district had significant area (9.15%) under slash and burn (shifting) cultivation while settled paddy based agriculture was practiced in only 4.55% area. Wasteland including scrubs occupied another 4.6% area (Fig.1b). Landuse pattern during 2005-2006 in Gasuapara Development Block also reflected similar trend. The block has 74.67% of geographical area under forest (dense forest 41.83% and open forest is 32.84%) while shifting cultivation is practiced in more than 9% area. However, area under settled agriculture (mostly rainfed rice) is 9.23% (Table 3).

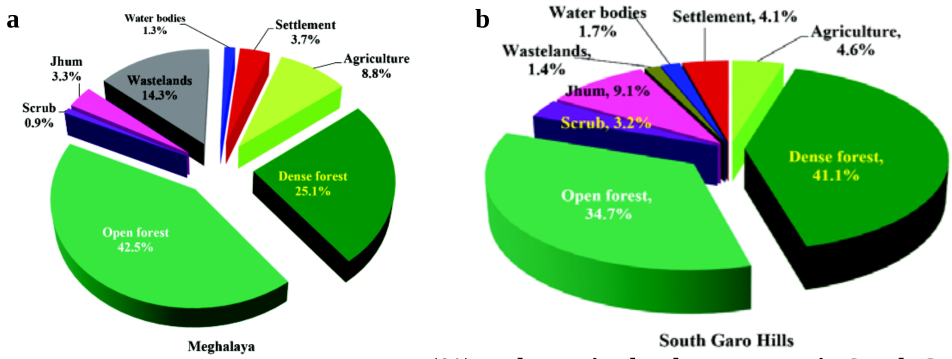
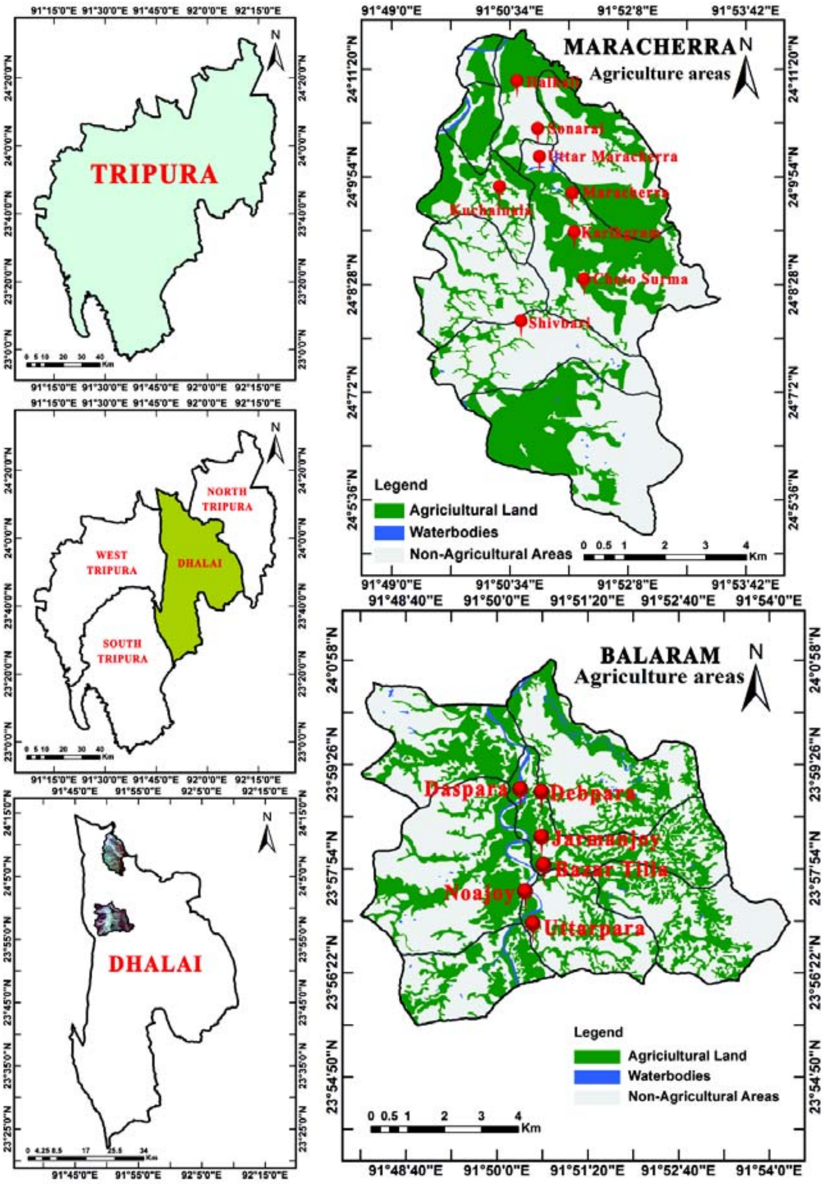


Fig. 1: Distribution of geographical area (%) under major landuse systems in South Garo Hills and Meghalaya

B. Dhalai (Tripura)

Dhalai is one of the most backward districts in the state of Tripura as well as in India which has been receiving funds from the Backward Regions Grant Fund Programme. Headquarters of the district is located at Ambassa. It is also the least populous district of Tripura, with a population of 3,77,988 for a geographical area of 2,52,300 hectare. The district has a sex ratio of 945 females for every 1000 males and a literacy rate of 86.8% (http://dhalai.nic.in). Topographically, it is mainly a valley in between two hilly terrains namely “Atharamura Range” and “Shakhan Range”.

Although the district is blessed with bounty of natural resources, yet, multifarious constraints related to poor socio-economy, resource availability, technological awareness, poor infrastructure, marketing facility etc. limited its use. Majority of the agricultural area (86%) is under low productive rainfed, marginal input intensive mono-cropping systems. Farmers of the region are mostly dependent on agriculture and allied sources, more particularly rice/fish based farming for their livelihood. As a result, the agricultural productivity *vis-à-vis* food grain and livelihood security in the region is under constant threat. Keeping these in view, under NAIP-III, two clusters namely Maracherra & Balaram located in the district at 40 km away from each other were selected for sustainable rural livelihood improvement through various location specific technological interventions. Cluster Balaram consists of 6 villages (namely Daspara, Bazartilla, Uttarpara, Debpara, Jamanjoypara and Noajoy para) and Cluster Maracherra consists of 8 more villages (Choto Surma, Karikgram, Shivbari, Halhali, Kuchainala, Maracherra, Uttar Maracherra and Sonarai) (Map 3).



Map 3: Location of the study area at Dhalai (NAIP clusters at Maracherra and Balaram), Tripura

Climate, soil and landuse pattern

Landuse pattern (2005-06) extracted from NRSC (2011) map for the state of Tripura reflects that around 55.3% area is under forest cover, of which dense forest (canopy density >40%) alone occupies 46% of the total area of the state (1.02 Mha). Around 17.7% area is under settled cultivation (mostly rice based system), 5.88% area under plantation crops while shifting cultivation occupies 2.44% area of the state. Other landuses like grasslands occupied 4.57% area while area under wasteland is 4.88%. Area under water bodies is negligible (1.09%) (Table 1). In Dhalai district, dense forest occupies major chunk (42.7%) followed by open forest (18.8%), agriculture (12.8%) and plantation (10.7%). Nearly 5% area is under waste lands (including scrubs) while area under shifting cultivation is marginal (<1%) (Fig. 2).

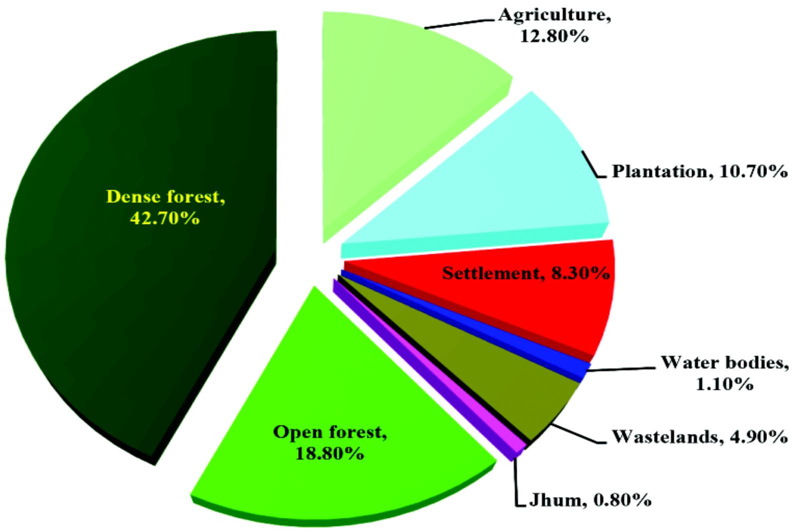


Fig. 2: Distribution of geographical area (%) under major landuse systems in Dhalai district, Tripura.

2. 2 LULC classification using multi-temporal satellite datasets

Multi-temporal satellite datasets are used as primary inputs for generation of spatial databases on temporarily variant of LULC classes. Due to the variation (temporal & spatial) of LULC across hilly topography with considerable heterogeneities involved in LULC, the extraction of LULC information using multi-temporal datasets by digital image processing become a complex process. Several parametric and non-parametric digital classification approaches were used to classify multi-temporal datasets. However, visual interpretation technique is more reliable in area statistics assessment, though it has several limitations, particularly involvement of labour and time.

2.3. Data Used

Remote Sensing data: The study aimed at deriving maximum possible information on landuse land cover (LULC) change, if any, before and after 5-6 years of implementation of the project. For LULC mapping, multi-date (February, April and December) high resolution satellite images of IRS-P6, LISS-IV (5.8 m) of year 2008 as well as 2011were procured from NRSC, Hyderabad. In the region, village level information (both digital boundary as well collateral data) is not available and the study area represents clusters (Sibbari, Balaram and Maracherra) of many villages, therefore, district level Agricultural Statistics provided by department of economics and statistics of the state couldn't be compared with the area statistics generated from LULC of 2008 and 2011 for change detection. Instead, for temporal variation and change detection over the years (2005-2008-2011), base line information was derived from the available classified LULC map (IRS-P6-LISS-III) of the study area for 2005-2006 (NRSC, 2011). The optimum coverage scenes were selected through browsing with different path/row combinations over the study area to screen out the cloud free scenes. Study area of Sibbari cluster (South Garo Hills) was optimally covered by Path/Row 137/43 scene of IRS-P6 LISS-IV data. Similarly, Balaram and Maracherra clusters of Dhalai were covered by Path/Row 136/43 scene of IRS-P6 LISS-IV data**.**

Collateral data: Primary data on socio-economic status pertaining to total household numbers, family members in each household, landholdings, occupation, monthly /annual income per household, education, and other miscellaneous information were collected randomly through survey (PRA) and the block development office.

Ground truth and in-situ measurements are important inputs for remote sensing data analysis. They are used to classify the data and obtain various thematic layers as well as verifying the accuracy of the outputs obtained. Ground truth was collected during different periods by visiting the fields and noting down the crop/ land cover information at the selected sites. Global Positioning System (GPS) and Survey of India (SOI) topographic maps of 1:50,000 scales were used to record the geographic coordinates of ground truth sites.

2.4 Methodology

For land use land cover mappingboth visual and digital image interpretation techniques were tried. Digital image analysis (DIA) was carried out but due to hilly terrain, marginal to small land holdings, extensively heterogeneous and small discontinuous sporadic patches of crops/other forms of landuses, the accuracy of the output image was not satisfactory. From ground truth verification, it was found that visual interpretation gives more accurate output compared to DIA. Therefore, to maintain accuracy in LULC mapping, visual image analysis technique was adopted for this study. The detail methodology followed in the study is presented graphically in Fig.3 and briefly described below

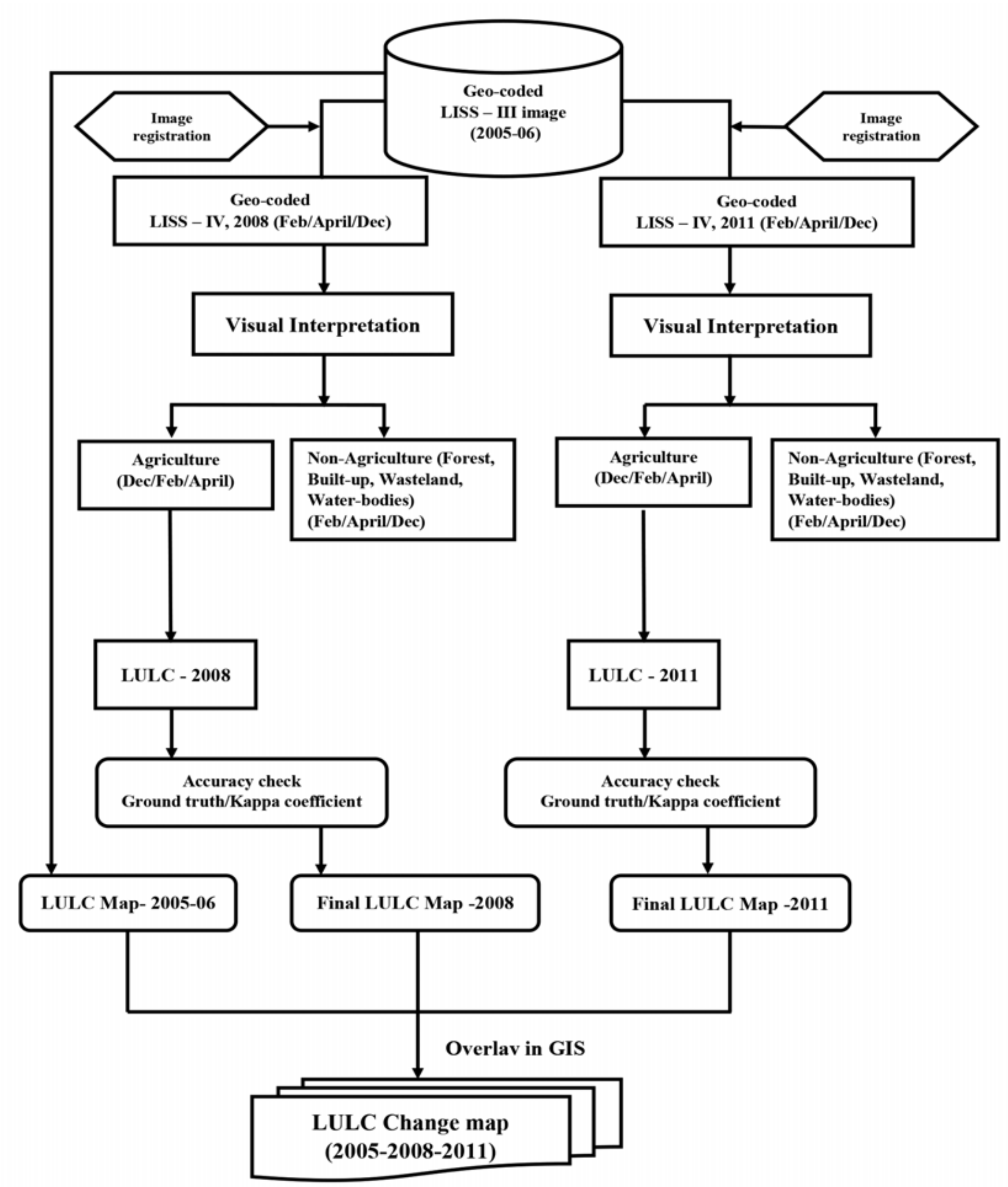


Fig. 3: Flow diagram depicting the step wise image analysis (visual interpretation) in detecting LULC changes

2.4.1 Preparation of Remote Sensing data

IRS P6 LISS-IV image of February, 2008 was registered with available geo-referenced IRS-P6-LISS-III data of 2005-06 following nearest neighbourhood resampling approach and 2nd order polynomial model using ERDAS imagine software (2010 v). Other images of 2008 and 2011 were registered following image-to-image registration using the rectified LISS-IV 2008 images. The image-to-image registration was done with sub-pixel accuracy. The geo-referenced images were re-projected to *POLYCONIC* projection and *WGS84* datum.

2.4.2 Land use land cover mapping

Land use land cover map of year 2008 and 2011 were prepared from LISS IV images of three seasons by using visual interpretation technique. The images were interpreted to non-agricultural and agricultural classes in the 1st level classification. Non-agricultural class includes forest (dense and open), plantation and horticulture, built-up, wasteland and water-bodies in the 2nd level classification. The forest class is further divided into dense forest and open forest based on density of canopy cover. The agricultural class included *rabi, kharif* and *zaid* crops. All three seasons were clubbed together into one class i.e agriculture. The classification accuracy was thoroughly checked from the collected extensive ground truth information. Different approaches including error matrix and Kappa coefficient were used for classification accuracy check and have been discussed in the following section.

2.4.3 Accuracy assessment /quality check of classification

Accuracy of the landuse land cover area classification maps generated was assessed by error/confusion matrix and KAPPA analysis (Tables 3-5). The error matrix is the standard

Table 3: Accuracy assessment for LULC classification (LISS-IV-2008) in South Garo Hills

Classification	DF	OF	Agr	Built up	Water body	PH	Wasteland
DF	17	0	0	0	0	0	0
OF	3	21	1	2	0	1	1
Agr	0	0	47	0	0	1	1
Built up	0	2	0	18	0	1	0
Water body	0	0	0	0	15	0	0
PH	0	2	3	1	0	19	2
Wasteland	0	0	0	0	0	0	17
Total GCP's	20	25	51	21	15	22	21
Agreement (AA)	17	21	47	18	15	19	17
Disagreement (DA)	3	4	4	3	0	3	4

Kappa Coefficient (K) $= \frac{(DA-AA)}{(1-AA)} = \frac{(21-154)}{(1-154)} = \frac{-133}{-153} = 0\ 869$

*DF: dense forest, OF: open forest, Agr: Agriculture land, PH: plantation and horticulture, GCP: ground control point method used to assess classification accuracy. KAPPA analysis is discrete multivariate technique which calculates the producer's and user's overall accuracy, as well as the Kappa accuracy level. The image classification accuracy was further assessed by overlaying the extensive geo-referenced ground truth points representing different landuses (175-182 for South Garo Hills and 250 points for Dhalai) collected over the study area during 2009-2011. To determine the accuracy of classification, a sample of pixel was selected on the classified image and their class identity was compared with the ground reference data.

Table 4: Accuracy assessment for LULC classification (LISS-IV-2011) in South Garo Hills

Classification	DF	OF	Agr	Built up	Waterbody	PH	Wasteland
DF	15	0	0	0	0	0	0
OF	2	24	2	2	0	2	2
Agr	0	2	35	0	0	2	1
Built up	0	1	0	14	1	1	0
Water body	0	0	0	0	19	0	0
PH	0	2	2	1	0	28	2
Wasteland	0	0	0	0	0	0	22
Total GCP's	17	29	39	17	20	33	27
Agreement (AA)	15	24	35	14	19	28	22
Disagreement (DA)	02	05	04	03	01	05	05

Kappa Coefficient (K) $= \frac{(DA-AA)}{(1-AA)} = \frac{(25-157)}{(1-157)} = \frac{-132}{-156} = 0.846$

DF: dense forest, OF: open forest, Agr: Agriculture land, PH: plantation and horticulture

Table 5: Accuracy assessment for LULC classification (LISS-IV-2008) in Dhalai

Classification	DF	OF	Agr	PH	SC	Wasteland	Water body	Built up
DF	24	0	0	0	0	0	0	0
OF	1	14	1	2	1	0	0	0
Agr	0	0	39	0	2	0	0	0
PH	2	3	2	45	2	1	0	0
SC	0	0	2	0	40	0	0	0
Wasteland	1	0	0	3	3	21	0	2
Water body	0	0	0	0	0	2	1	18
Built up	0	0	0	0	0	0	18	0
Total GCP's	28	17	44	50	48	24	19	20
Agreement (AA)	24	14	39	45	40	21	18	18
Disagreement (DA)	04	03	05	05	08	03	01	02

Kappa Coefficient (K) $= \frac{(DA-AA)}{(1-AA)} = \frac{(25-157)}{(1-157)} = \frac{-132}{-156} = 0.846$

DF: dense forest, OF: open forest, Agr: Agriculture land, PH: plantation and horticulture, SC: Shifting cultivation

The overall accuracy of the classification results from the error matrix was 86-88% for South Garo Hills and 86% for Dhalai (Tables 3-4). Similarly, Kappa coefficient (K) was 0.846-0.869 for South Garo Hills and 0.846 for Dhalai (Table5). These values fall within the range described by Congalton and Green (1999) as strong agreement.

2.5 Spatial multi-criteria based soil suitability analysis

2.5.1 Soil sampling strategy and sample collection

For collection of soil samples, grids of 0.2 km x 0.2 km were prepared in ArcGIS and then overlaid on landuse land cover map of the study area (Clusters- Sibbari, Balaram & Maracherra, Maps 2-3) derived from multi-temporal LISS-IV satellite image (5.8 m spatial resolution) of Indian Remote Sensing Satellite (IRPS-P6) during 2008. Grids representing major landuses in the clusters namely agriculture, horticulture cum plantation (fruits & vegetables, coffee, cashew) and waterbodies (pond / fisheries) on LISS-IV derived LULC were selected. Total agricultural area in Sibbari cluster was 697 ha (nearly 7 km^2). Therefore, a total of 150 grids each with an area of 0.045 km^2 (0.2 km x 0.2 km dimension) for 7 km^2 agricultural area in Sibbari cluster, South Garo Hills were selected and the mapping scale was 1:10,000. In Dhalai, Maracherra cluster had 20.85 ha and Balaram had 25.14 ha agricultural area (derived from satellite based estimation of LULC-2008). Therefore, for total agricultural area of approximately 4600 ha (46 km^2) for both clusters, we prepared nearly 450 grids having sizes (0.3 km x 0.3 km) and the samples were collected at 1:12,500 scale. From each of 150 and 450 grids at South Garo hills and Dhalai, geo-referenced composite (of 3) surface (0-15 cm) soil samples were collected during post monsoon months in 2010-2011. Total number of composite samples varied across landuses in the clusters (Table 13).

2.5.2 Laboratory analysis and interpretation

Soil bulk density (BD) was determined for all locations from the undisturbed samples by clod method (Blake and Hartge, 1986). The disturbed bulk soil samples were air dried, crushed and grinded to pass through a 0.5 mm sieve and then analysed for soil organic carbon content following wet digestion method (Walkley and Black, 1934). Soil textural class was determined by Hydrometer method (Buyoucous, 1962). Other soil properties like pH (1:2 soils: water), exchangeable Aluminium, effective CEC (1:2 soils: water), exchangeable cations (calcium, magnesium and potassium), available macro-nutrients (Nitrogen-N, Phosphorus-P, Potash-K and Sulphur-S) were determined following standard procedures (Jackson, 1973).

2.5.3 Spatial mapping of attributes and soil suitability index

Different thematic maps of soil properties were generated at 1:10,000 to 12,500 scales by using location of sample sites collected with GPS and sample analysis results of respective locations. A point layer was generated by entering latitude and longitude of sample sites by using ArcGIS software (v10). Sample analysis results were entered as attributes in the point layer. The attributes include sand, silt, clay percent, pH, ex. Al and ex. acidity, Al saturation, ex. bases, ECEC, N, P, K and S. The point layer represents location of 600 soil samples (150 from South Garo hills and 450 from Dhalai). Thematic maps were generated from the point layer by using spatial analyst tools of Arc Toolbox. For this study, kriging interpolation technique was applied. Based on the range of variation of different attributes, the thematic maps were classified into different classes and area statistics under each class was generated.

Setting up of scoring values of the indicators and transforming them into 1 to 4 scale

Before developing composite soil suitability index through soil weight matrix, parameters were given scores and accordingly, boundaries and shape of the scoring functions were set (Fig 4). This step scales and normalizes soil acidity, fertility and physical parameter measured in different units so that they can be combined into composite indices. The above soil parameters were transformed into unit less (1 to 4 scale) value by using three types of standardized scoring functions (i) More is better (ii) Less is better (iii) and Optimum is better.

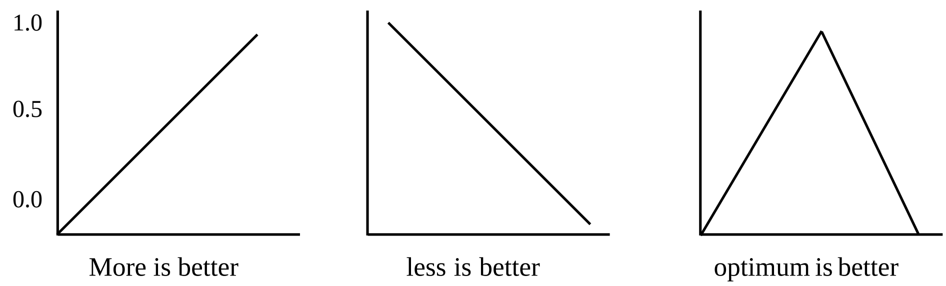


Fig.4: Standard scoring functions (SSF) used for normalization of soil quality indicators

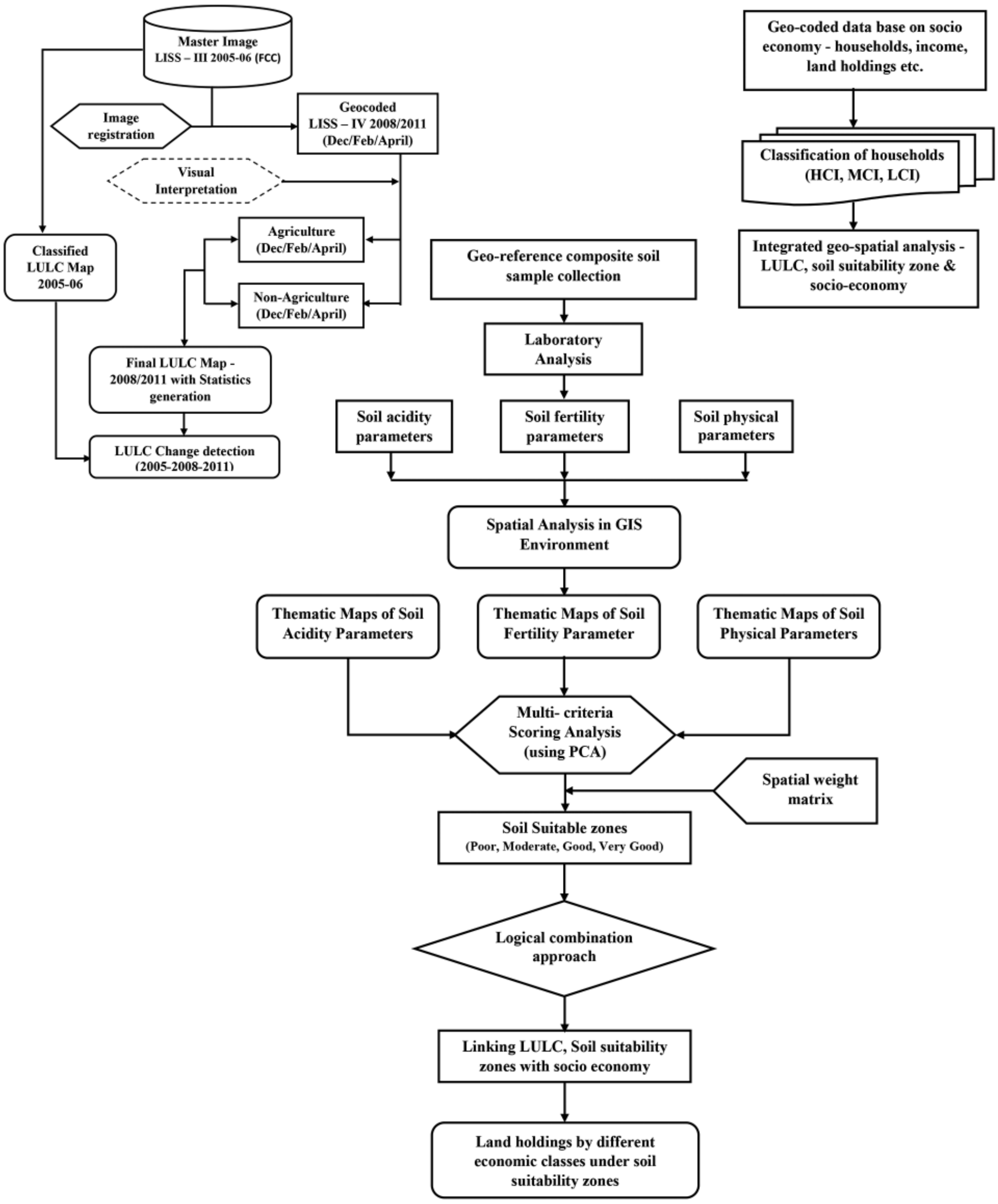
2.6 Socio-economic analysis

In Sibbari cluster, there were 11 villages comprising of 505 households stretched from 25.16 to 25.19 N latitude and 90.46 to 90.50 E latitude (Map 2, Table 2). Out of 505 households, following standard personal reprisal assessment (PRA) procedure, we surveyed randomly 135 households, geo-referenced and collected primary data on socio-economic aspects (annual income, source of income, land owned, agricultural land, family members). Primary data of 135 households were then extrapolated to represent the total 505 households of the cluster. Based on the range of variation in annual income of each household across the 11 villages of Sibbari cluster, we arranged them into three categories: high (annual income > Rs.1,20,000), medium (Rs.60,000-1,20,000) and low (<Rs. 60,000).

2.7 Integration of LULCC, soil suitability zone and socio-economy

Spatial multi-criteria decision-making approach is a process where geographical data is combined and transformed into a decision. It involves input data, the decision makers' preference and manipulation of both information using specified decision rules. Following standard procedure, a composite spatial soil suitability index was developed using multi-criteria decision-making approach in Geographical Information Systems (GIS) and statistical weighting/ratings (principal component analysis), through soil weight matrix and from the integration of spatial maps of different soil attributes (sand, silt, clay, bulk density, soil water retention, pH, exchangeable aluminium, ex. acidity, aluminium saturation in ex. complexes, ex. bases, ECEC, N, P, K and S) and their distribution pattern across the study area. During the course, scoring function (1-4) for individual parameters (based on sufficiency-deficiency criteria for acid soils) followed by spatial mapping in Arcmap 10, super-imposition of multilayer information, logical combination and finally, cumulative weighted score (25-51) zones were generated. Based on cumulative weighted rating score, four rating systems namely low (20-25), medium-low (26-30), medium-high (31-35) and high (36-51) were contrived. A detailed procedure of integration of landuse land cover map, soil suitability zone and socio-economic status of the households in delineation and assessment of distribution pattern has been presented in Fig. 5.

Fig.5: Flow diagram representing the stepwisespatial multi-criteria decision-making approachin integration of LULC map, soil suitability zone and socio-economic status



CHAPTER 3

RESULTS

3.1 LULC classification and change detection

A. Sibbari cluster, Gasuapara block, South Garo Hills

Land use land cover map of 2005-06 showed that in the Gasuapara block of South Garo Hills district, only 9.23% area was under settled agriculture (mostly paddy followed by vegetables) and an equal percent area (9.03%) was under shifting cultivation. The block had nearly 75% area under forests (dense & open) while the remaining area (7.07%) was under settlement, wasteland and water bodies (Table 6).

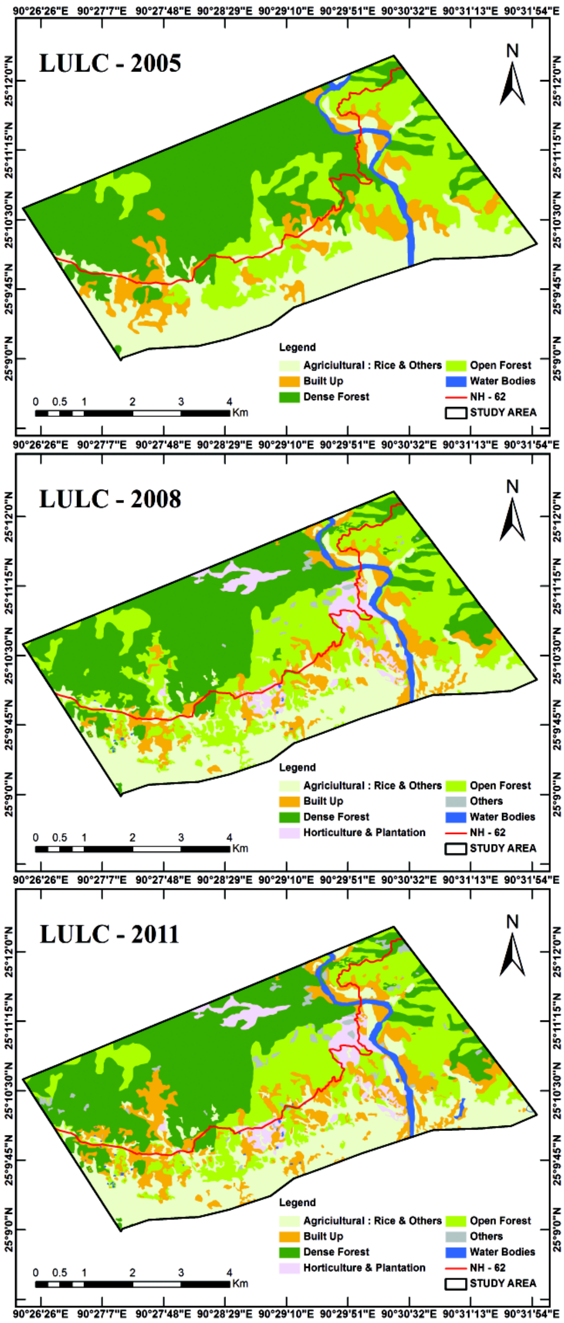
Table 6: Landuse pattern of Gasuapara Block, South Garo Hills District, Meghalaya estimated from satellite data (2005-06)

Landuse	Area (in ha)	Percent of geographical area
Agricultural Land	2610.7	9.23
Dense forest	11833.7	41.83
Open forest	9289.4	32.84
Shifting cultivation	2554.9	9.03
Wastelands	138.9	0.49
Water bodies	388.2	1.37
Built Up	1473.3	5.21
Total	**28289.1**	**100.00**

In the study area (Sibbari cluster comprising 11 villages), since no village boundary in digital format was available, we generated a digital boundary covering all the villages and some additional areas (mostly non-agriculture) surrounding the cluster of villages. While drawing boundary layer, care was taken to consider all the area covered by the IRS-P6 LISS-IV image (Path-row137/43). So, all together, an area of nearly 3058 hectare was considered for generation of landuse land cover map (2005-2008-2011) and finally, temporal change detection was done over a span of six years (2005/06-2008-2011). LULC map of 2005-06 derived from IRS-P6 –LISS-III (NRSC, 2011) was considered as baseline information while in 2008 and 2011, IRS-P6 LISS-IV multi-date data were used to derive LULC map of the respective years (discussed in Material and Method section).

Spatial distribution of landuses during 2008 and 2011 derived from remote sensing data (IRS-P6, LISS-IV) were shown in Map 4. During 2005-06, forests (dense and open) dominated the landuse by occupying nearly one third of the area (63.8%) followed by agriculture (24.5%), settlements (10.0%) while very less area (1.69%) was under water bodies (Table7). During 2008, forests (dense + open) occupied nearly 60% area followed by agriculture (22.98%), settlement (10.49%), horticulture and plantation (4.4%), water bodies (1.73%) and wastelands (0.58%). Similarly, during 2011, forests (dense + open) was the dominant landuse (55.37%) followed by agriculture (22.79%), settlement (13.95%), horticulture and plantation (4.46%), water bodies (1.91%) and wastelands (1.53%). Due to use of relatively finer resolution satellite data (LISS IV, 5.8 m spatial resolution) during 2008 & 2011 over 2005-06 (LISS-III, 23.5 m spatial resolution), we could be able to segregate and map an additional class i.e., wasteland in LULC map. Similarly, adoption of horticulture and pond based integrated farming systems during NAIP project intervention (2007 onwards) resulted in marginal increase in area under horticulture/plantation as well as water bodies.

Change detection over the periods (before implementation of NAIP period-2005-06 and after implementation-2011) reflected major shift in dense to open forest categories



Map 4: Temporal changes (2005-2008-2011) in landuse land cover derived from remote sensing data at Sibbari cluster, South Garo Hills

Table 7: Temporal changes in landuse pattern (in hectare) derived from remote sensing data of 2005-2011 in the study area (NAIP Cluster, Gasuapara Block, South Garo Hills)

Landuse classes	2005	2008	2011
Agriculture *	748.1	702.6	696.7
Settlement	306.7	320.7	426.4
Dense Forest	1226.8	992.0	977.7
Open Forest	724.0	835.6	715.3
Others#	—-	17.9	46.7
Horticulture & Plantation	—-	135.9	136.4
Water Bodies	51.8	52.8	58.3
Total	**3057.4**	**3057.4**	**3057.4**

*: mono and double cropped area; # degraded forests, barren + rocky lands, waste lands

(Fig. 6). Dense forest decreased from 40.25% of the total area (3,058 ha) in 2005-06 to 32.45% in three years period (during 2008) and at the same time, open forest increased from 23.68% (2005-06) to 27.33% (during 2008) of the area. However, on advancing from 2008 to 2011, area under open forest decreased from to 27.33% (in 2008) to 23.39% (2011).

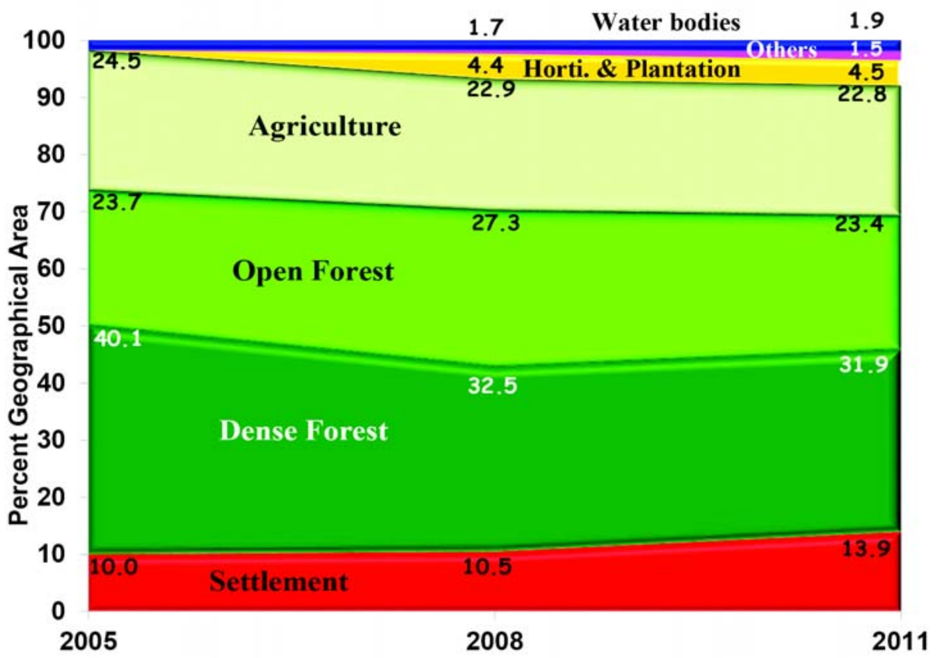


Fig. 6: Percent change (+/-) in LULC area of Sibbari cluster estimated from satellite data (2005-2011)

Similarly, during the same period, dense forest also decreased from 32.45% (in 2008) to 31.98% (2011) of the total area (3058 ha). This decrease in forest areas might be due to the increase in settlements from 10.5% (in 2008) to 13.95% (in 2011) as well as increase in wastelands from 0.58% (in 2008) to 1.53% (in 2011). During the same period (2008-2011), area under water bodies marginally increased from 1.73% to 1.91% while areas under horticulture-plantation remained almost constant (4.44-4.46%). Therefore, a general trend experienced in the study area was a decrease in forest cover (both dense & open) while settlements and wasteland were at increasing trend. Area under Horticulture-plantation and pond based integrated landuse system were slowly expanding in the Sibbari clusters.

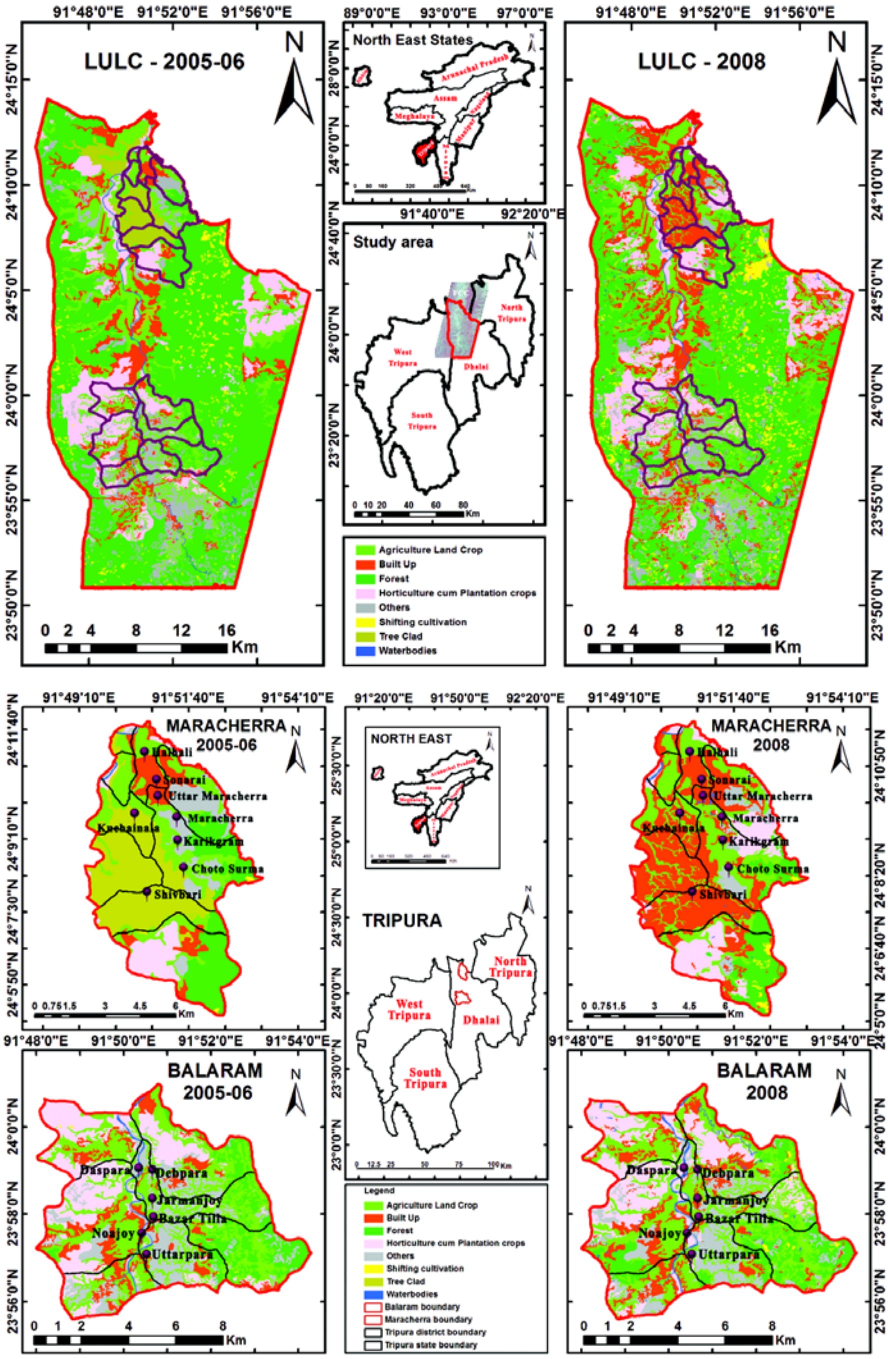
B. Maracherra and Balaram clusters, Dhalai, Tripura

The Map 5 shows the spatial distribution of landuses during 2005-06 (NRSC, 2011) and 2008 derived from remote sensing data (IRS-P6, LISS-IV) for Maracherra cluster, Dhalai. Total geographical area (TGA) in Maracherra cluster comprising 8 villages (*viz*. Choto Surma, Karikgram, Shivbari, Halhali, Kuchainala, Maracherra, Uttar Maracherra and Sonarai) was 5050.9 hectare. Remote sensing based estimated landuse pattern during 2005-06 reflects that among the major LULC, open forest (31.8% of TGA) followed by settled agriculture (23%) and dense forest (18%) occupied nearly 73% of the TGA (Table 8). Horticulture and plantation also occupied significant chunk of the area (7.5%). Settlement (rural and urban) occupied 9.2% of TGA. Area under shifting cultivation (0.21%) and water bodies (0.33%) were marginal while others mostly wastelands (scrubs/riverine/sandy), occupied considerable (10%) area of the cluster. Over a span of three years (2008 over 2005-06), LULC reflected considerable changes. Among the most significant changes, area under built up increased substantially from 9.2 (in 2005-06) to 40.7% of TGA in 2008 (Table 8).

Similarly, area under settled agriculture also increased from 23.0% (in 2005-06) to 27.6% (in 2008). Horticulture and plantation also experienced an expansion in area from7.5%

Table 8: Remote sensing derived landuse land cover change in Maracherra clusters, Dhalai

Maracherra cluster	2008	%	2005-06	%	Change	% difference
Agriculture	1394.8	27.6	1161.1	23.0	233.7	4.6
Built Up	2056.6	40.7	464.9	9.2	1591.7	31.5
Dense forest	574.7	11.4	906.7	18.0	-332.0	-6.6
Open forest	0.0	0.0	1604.3	31.8	-1604.3	-31.8
Horti. + Plantation	690.4	13.7	379.0	7.5	311.4	6.2
Others	253.1	5.0	507.6	10.0	-254.5	-5.0
Shifting cultivation	51.0	1.01	10.6	0.21	40.4	0.8
Waterbodies	30.3	0.60	16.8	0.33	13.5	0.3
Total area			**5050.9 ha**			



Map 5: Temporal changes (2005 & 2008) in LULC derived from remote sensing data at Maracherra and Balaram clusters, Dhalai

(in 2005-06) to 13.7% (in 2008), which might be due to the intervention of horticulture based integrated farming systems during the NAIP project implementation period in that cluster. This was also evident from the considerable decrease in area under wastelands from 10.0% (in 2005-06) to 5.0% in 2008. Some of the areas under wasteland had been transformed into horticulture based LULC. However, due to the increase in population pressure and subsequent increase in area under built up by 31.5% of TGA resulted in complete removal of open forests which reduced from 31.8% in 2005-06 to almost negligible in 2008. Similarly, increase in horticulture and plantation as well as agricultural area also resulted in significant reduction in dense forests from 18.0% (in 2005-06) to 11.4% in 2008. The general trend in LULC change in Maracherra cluster was on the way to deforestation (evident from the decrease in forest areas), mostly driven by population pressure led increase in settlement areas. However, with the collective efforts of NAIP as well as other line departments**,** there is silver lining reflected by an increase in area under horticulture based plantation as well as decrease in wastelands.

Spatial distribution of landuses during 2005-06 (NRSC, 2011) and 2008 derived from remote sensing data (IRS-P6, LISS-IV) for the Balaram cluster, Dhalai was shown in Map 5. Balaram cluster comprising 6 villages (Uttarpara, Noajoy, Bazar Tilla, Jarmanjoy, Debpara and Daspara) had TGA of 6420.1 ha and during 2005-06, agriculture was the dominant landuse (37.0%) followed by horticulture -plantation (21.97%). Forest (dense) occupied only 12.1% area while wastelands occupied significant proportion of the TGA (17.0%) (Table 9). After three years (2008), landuse pattern was more or less comparable to 2005-06. During 2008, agriculture was the dominant (36.43%) landuse followed by horticulture -plantation (19.72%), wastelands (15.1%), dense forests (13.59%) and built up (13.15%). Shifting cultivation and water bodies occupied marginal areas. Change detection over a span of 3 years (2005-06 to 2008) reflected an increasing trend in area under built up, dense forest, shifting cultivation and water bodies while a decreasing trend was observed in areas under horticulture and plantation, wastelands and agriculture (Table 9).

Table 9: Remote sensing derived landuse land cover change in Balaram cluster, Dhalai

Balaram cluster	**2008**	**%**	**2005-06**	**%**	**Change**	**% difference**
Agriculture	2339.1	36.43	2377.4	37.03	-38.2	-0.60
Built Up	844.4	13.15	698.8	10.88	+145.6	+2.27
Dense forest	872.3	13.59	777.7	12.11	+94.6	+1.47
Horti. + Plantation	1266.1	19.72	1410.6	21.97	-144.5	-2.25
Others	965.9	15.05	1093.3	17.03	-127.4	-1.98
Shifting cultivation	32.7	0.51	3.1	0.05	+29.6	+0.46
Water bodies	99.6	1.55	59.2	0.92	+40.4	+0.63
Total area			**6420.1 ha**			

3.2 Spatial variability in soil health attributes

A. Sibbari cluster, South Garo Hills, Meghalaya

Soil physical and chemical properties were determined from geo-referenced composite samples of 150 locations at 1: 10,000 scale representing the agricultural area (693.7 ha) in the Sibbari cluster (Tables 10-12). Majority of the soils (97.2% of the total agricultural area of 693.7 ha) were coarse to medium in texture, with high sand content (>50%). Nearly 75% TAA had silt contents in the range of 10-20% and clay content of 20-25% (Table 10). Spatial distribution of soil separates mapped at 1:10,000 scale is shown in Map 6.

Table 10: Distribution of soil separates (sand, silt & clay) across agricultural area of Sibbari cluster

Sand (%)	% TAA	Silt (%)	% TAA	Clay (%)	% TAA
25 - 40	0.14	5 - 10	1.15	10 - 20	18.08
40 - 50	2.59	10 - 20	74.57	20 - 25	76.80
50 - 60	54.1	20 - 30	24.24	25 - 35	5.08
60 - 80	43.1	30 - 40	0.04	35 - 45	0.04

Total agricultural area (TAA) = 693.7 ha

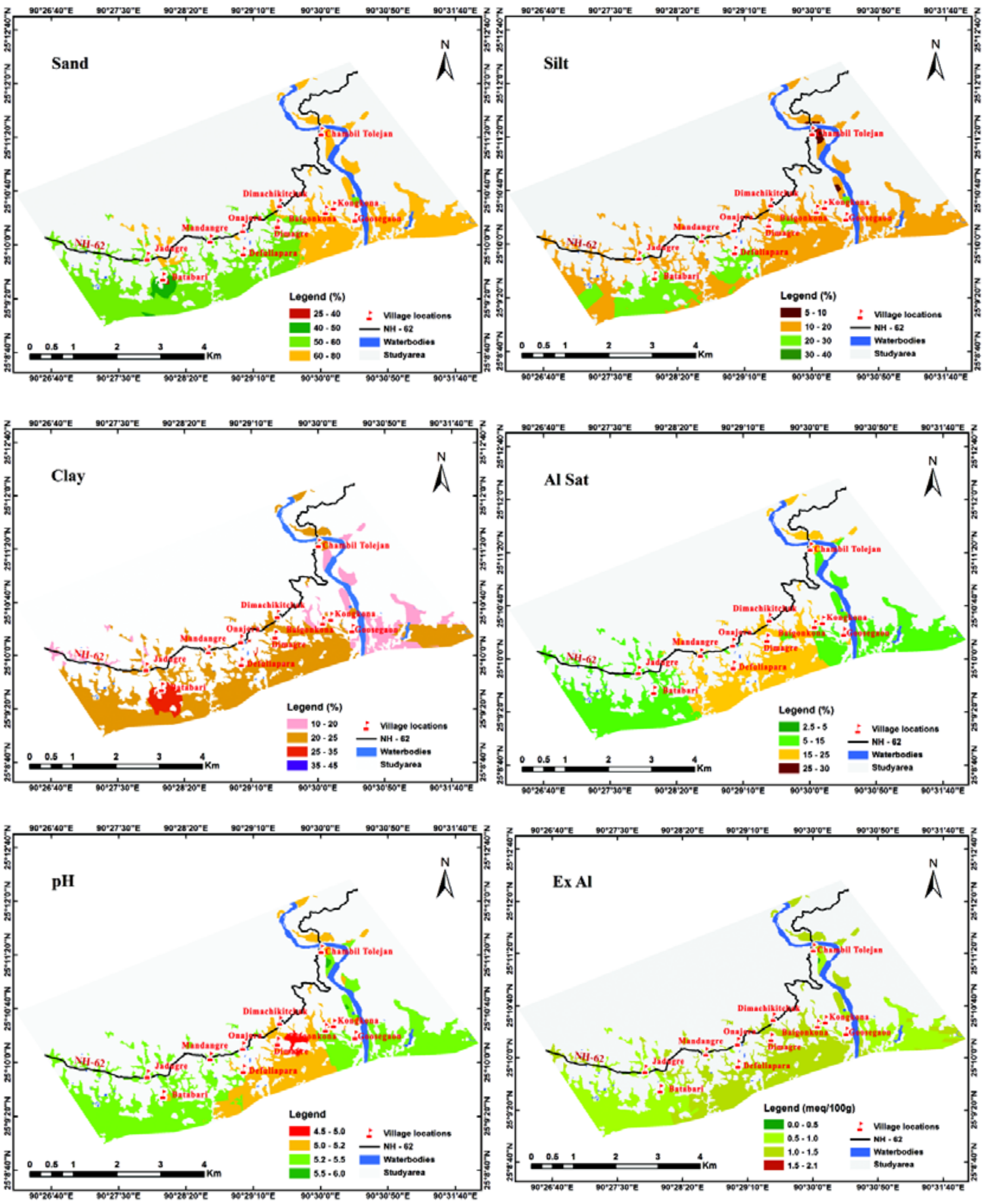
Unlike other parts of Meghalaya having dominance of strong acid soils (pH<5.0) (Patiram, 2007), majority of these soils (>97% of TAA) in the study area (Sibbari cluster) were moderately acidic in reaction (pH>5.0) but low to medium (4-8 meq/100 gm soil) in exchangeable bases (Table 11). In 98.3% TAA, effective cation exchange capacity was low (ECEC: 5-8 meq/100 g soil) while more than 54% TAA had higher exchangeable aluminium (Al^{3+}) content (1.0-1.5 meq/100 g soil) than the critical limit of 1.0 meq/100 g soil (Patiram, 2007). Nearly 2/3rd area (65.1% of TAA) had permissible aluminium saturation (5-15%) in the exchange complexes of clay while the remaining one third (34.9% of TAA) had relatively higher aluminium saturation in clay complexes (Table 11).

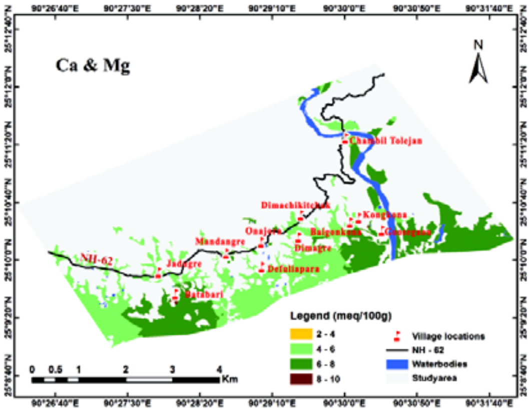
Table 11: Distribution of soil acidity parameters across agricultural area of Sibbari cluster

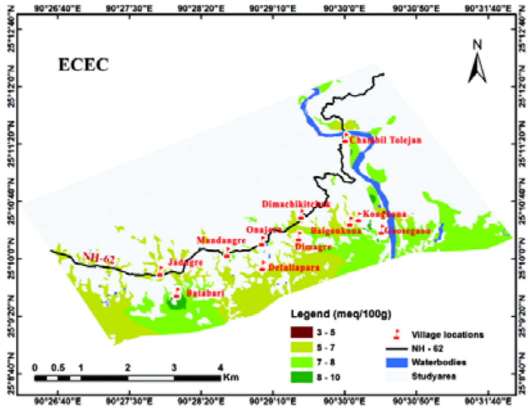
pH	TAA (%)	Bases (meq/ 100g)	TAA (%)	ECEC (meq/ 100g)	TAA (%)	Ex.Al (meq/ 100g)	TAA (%)	Al saturation (%)	TAA (%)
4.5 - 5.0	1.82*	4 - 6	53.45	5 - 7	50.00	0.5 - 1.0	45.98	5 - 15	65.10
5.0 - 5.5	97.53	6 - 8	46.47	7 - 8	48.30	1.0 - 1.5	54.01	15 - 25	34.90
5.5 - 6.0	0.65	8 - 10	0.08	8 - 10	1.70				

Total agricultural area (TAA) = 693.7 ha   * Percent of total agricultural area

Map 6: Spatial distribution of sand, silt and clay (in %) and soil acidity parameters across agricultural area in Sibbari cluster







Majority (>96% of TAA) of the soils of the study area were very high in soil organic carbon content (SOC: 1.5-2.5%) while only marginal area (<2.5% TAA) had SOC content of <= 1.0%. Soils were medium (200-300 kg ha^{-1}) medium in available nitrogen (N) and potash (250-350 kg ha^{-1}) contents. However Soils were mostly defficient in available phosphorus (<= 30 kg ha^{-1}) (Table 12). Due to very high in SOC and medium in clay contents, available sulphur content in the soils was medium (20-40 kg ha^{-1}) to very high (40-60 kg ha^{-1}) (Table 12). Spatial distribution pattern in soil fertility status mapped at 1:10,000 scales across the cluster is presented in Map 7.

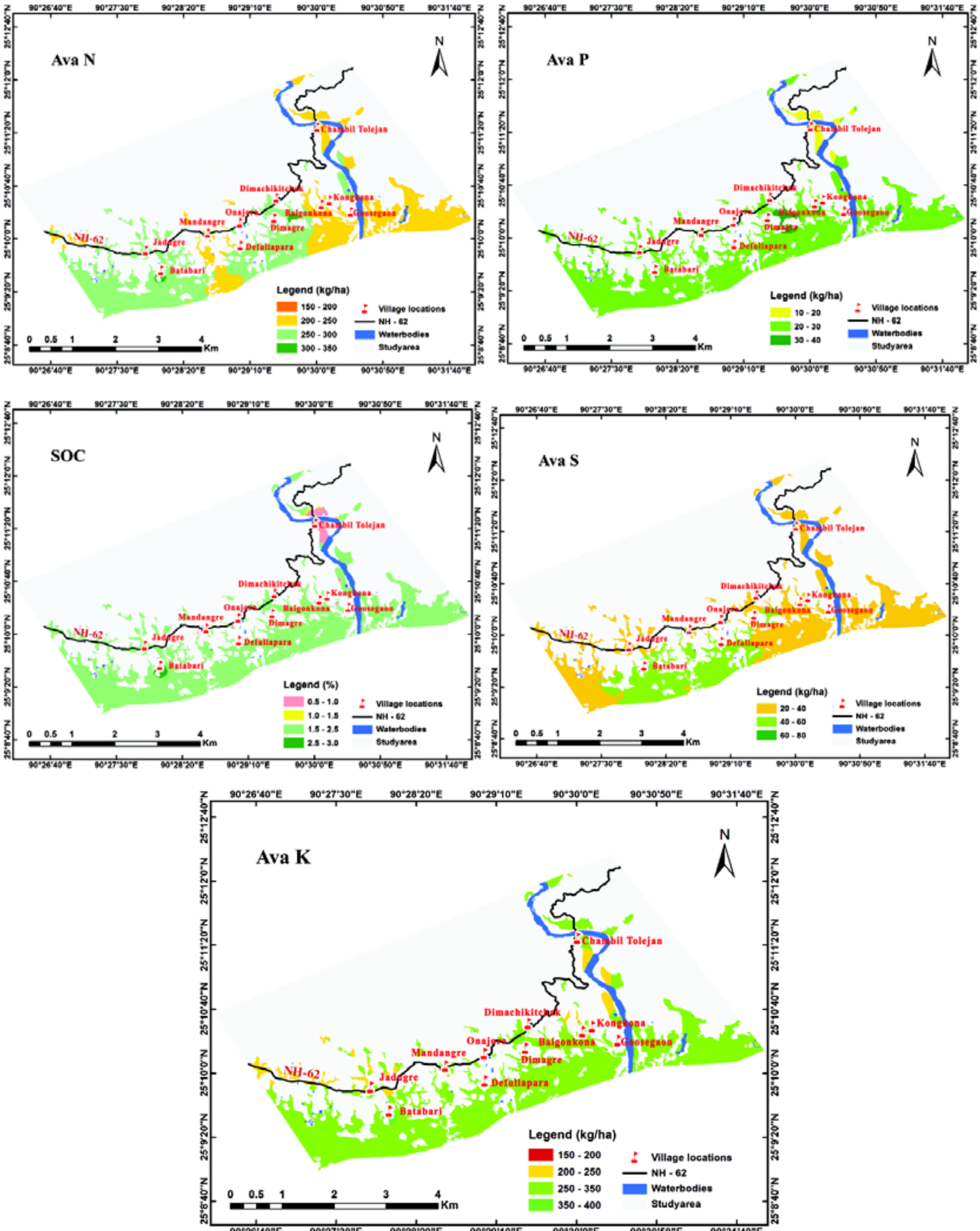
Table 12: Distribution of soil fertility parameters across agricultural area of Sibbari cluster

OC (%)	TAA (%)	Av.N kg ha^{-1}	TAA (%)	Av.P kg ha^{-1}	TAA (%)	Av.K kg ha^{-1}	TAA (%)	Av.S kg ha^{-1}	TAA (%)
0.5 - 1.0	2.49*	150 - 200	0.03	10 - 20	3.93	150 - 200	0.00	20 - 40	66.90
1.0 - 1.5	0.30	200 - 250	43.20	20 - 30	93.40	200 - 250	6.31	40 - 60	33.10
1.5 - 2.5	96.70	250 - 300	55.90	30 - 40	2.72	250 - 350	93.2	60 - 80	0.02
2.5 - 3.0	0.53	300 - 350	0.79			350 - 400	0.46		

Total agricultural area (TAA) = 693.7 ha

* Percent of total agricultural area

Overall, soils of the area (Sibbari clusters) were moderately acidic but fertile compared to other regions of Meghalaya including South Garo Hills district. Therefore, in the immediate future, the chances of acidity induced fertility stress on crop growth is minimal and acid soil ameliorative measures like application of inorganic amendments (e.g. agricultural lime) can be avoided for some more time. However, for sustaining soil health including fertility status,



Map 7: Spatial distribution of soil fertility parameters across agricultural area in Sibbari cluster

physical health and crop intensification, periodic replenishment of plant nutrients from organic sources along with supplementation from inorganic sources to support optimum crop production is needed.

B. Maracherra cluster, Dhalai, Tripura

Spatial distribution of soil textural (sand, silt & clay) as well as bulk density properties mapped at 1:12,500 scale in the Maracherra cluster, Dhalai is presented in Map 8**.** In nearly 75% total agricultural area (TAA: 2085.2 ha), percent sand content varied between 70 to 80% while in the remaining area (25% of TAA), sand was 50-70% (Table 13).

Table 13: Distribution of soil separates and bulk density across agricultural area of Maracherra cluster, Dhalai

Sand (%)	% TAA	Silt (%)	% TAA	Clay (%)	% TAA	BD (Mg m^{-3})	% TAA
50 - 70	25.01*	2.0 - 3.0	43.10	11 - 20	5.05	0.9 - 1.2	0.24
70 - 80	74.83	4.0 - 6.0	54.25	20 - 30	94.95	1.2 - 1.4	99.29
80 - 85	0.15	6.0 – 13.0	2.65	—-	—-	1.4 - 1.5	0.47

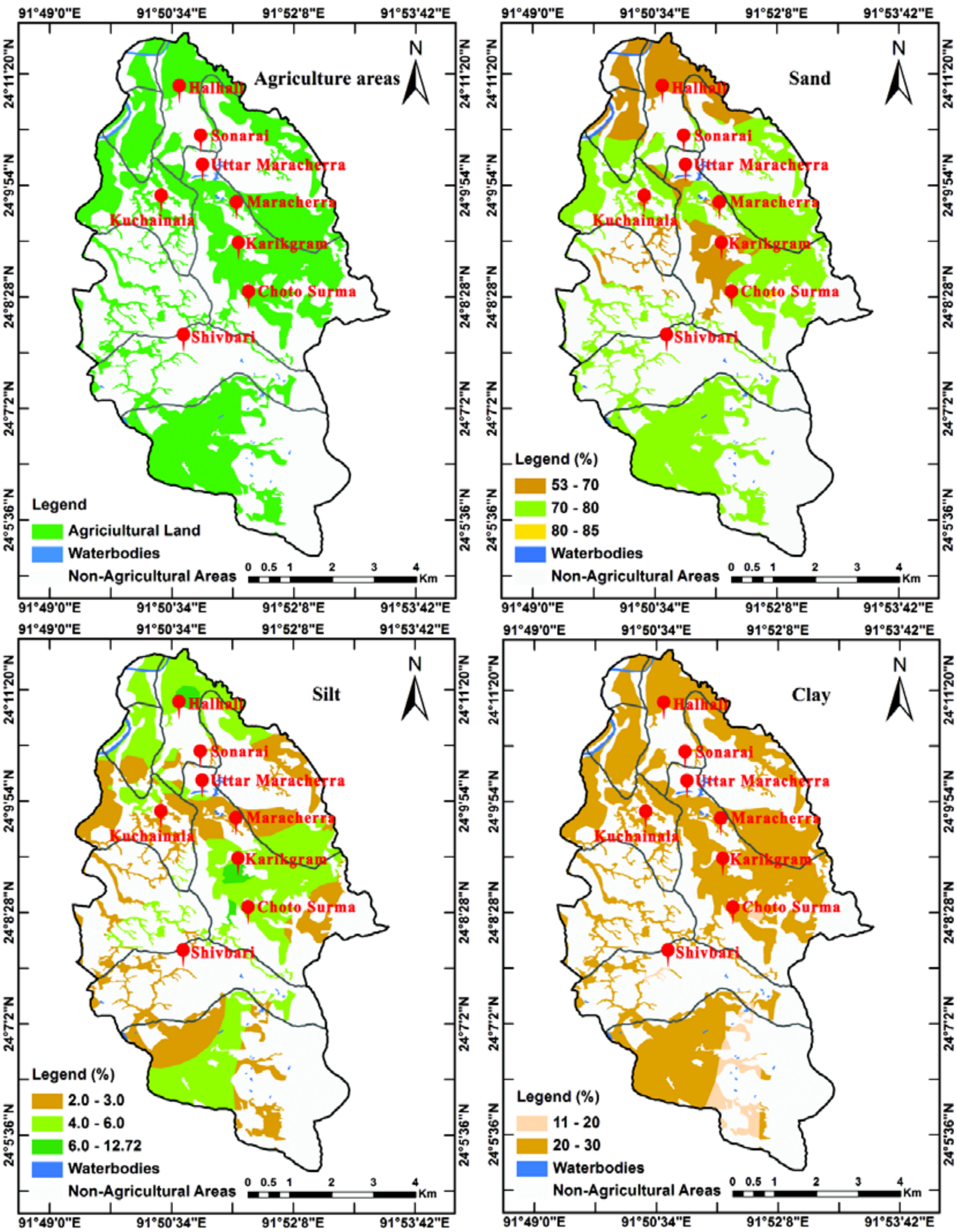
Total agricultural area (TAA) = 2085.2 ha

* Percent of total agricultural area

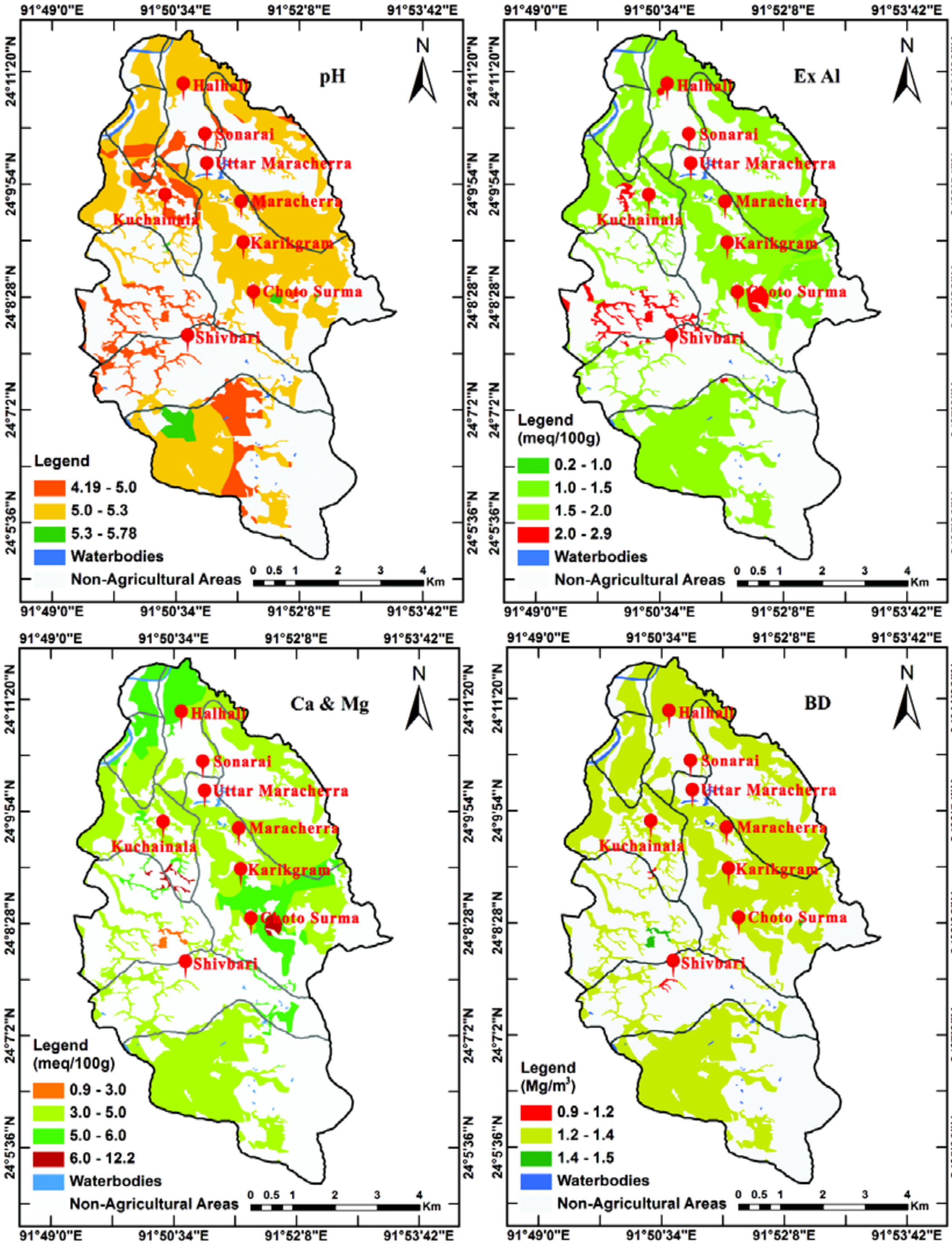
This shows that soils of the cluster were coarse in texture with very high sand content. Silt content in majority of the TAA (>90%) was very less (<7%). However, clay content was moderate (20-30%) (Table 14). In this coarse textured soils, presence of moderate clay content will partially help in overcoming water retention and other associated hydro-physical constraints. Due to the dominance of coarser texture (sands), soil bulk density values in the soils were relatively high (1.2-1.4 Mg m^{-3}) compared to 1.1-1.2 Mg m^{-3} in most of the agricultural upland soils of NE Region (Choudhury et al., 2013).

Spatial distribution pattern in soil acidity parameters have been mapped at 1:12,500 scales and were shown in Map 9. In the study area (Maracherra cluster), nearly 80% soils in the agricultural area (TAA) were moderately acidic in reaction (pH>5.0) while soils in 1/ 5^{th} area (19.53% TAA) were strongly acidic (pH: 4.2-5.0) in reaction (Table 14).

pH was relatively higher (>5.0) in most of the soils, yet, exchangeable aluminium contents in the soils (>99.9% TAA) were in higher range (> 1.0 meq/100 g soil) much above the critical limit of (1.0 meq/100 g soils). Due to higher exchangeable aluminium and ex. acidity, nearly 80% soils had low (<5 meq/100 g soils) exchangeable bases (Ca and Mg). Thus, it demands selective soil acidity related ameliorative measures for overcoming acidity induced abiotic stress for optimum crop growth.



Map 8: Spatial distribution of sand, silt and clay (in %) across agricultural area in Maracherra cluster, Dhalai



Map 9: Spatial distribution of soil acidity parameters across agricultural area in Maracherra cluster

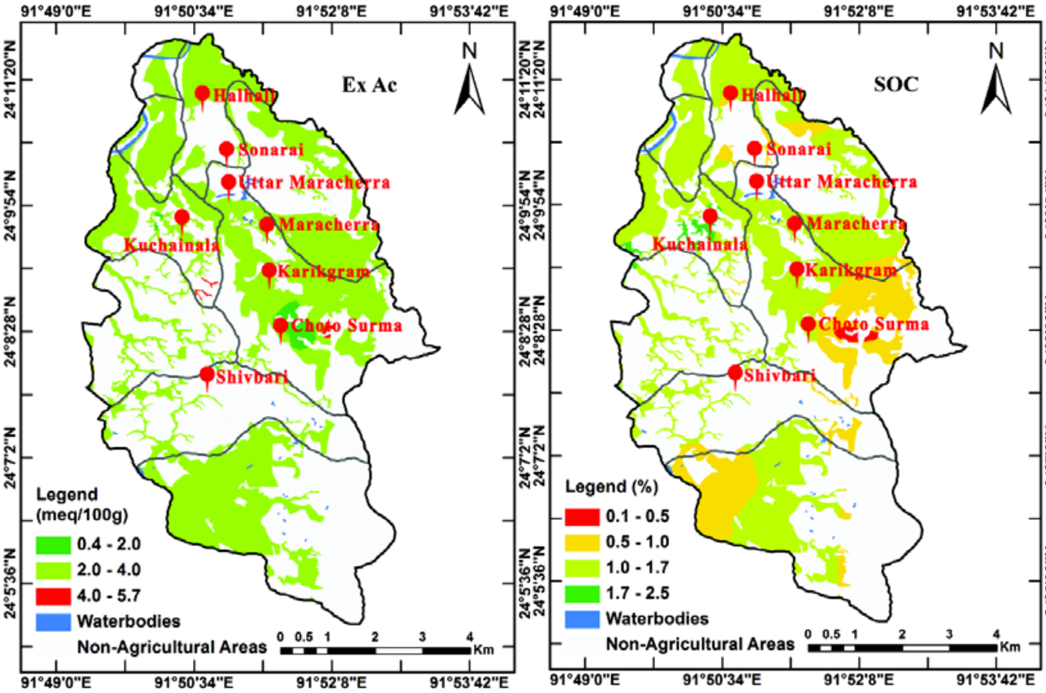


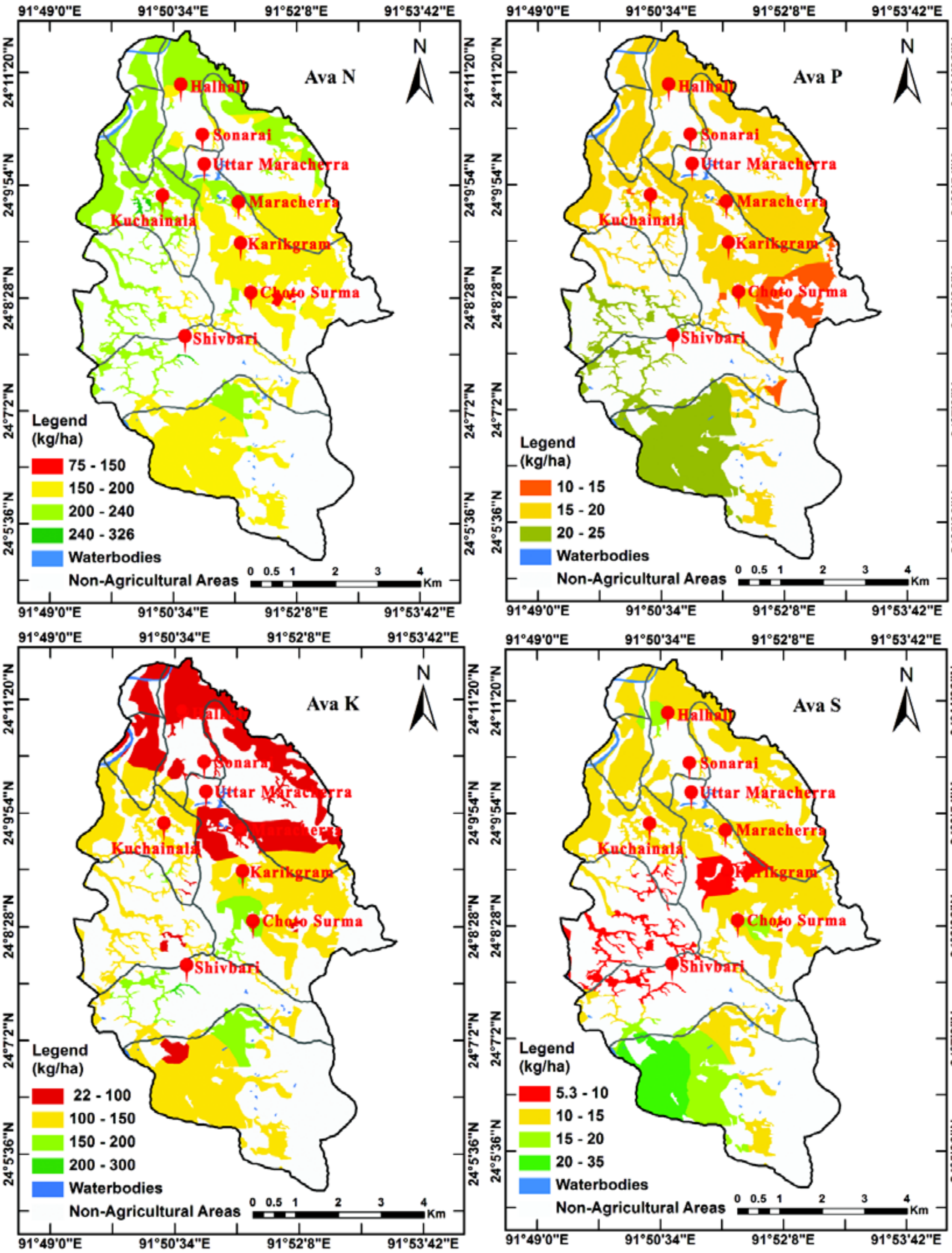
Table 14: Distribution of soil acidity parameters across agricultural area of Maracherra cluster, Dhalai

pH	Area (%)	Ex. acidity (meq/100g)	Area (%)	Ex.Al (meq/100g)	Area (%)	Ex. Ca+Mg (meq/100g)	Area (%)
4.2 - 5.0	19.53*	0.4 - 2.0	2.12	0.2 - 1.0	0.06	0.9 - 3.0	0.51
5.0 - 5.3	78.10	2.0 - 4.0	97.58	1.0 - 1.5	8.29	3.0 - 5.0	78.01
5.3 - 5.78	2.37	4.0 - 5.7	0.31	1.5 - 2.0	87.11	5.0 - 6.0	20.42
——	—-	—-	——	2.0 - 2.9	4.54	6.0 - 12.2	1.06

Total agricultural area = 2085.2 ha

* Percent of total agricultural area

Spatial distribution of soil fertility parameters (SOC, available N, P, K & S) didn't show any particular pattern and the content varied spatially across the clusters (Map 10). Nearly 3/4th of the soils (>72% TAA) was high in soil organic carbon (SOC: 1.0-1.7%) content while 1/4th of agricultural area (>26% TAA) had low soil organic carbon content (SOC :< 1.0%) (Table 15). Among the NE states, and large, SOC content in the soils of Tripura are relatively low compared to other NE states (Choudhury et al., 2013). Due to low SOC content, available nitrogen (N) content was low (150-200 kg ha^{-1}) in more than 56%



Map 10: Spatial distribution of soil macro-nutrients across Maracherra cluster, Dhalai

TAA while medium (200-240 kg ha^{-1}) in >42% of TAA. Overall, soils were mostly deficient in available phosphorus (<= 25 kg ha^{-1}) and nearly 75% TAA had extremely low (<= 20 kg ha^{-1}) available phosphorus content. Available potash content was also extremely low (<150 kg ha^{-1} in >91% of TAA) (Table 15). Due to low to medium SOC and clay contents, available sulphur content in the soils was low (<20 kg ha^{-1}) in majority of the area (>90% TAA) (Table 15). Overall, the soils under agricultural area in Maracherra cluster of Dhalai district was low in soil fertility status (low SOC, available N, P, K and S). Therefore, periodic replenishment of plant nutrients both from organic and inorganic sources in balanced proportion is the urgent need for sustaining crop as well as land productivity *vis-à-vis* soil health and food security in the region.

Table 15: Distribution of soil fertility parameters across agricultural area of Maracherra cluster, Dhalai

OC (%)	Area (%)	Av.N kg ha^{-1}	Area (%)	Av.P kg ha^{-1}	Area (%)	Av.K kg ha^{-1}	Area (%)	Av.S kg ha^{-1}	Area (%)
0.1 - 0.5	0.64*	150 - 200	57.36	10 - 15	8.93	20 - 100	31.89	5.0 - 10	9.89
0.5 - 1.0	25.39	200 - 240	42.26	15 - 20	65.60	100 - 150	59.40	10 - 15	68.81
1.0 - 1.7	72.36	240 - 326	0.38	20 - 25	25.47	150 - 200	8.52	15 - 20	12.03
1.7 - 2.5	1.61	——		—-	—-	200 - 300	0.20	20 - 35	9.27

Total agricultural area = 2085.2 ha

* Percent of total agricultural area

C. Balaram cluster, Dhalai, Tripura

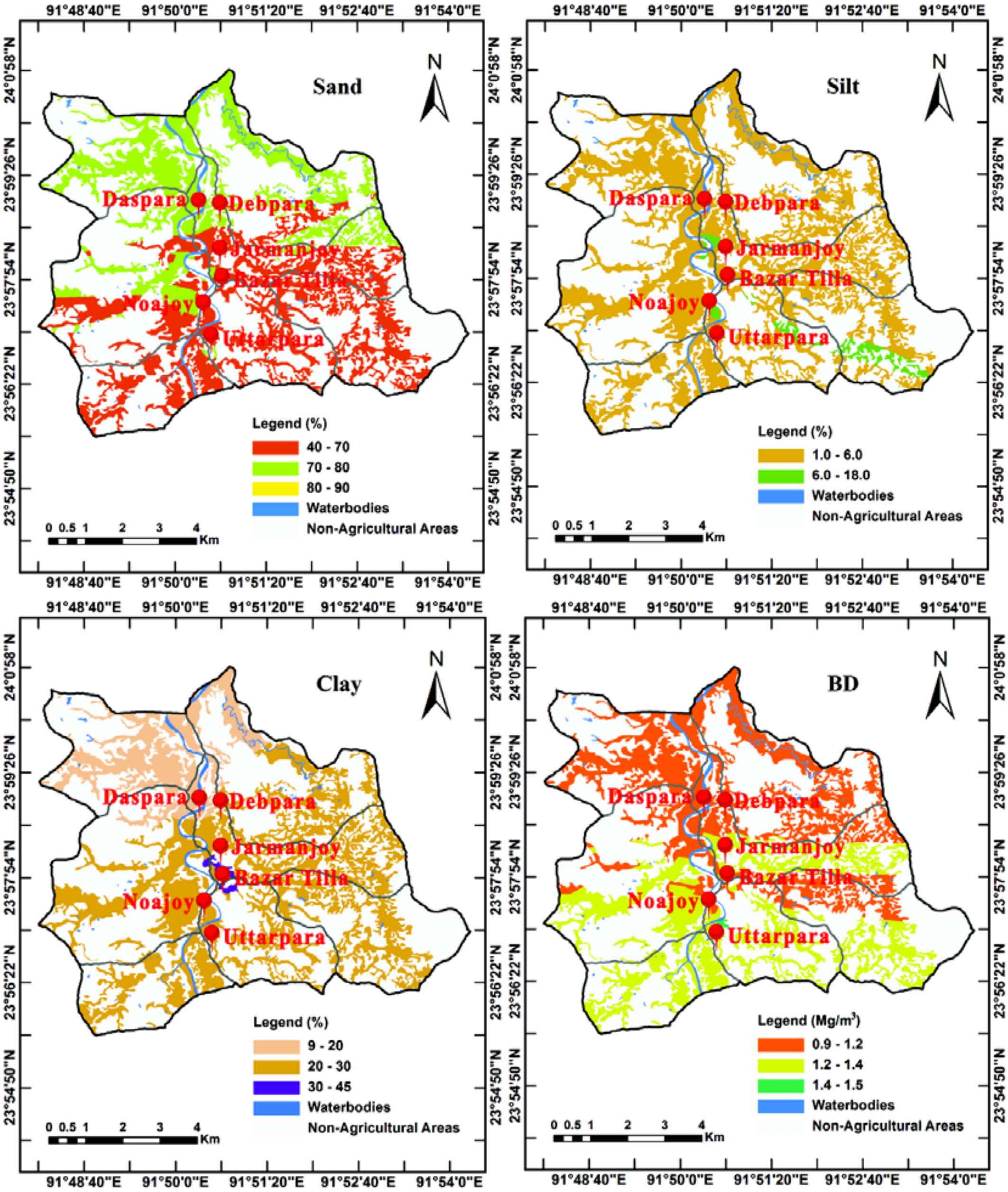
Spatial distribution of soil separates (sand, silt & clay) and bulk density across agricultural area in Balaram cluster, Dhalai was mapped at 1:12,500 scale and has been presented in Map 11. Among the soil separates, sand was the dominant fraction, with a variation from a minimum content of 40% to as high as 90% and in 45.19% agricultural area, minimum sand content ranged from 70-80% (Table 16). In the remaining 54.68% TAA, sand content ranged from 40-70%.This shows that soils of the cluster was invariably coarser in texture with very

Table 16: Distribution of soil separates and bulk density across agricultural area of Balaram cluster

Sand (%)	Area (%)	Silt (%)	Area (%)	Clay (%)	Area (%)	BD(Mg m^{-3})	Area (%)
40 - 70	54.68*	1.0 - 6.0	95.77	9 - 20	24.15	0.9 - 1.2	53.59
70 - 80	45.19	6.0 - 18.0	4.23	20 –30	74.71	1.2 - 1.4	46.23
80 - 90	0.12	—-	—-	30–45	1.14	1.4 - 1.5	0.18

Total agricultural area = 2513.6 ha

* Percent of total agricultural area



Map 11: Spatial distribution of soil separates and bulk density parameters across agricultural area in Balaram cluster

high sand content. Silt content was considerably low (<20%), and in >95% TAA silt content varied from 1-6% only. However, clay content was moderate (20-30%) in major chunk of TAA (>74%). However, in 1/4th of the agricultural area, clay content was low (9-20%) (Table 15). Due to the dominance of coarse texture, soil bulk density values were moderate (0.9-1.2 Mg m^{-3}) to high (1.2-1.4 Mg m^{-3}) in significant chunk of agricultural area (Table 16).

Spatial distribution pattern in soil acidity parameters have been shown in Map 12. More than half of the soils (>55% of TAA) in the Balaram clusters were strongly acidic in reaction (pH =5.0) while the remaining (44.36% of TAA) soils were moderately acidic in reaction (pH: >5.0-5.7<) (Table 17). Due to strong to moderately acidic pH, exchangeable bases, particularly Ca and Mg contents were very low (3-5 meq/100 g soil) in most of the soils (>91% of TAA).

In-spite of strong soil acidity in major chunk of agricultural area (>55%) and low bases in >90% TAA, exchangeable aluminium content in more than half of the area (>56% TAA) was below critical range (1.0 meq/100 g soil). However, in more than 42% TAA, level of exchangeable aluminium was above critical range and thus, needs location specific soil acidity induced stress management (amelioration) for optimum crop growth and sustainability of soil health on long run.

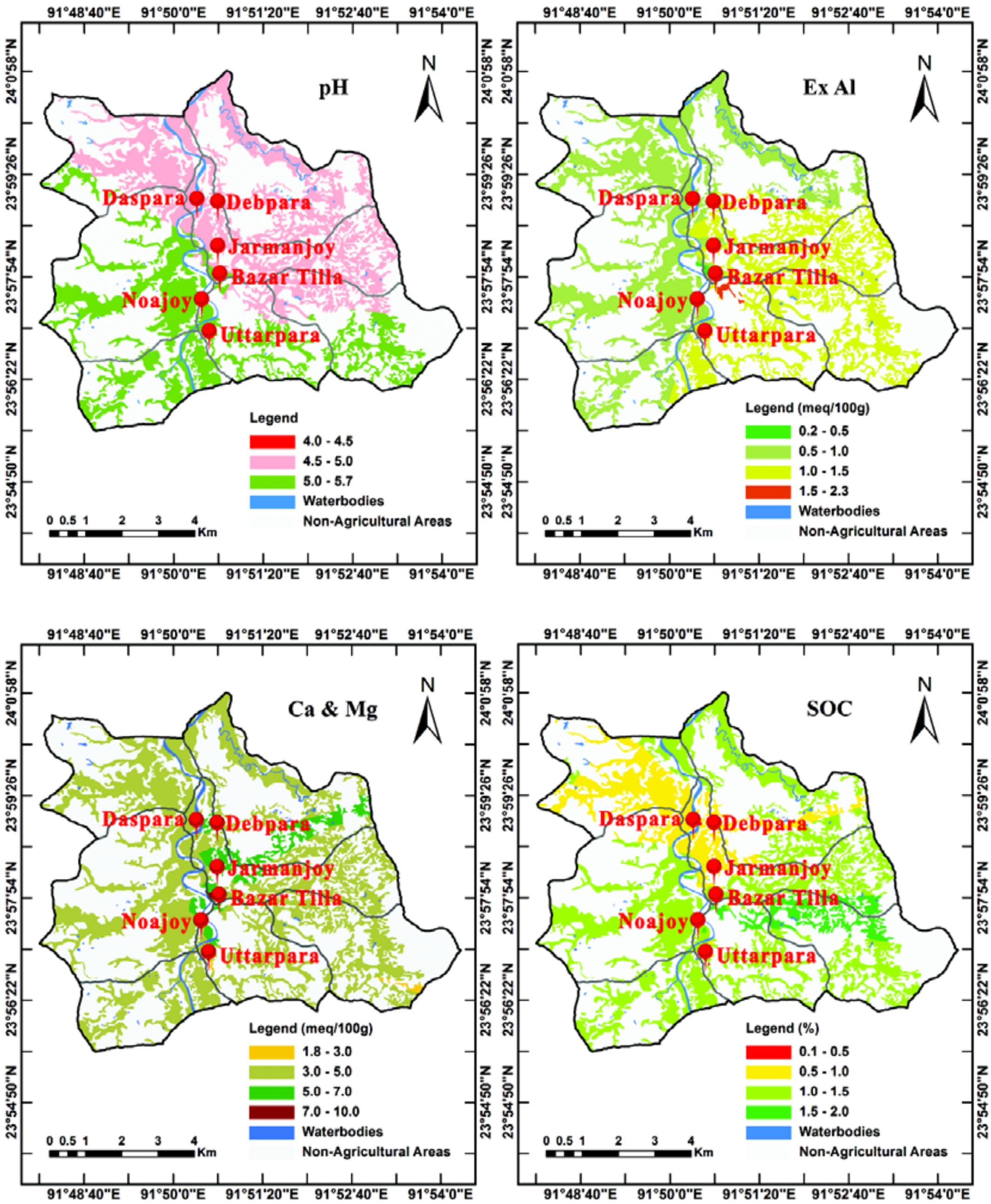
Table 17: Distribution of soil acidity parameters across agricultural area of Balaram cluster, Dhalai

pH	Area (%)	Ex. acidity (meq/100g)	Area (%)	Ex.Al (meq/100g)	Area (%)	Ex. Ca+Mg (meq/100g)	Area (%)
4.0 - 4.5	0.01*	0.3 - 1.5	6.78	0.2 - 0.5	0.25	1.8 - 3.0	0.57
4.5 - 5.0	55.63	1.5 - 2.5	54.99	0.5 - 1.0	56.86	3.0 - 5.0	91.60
5.0 - 5.7	44.36	2.5 - 3.5	37.92	1.0 - 1.5	42.50	5.0 - 7.0	7.63
—-	——	3.5 - 5.0	0.31	1.5 - 2.3	0.39	7.0 - 10.0	0.21

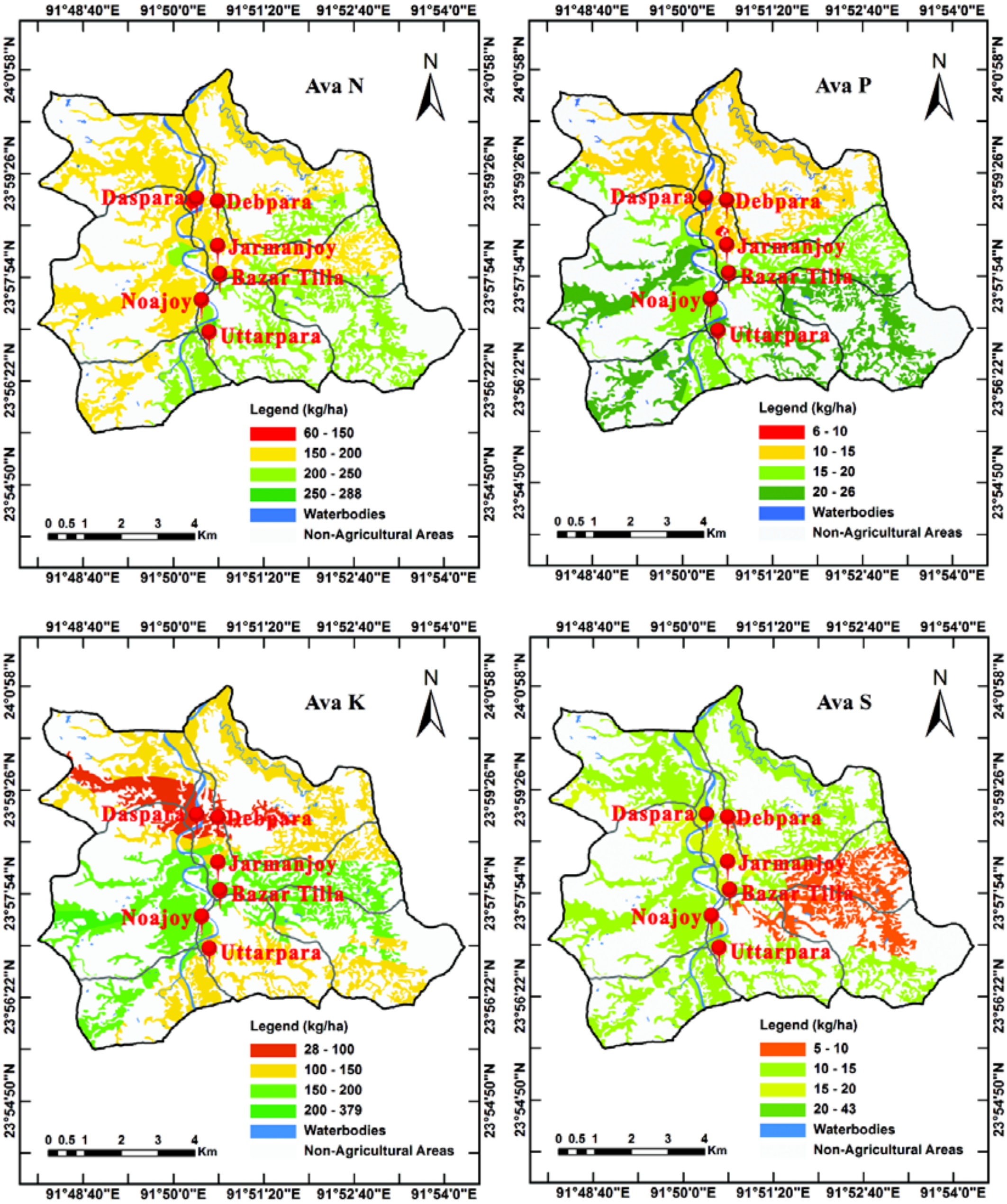
Total agricultural area = 2513.6 ha

* Percent of total agricultural area

Spatial distribution pattern of different soil fertility parameters (SOC, available N, P, K & S) varied widely across the agricultural area of the Balaram cluster and were mapped at 1:12,500 scale (Map 13). Nearly 70% agricultural area had medium soil organic carbon (SOC: 1.0-1.5%) content while 23% agricultural area were low in SOC content (SOC : <1.0%). Only 8.29% of TAA had very high SOC content (1.5-2.0%) (Table 18). Compared to other NE states, soils of Tripura are low in SOC content (Choudhury et al., 2013) and this has been reflected in the present study also. Due to low in SOC content, available nitrogen (N) content was very low (150-200 kg ha^{-1}) in more than 62% TAA while low to medium (200-250 kg ha^{-1}) in the remaining areas (TAA: 37.29%). Overall, soils were mostly deficient in available phosphorus (<= 25 kg ha^{-1}) and in >34% TAA, available phosphorus was extremely



Map 12: Spatial distribution of soil acidity parameters and SOC content across agricultural areas in Balaram cluster



Map 13: Spatial distribution of soil fertility parameters across agricultural area in Balaram cluster

low (<=15kg ha^{-1}) (Table 18). Similarly, available potash content was also extremely low (=150kg ha^{-1}) in >58% TAA of the cluster and in the remaining area (41.82% TAA) also, available potash content was < 200 kg ha^{-1}. Due to low to medium in SOC and clay contents, available sulphur content in the soils were very low (<=15 kg ha^{-1}) in majority of the area (>90% TAA) (Table 18). Overall, soils under agricultural area in Balaram cluster of Dhalai district, similar to Maracherra cluster of the same district was low in soil fertility status (low SOC, available N, P, K and S). Therefore, periodic replenishment of plant nutrients both from organic and inorganic sources in balanced proportion is the urgent need for sustaining crop as well as land productivity *vis-à-vis* soil health and food security in the region.

Table 18: Distribution of soil fertility parameters across agricultural area of Balaram cluster, Dhalai

OC %	Area %	Av.N kg ha^{-1}	Area %	Av.P kg ha^{-1}	Area %	Av.K kg ha^{-1}	Area %	Av.S kg ha^{-1}	Area %
0.1 - 0.5	0.04	150 - 200	62.63	10 - 15	34.39	28 - 100	11.48	5 - 10	17.16
0.5 - 1.0	22.79	200 - 250	37.29	15 - 20	30.74	100 - 150	46.70	10 - 15	73.63
1.0 - 1.5	68.88	250 - 288	0.07	20 - 25	34.87	150 - 200	39.23	15 - 20	9.09
1.5 - 2.0	8.29	—-	—-	——	—-	200 - 379	2.59	20 - 43	0.12

Total agricultural area = 2513.6 ha
* Percent of total agricultural area

3.3 Effect of landuse systems on soil health attributes in Sibbari cluster

Landuse land cover change has considerable influences on soil physical, chemical, biological properties and processes responsible for soil development. Landuse change in NE region of India depicts a distinct pattern as compared to rest of the country. Abrupt land transformation and land cover change due to large scale deforestation, clearing of forest lands to temporary agricultural land through adoption of settled and shifting agriculture (*jhuming*) results in considerable change in soil properties, which affects agricultural productivity as well as security of rural livelihood. In the study area (Sibbari clusters), effect of four landuses (*viz*. pond bed, lowland paddy, upland vegetable and plantation-horticulture) on soil properties were studied (Tables 19-21). Particle size distribution reflected that pond bed followed by lowland paddy soils had significantly ($p<0.05$) higher finer fractions (silt & clay) of soil separates than upland soils under vegetables and plantation-horticulture (PH) (Table 19). Sand content was significantly higher in PH and vegetable based landuses over pond bed and paddy soils while silt and clay contents were significantly higher in the later two landuse systems (Table 19). Across all the landuse systems, sand content varied from 49.4 (±13.3) to 64.8 (± 9.1) percent, silt content was 14.8 (±5.7) to 24.3 (±7.7) percent while clay content varied from 20.3 (±4.4) to a maximum of 30.2 (± 9.2) percent (Table 19).

Despite higher level of soil compaction resulted in from the involvement of puddling operations in lowland paddy based system, soil bulk density (1.11±0.15 Mg m^{-3}) was comparable to upland soils (vegetables/PH). This might be due to higher SOC content as well as finer fractions (silt and clay) which offset the effect of puddling on soil compaction and subsequent rise in bulk density value was arrested.

Table 19:Effect of landuse on soil physical parameters in Sibbari cluster, South Garo Hills, Meghalaya

Landuse	Sample size	Sand	Silt (%)	Clay	BD (Mgm^{-3})
Pond bed	30	$49.4^{bc} \pm 13.3$*	$20.3^{b} \pm 8.7$	$30.2^{a} \pm 9.2$	$1.15^{a} \pm 0.16$
Paddy field	35	$53.4^{b} \pm 12.1$	$24.3^{a} \pm 7.7$	$22.3^{b} \pm 7.9$	$1.11^{a} \pm 0.15$
PH	45	$64.8^{a} \pm 9.1$	$14.8^{d} \pm 5.7$	$20.4^{bc} \pm 4.7$	$1.14^{a} \pm 0.12$
Vegetables	40	$61.7^{a} \pm 8.2$	$17.9^{c} \pm 6.2$	$20.3^{bc} \pm 4.4$	$1.10^{ab} \pm 0.08$

*Means in the column followed by common letter (a-c) are statistically non-significant at 5% level.

Landuse type also significantly (*p<0.05*) influenced soil acidity parameters, particularly soil reaction (pH), exchangeable aluminium (Ex. Al) and its saturation in exchange complexes, bases and effective cation exchange capacity (ECEC) (Table 20). Compared to pond bed and upland soils under vegetables and PH, soil reaction was strongly acidic (pH: 4.87) in lowland paddy soils but exchangeable aluminium content and its saturation in clay complexes were significantly low (0.72 meq/100 g soil, 13.6%, respectively). Similarly, ex. bases including calcium and magnesium and ECEC were also significantly low in paddy soils compared to pond bed, vegetables and PH based landuses (Table 20). Practice

Table 20: Effect of landuse on soil acidity parameters in Sibbari cluster, South Garo Hills, Meghalaya

Landuse	pH	Ex. Al	Ca+Mg	Ex. K	Ex. Na Cmol (+)/kg	bases	ECEC	%Al sat.
Pond bed	5.44^{a} ±0.32*	1.01^{b} ±0.18	4.81^{c} ±1.01	0.31^{a} ±0.09	0.15^{a} ±0.03	5.27^{c} ±1.12	6.32^{c} ±1.22	7.3^{b} ±4.60
Paddy field	4.87^{c} ±0.28	0.72^{c} ±0.31	4.16^{cd} ±1.10	0.32^{a} ±0.06	0.11^{b} ±0.03	4.59^{d} ±1.21	5.30^{d} ±1.01	3.6^{c} ±6.71
PH	5.13^{bc} ±0.34	1.01^{b} ±0.33	6.09^{a} ±1.18	0.31^{a} ±0.07	0.14^{a} ±0.04	6.53^{a} ±1.39	7.54^{a} ±1.14	3.9^{c} ±5.57
Vegetables	5.27^{b} ±0.29	1.36^{a} ±0.28	5.45^{b} ±1.25	0.30^{a} ±0.06	0.14^{a} ±0.01	5.89^{b} ±1.23	7.26^{ab} ±1.31	9.4^{a} ±5.72

*Means in the column followed by common letter (a-c) are statistically non-significant at 5% level.

of marginal application of external inputs like fertilizers, manures while continuously removing bases by crop uptake might have resulted in low base contents. However, aerobic-anaerobic transformation and the near saturated condition of paddy soils might have helped in reducing aluminium saturation in clay complexes than upland vegetables /PH as well as dry pond bed soils.

Among the landuses, lowland paddy soils had significantly ($p<0.05$) higher SOC content (2.01±0.46%). Due to higher SOC content, available nitrogen (N) content was also significantly higher in lowland paddy soils. Similarly, available potash (K) content was significantly ($p<0.05$) higher in lowland paddy soils compared to other landuses (Table 21). Upland vegetable based system had also significantly ($p<0.05$) higher available P content (31.5±5.2 kg ha^{-1}) while pond bed soils were very high in available sulphur content (48.8±19.8 kg ha^{-1}). SOC content in all the landuses were very high (<=1.75 to 2.01%) while K content was in medium range. Available sulphur content was, however, in the sufficiency range (34-48.8 kg ha^{-1}) (Table 21). Higher SOC content in lowland paddy fields might be due to slow decomposition rate of organic matter, higher dry matter production and robust underground biomass addition (Batlle-Bayer et al., 2010). Pond bed soils were expected to be high in SOC and nutrient contents but due to long period of aerobic transformation (drying) as well as absence of any deposition of organic matters/ residues/vegetations might have resulted in low fertility status compared to lowland paddy and vegetable based systems and PH which are less input intensive in these areas

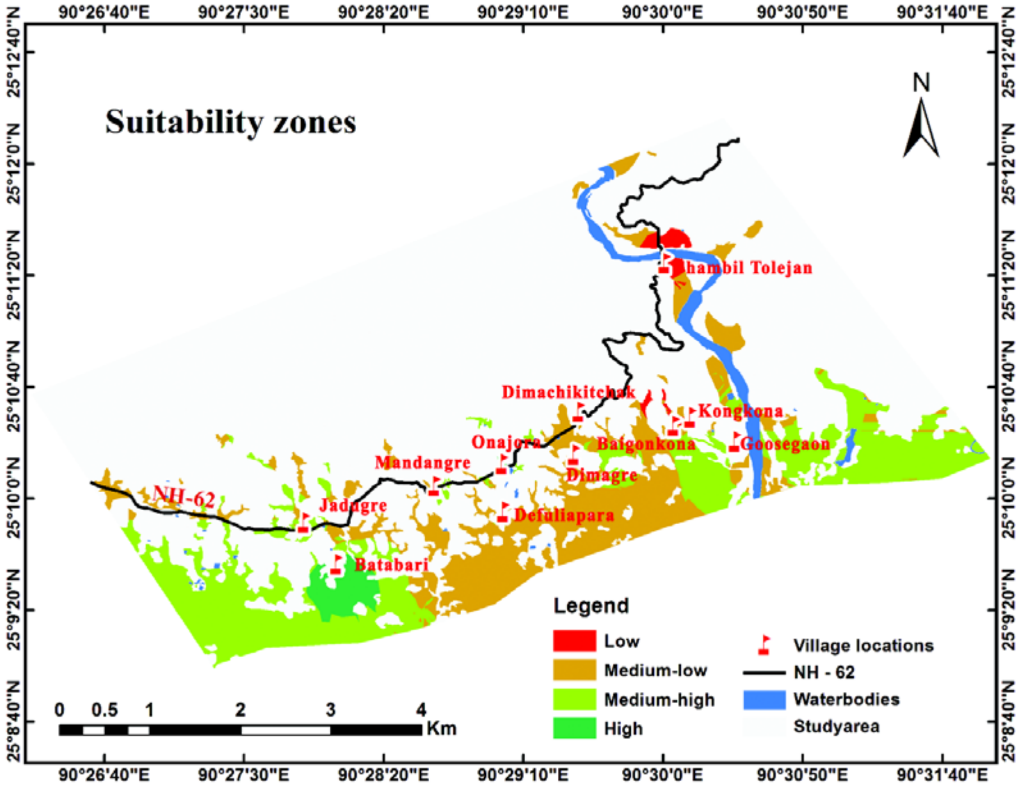
Table 21: Effect of landuse on soil fertility parameters in Sibbari, South Garo Hills, Meghalaya

Landuse	OC (%)	Avail N	Av.P kg ha^{-1}	Av.K	Av. S
Pond bed	1.75^{b}±0.32*	244.0^{b}±25.7	25.2^{b}±6.8	274.8^{b}±66.1	48.8^{a}±19.8
Paddy field	2.01^{a}±0.46	280.4^{a}±37.3	27.0^{b}±5.4	281.8^{a}±29.4	40.7^{b}±12.5
PH	1.79^{b}±0.50	248.3^{b}±56.5	22.8^{c}±6.4	271.1^{b}±45.3	34.6^{c}±11.0
Vegetables	1.90^{b}±0.34	234.3^{c}±37.9	31.5^{a}±5.2	266.3^{bc}±53.1	41.9^{b}±18.2

*Means in the column followed by common letter (a-c) are statistically non-significant at 5% level.

3.4 Spatial multi-criteria based soil suitability mapping

Integration of multi-criteria decision-making approach in Geographical Information Systems (GIS) and statistical weighing/ratings (*e.g*. principal component analysis) of different variables (sand, silt, clay, bulk density, water retention-transmission characteristics, pH, exchangeable aluminium, ex. acidity, aluminium saturation in ex. complexes, ex. bases, ECEC, N, P, K and S), a composite spatial soil suitability index was developed. Based on cumulative weighted rating score, four rating systems namely low (20-25), medium-low (26-30), medium-high (31-35) and high (36-51) were contrived. Soil suitability zones were delineated at 1:10, 000 to 1:12,500 scales for all the sites (Sibbari, Maracherra and Balaram clusters) (Maps 14-16).



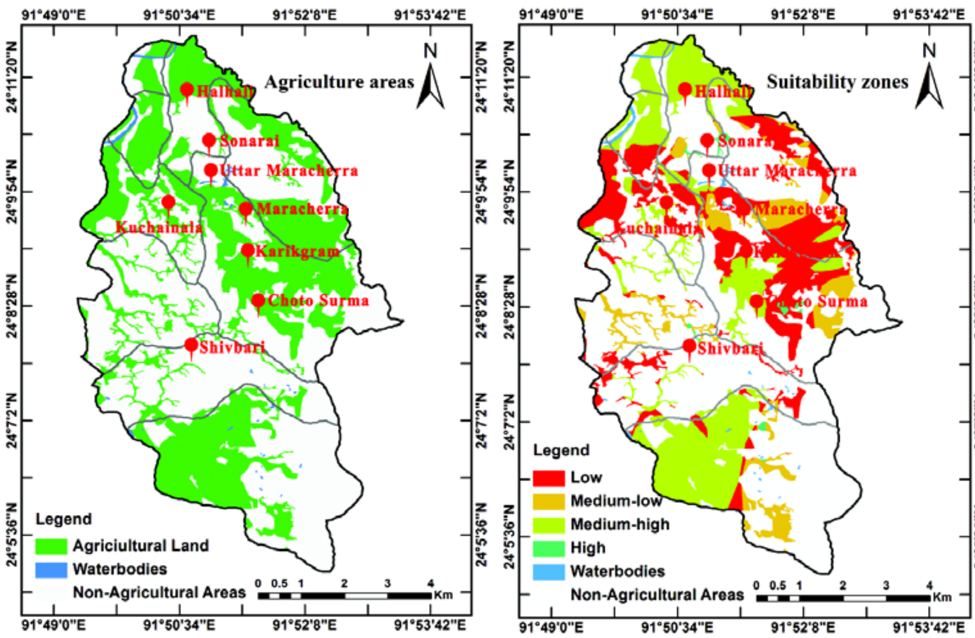
Map 14: Soil suitability zones derived from spatial multi-criteria decision-making approach for crop intensification in Sibbari cluster, South Garo Hills, Meghalaya

In-case of Sibbari cluster (South Garo Hills), of the total agricultural area (696.7 ha), areas highly suitable to crop intensification was negligible (<5.0% of TAA). However, nearly 50% area falls in medium-high category of soil suitability zones (Table 22). The soil health condition with respect to nutrient availability, acidity induced fertility stress and water retention –transmission based functions, these areas can support intensive cultivation of at least 2 crops in a year round cycle. Therefore, location specific crop intensification can be good option in these areas (spatially distributed, shown in Map 14). Soil suitability to crop intensification in the remaining 43.3% area falls under medium-low category, and thus can support less nutrient/water exhaustive crops/ cropping systems (like vegetables/oilseeds-pulses).

Table 22: Remote sensing and GIS based generation of soil suitability zones (% of agricultural area) for crop intensification in NAIP clusters (South Garo Hills & Dhalai)

Soil Suitability	Sibbari		Maracherra		Balaram	
	Area, ha	% Area	Area, ha	% Area	Area, ha	% Area
Low	14.31	2.05	780.79	37.44	707.9	28.16
Medium-low	301.94	43.34	342.12	16.41	722.3	28.73
Medium-high	348.99	50.09	938.78	45.02	1021.8	40.65
High	31.49	4.52	23.54	1.13	61.7	2.46
Total agricultural area (ha)	**696.7**		**2085.2**		**2513.6**	

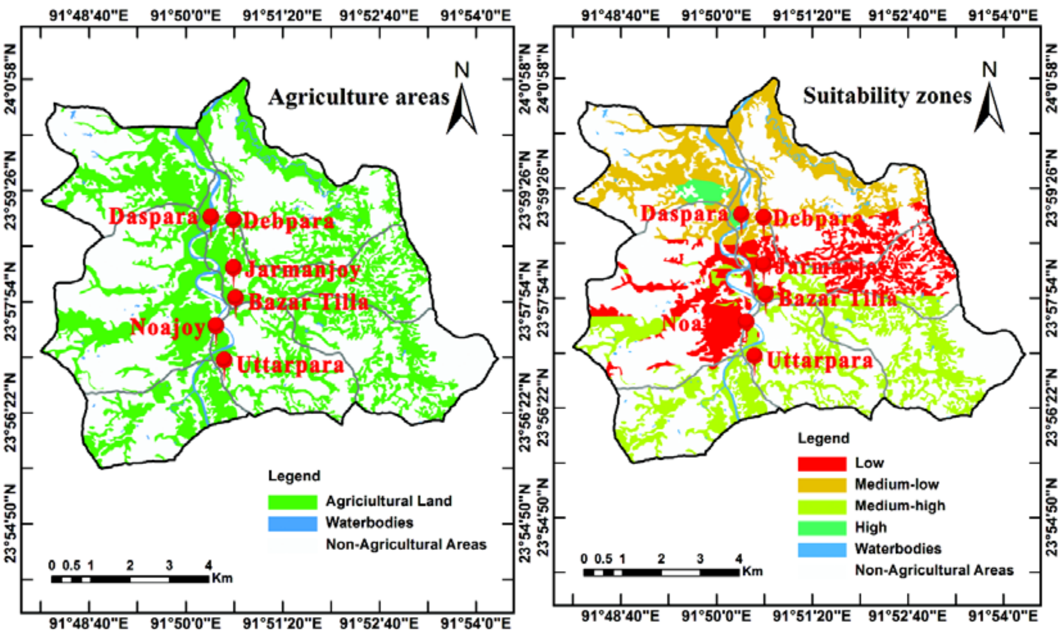
Location specific spatial distribution of suitability zones across Maracherra cluster were delineated and mapped at 1:12,500 scale (Map 15), which will felicitate in adopting location specific soil health restoration approaches. In Maracherra cluster, more than 1/3rd agricultural area (>37% of TAA) falls under poor soil suitability class and without any soil health restoration approaches (external nutrient supplementation/in-situ resource conservation), these areas are not conducive for intensive crop cultivation.



Map 15: Soil suitability zones derived from spatial multi-criteria decision making approach for crop intensification in Maracherra cluster, Dhalai, Tripura

Similarly, in another 16.4% agricultural area of the cluster, location specific soil health restoration approaches need to be followed to increase crop intensification as well as land-crop productivity (Table 22). However, 45% agricultural area falls under medium-high soil suitability category, which can support crop intensification. Area falling under high suitability class was negligible (1.13%).

Similar trend of significant area (>56% of TAA) under low to medium-low soil suitability falls in Balaram cluster (Table 22). The cluster had only 40.6% area under medium-high soil suitability class. These areas can be exploited for crop intensification by growing 2-3 crops in a sequence round the year. Spatial distribution of soil suitability zones across Balaram cluster was mapped at 1:12,500 scale (Map 16**)**, which will facilitate in improving location specific ameliorative/nutrient/resource conserving technology adoption.



Map 16: Soil suitability zones derived from spatial multi-criteria decision making approach for crop intensification in Balaram cluster, Dhalai, Tripura

Alike Maracherra cluster, area under high soil suitability class was negligible (<2.5%) in Balaram cluster. Therefore, in Balaram cluster, more than 48% of the total agricultural area was not favourable for crop intensification in the existing condition and thus, the utmost need is to adopt periodic nutrient replenishment, integrated nutrient management with special emphasis on external nutrient supply at correct stages of crop growth.

3.5 Socio-economic status on LULC and soil health– distribution of land holding and annual house hold incomes at Sibbari cluster

In Sibbari cluster, there were 11 villages comprising a total of 505 households stretched from 25.16° to 25.19° N latitude and 90.46° to 90.50° E latitude (Map 2, Table 2). Out of 505 households, we surveyed randomly 135 number of households, geo-referenced and collected required primary information on socio-economic aspects (annual income, source of income, land owned, leased, agricultural land, family members) following standard personal reprisal assessment (PRA) procedure. Based on 135 households information (nearly 27% population), we extrapolated for rest of the households in the cluster. Among the 11 villages, Baigonkona had the highest number of households (95) while Onajara had the lowest households (16) (Table 23). When household annual income was assessed, it varied widely across the cluster comprising 11 villages: Rs. 45,000 (in Defuliapara) to Rs. 2, 46, 000 (Mandangre). Average annual income of households was highest (Rs. 1, 29,000±25,736) in Mandangre village followed by Kongkona (Rs. 1,01,455±23,927) and Jadugre (Rs.98,000±27,973) while annual income of household was lowest in Onajara village (Rs. 68400±21801). Average annual income of households was relatively less in Dimagre, Baigonkona and Batabari villages (Table 23). Total agricultural land area in the cluster was 697.3 ha. Average agricultural land holding per household also varied widely across the cluster as well as villages: 1.06±0.55 ha (in Jadugre) in to 2.00±0.66 (in Defuliapara). Land holding per household was highest in Defuliapara (2.00±0.66 ha), which was home to 54 households followed by Batabari (1.83±0.86 ha) and Kongkona (1.68±0.97 ha) (Table 23).

Table 23: Status of the socio-economic aspects (households, annual income, agricultural land holding) of the inhabitants of 11 villages of Sibbari cluster in South Garo Hills, Meghalaya.

Village	Households		Annual Income per household, Rs			Agri. area, per household, (ha)
	Total	Surveyed	Min	Max	Average	
Jadugre	36	9	60000	135000	98000±27973	1.06±0.55
Mandangre	43	11	60000	246000	129000±25736	1.23±0.41
Defuliapara	54	16	45000	170000	91071±22054	2.00±0.66
Onajara	16	6	50000	105000	68400±21801	1.38±0.37
Dimagre	54	14	50000	90000	72286±13225	1.23±0.46
DimaChigitchak	36	9	55000	184000	97889±25432	1.57±0.55
ChambilTolejang	31	8	70000	145000	97500±22049	1.00±0.42
Baigonkona	95	22	65000	85000	76000±8216	1.09±0.33
Kongkona	36	12	45000	155000	101455±23927	1.68±0.97
Goosegaon	64	16	75000	90000	82500±6892	1.42±0.43
Batabari	40	12	55000	100000	77571±13770	1.83±0.86
Total	**505**	**135**	**45000**	**246000**	**90420±18224**	**1.51±0.67**

Primary data on household annual income was collected randomly across 135 households and was then extrapolated to represent the total households (505) of the cluster. Based on the range of variation in annual income of each household across the 11 villages of Sibbari cluster, we arranged them into three categories: high (annual income > Rs.1, 20, 000), medium (Rs.60, 000 to 1, 20,000) and low (<Rs. 60,000/-) income group. Village wise distribution of annual income has been discussed in the previous section (Table 24). In the cluster, nearly 43% of the total households fall under low category income group (<Rs.60, 000/- annum). Another 40% of the total households were in medium category (60,000 to 1, 20,000) income group, with monthly total income (from all sectors including agriculture) varying from Rs.5, 000 to Rs.10, 000 per household. Households with annual income > 1, 20,000/- were only 17%. Therefore, in the cluster, majority of the households (83%) with family members of 5-7 in number had monthly income less than Rs. 10,000/- or Rs.1, 20,000/ - per annum. Along with variation in annual income, agricultural land holding also varied widely and increased with increase in annual income across the clusters. Average agricultural land holdings per household of high income group was 2.50 ha, which was 2.98 times higher than the low income group households (0.84 ha). Medium income group had 1.77 times higher land holding (1.49 ha) than low income group (Table 24).

Table 24: Annual income based stratification (3 strata) in household numbers and the average agricultural land holding (per household) across Sibbari cluster

Income group	Annual income (Rs)	Income range (Rs)	Surveyed household	Total household	Agri. land / household (ha)
Low	<60,000	45,000 to 60,000	58	217 (42.9%)	0.84
Medium	60,000 -1,20,000	60,000 to 1,20,000	54	202(40%)	1.49
High	>1,20,000	1,21,000 to 2,46,000	23	86 (17.0%)	2.50

By integrating spatial multi-criteria soil suitability class in GIS along with geo-referenced household survey information and land holdings, we generated information on distribution of agricultural land with different soil suitability class among the three income groups: low, medium and high. Of the total 696.7 ha, low income group (42.9% of total household) had 26% of the land while medium income group (40% of the total household) had the highest land area (300.4 ha, 43.1%). High income group represented only 17% of the total households, yet, agricultural land under them was almost double (>30% of the total agricultural land) (Table 24).

In the cluster, more than 90% of the total agricultural land (696.7 ha) fall under medium-low to medium-high category soil suitability zone. Only 4.5% area was very high soil suitability zone while area under low suitability was marginal (2.05%) (Table 25). Majority of the low to medium-low suitability soil areas belonged to low income group farmers while

Table 25: Distribution of agricultural land holdings and area under different levels of soil suitability zones among low, medium and high income groups of households

Soil Suitability class	Area, ha	Area (ha) under different income groups		
		Low income	Medium income	High income
Low	14.3 (2.05%)*	11.9 (82.6%)	1.6 (11.1%)	0.9 (6.3%)
Medium-low	301.9 (43.3%)	129.8 (43%)	157.0 (52%)	15.1 (5%)
Medium	349.0 (50.1%)	38.4 (11%)	136.1 (39%)	174.5 (50%)
High	31.5 (4.5%)	1.9 (6%)	5.7 (18.1%)	23.9 (75.9%)
Total agril. area, ha	**696.7**	**182 (26%)**	**300.4 (43.1%)**	**214.4 (30.7%)**

*Figure in parenthesis represents % area

medium income group had major share in medium-low to medium –high soil suitability class areas. High income group had minimal share (3-5%) of land area under low to medium-low soil suitable zones. More than 90% agricultural land area (198.4 ha of 214.4 ha) of the high income group fall under high to medium-high in soil suitability for crop intensification. Higher income group households might have adopted periodic replenishment of soil nutrients, ameliorative measures, manuring and soil health restoration approaches, which might have helped in restoration of soil health. In case of low income group, farmers are mostly marginal to small in land holding and resources. They also adopt marginal input intensive subsistence nature of farming. As a result, periodic replenishment on nutrients was lacking. Moreover, they don't leave any crop residues (particularly rice straw) to decompose in the field for soil health improvement, rather removed them for fodder (Choudhury et al., 2013). All these resulted in severe depletion of nutrients, deterioration of soil health and thus, low in soil suitability. Therefore, this study showed that soil fertility restoration had an indirect link to the owner's resource status.

CHAPTER 4

CONCLUSION

Landuse land cover change (LULCC)

1. **In Sibbari cluster (South Garo Hills),** total geographical area (TGA) was 3057. 4 ha. Forests (dense + open) was the dominant landuse (55.37% of TGA) followed by agriculture (22.79%), settlement (13.95%), horticulture and plantation (4.46%), water bodies (1.91%) and wastelands (1.53%). Change detection reflected a decreasing trend in forest covers (both dense & open) while settlements and wasteland were at increasing trend. Horticulture-plantation and pond based integrated landuse systems were encroaching slowly in marginal to sizeable areas in the Sibbari cluster.
2. **In Maracherra cluster (Dhalai),** total geographical area (TGA) was 5050.9 ha. LULC pattern reflected that built up (urban + rural) occupied 40.7% of TGA followed by settled agriculture (27.6%), horticulture and plantation (13.7%) and wastelands (5.0%). The general trend in LULC change was decrease in forest area, mostly driven by population pressure led increase in settlement areas. However, an increase in area under horticulture based plantation and decrease in wastelands were observed.
3. **In Balaram cluster (Dhalai),** total geographical area (TGA) was 6420.1 ha. Agriculture was the dominant (36.43%) landuse followed by horticulture -plantation (19.72%), wastelands (15.1%), dense forests (13.59%) and built up (13.15%). Change detection reflected an increasing trend in built up, dense forest, shifting cultivation and water bodies areas while a decreasing trend was observed in areas under horticulture and plantation, wastelands and agriculture.

Spatial mapping of soil attributes at 1:10,000 to 12, 5000 scales within agricultural area

1. **In Sibbari cluster**, soils were coarse to medium in texture (sand content >50%), moderately acidic in reaction (pH>5.0) but low to medium (4-8 meq/100 g soil) in exchangeable bases and higher exchangeable aluminium (Al^{3+}) content (1.0-1.5 meq/100 g soil). Soils were very high in soil organic carbon (SOC: 1.5-2.5%), medium in available nitrogen (N: 200-300 kg ha^{-1}) and potash (K: 250-350 kg ha^{-1}) but deficient in available phosphorus (<= 30 kg ha^{-1}). Available sulphur content in the soil was medium (20-40 kg ha^{-1}) to very high (40-60 kg ha^{-1}).
2. **In Maracherra cluster (Dhalai)**, soils were invariably coarser in texture with very high sand content(70 to 80%), moderate in clay content (20-30%), moderately acidic

in reaction (pH>5.0), high in exchangeable aluminium (>1.0 meq/100 g soil) and low in exchangeable bases (Ca and Mg: <5 meq/100 g soils). Soils were moderate in SOC content (1.0-1.7%), low in available N (150-200 kg ha^{-1}), P (<= 20 kg ha^{-1}), K (<150 kg ha^{-1}) and S contents (<20 kg ha^{-1}).

3. **In Balaram cluster (Dhalai)**, soils were coarser in texture (sand content: 40-90%), strong (pH<= 5.0) to moderately (pH>5.0-5.7<) acidic in reaction, low in exchangeable aluminium (<=1.0 meq/100 g soil) and very low in bases (3-5 meq/100 g soil). Soils were medium in organic carbon (SOC: 1.0-1.5%), very low in available N (150-200 kg ha^{-1}), deficient in available P (<= 20 kg ha^{-1}), K (<= 150 kg ha^{-1}) and S contents (<= 15 kg ha^{-1}).

Spatial multi-criteria soil suitability mapping within agricultural area

1. **In-case of Sibbari cluster**, nearly 50% of the total agricultural area (696.7 ha), falls in medium-high category of soil suitability zone and can support intensive cultivation of atleast two nutrient exhaustive crops in a year. Soil suitability to crop intensification in the remaining 43.3% area falls under medium-low category and thus, can support less nutrient/water exhaustive crops/ cropping systems (like vegetables/oilseeds-pulses).
2. **In Maracherra cluster**, only 45% agricultural area falls under medium-high soil suitability category, which can support crop intensification. However, more than 53% agricultural area falls under medium-low to poor soil suitability class and needs soil health restoration approaches for crop intensification as well as land-crop productivity.
3. **In Balaram cluster**, only 40.6% area falls under medium-high soil suitability class. These areas can be exploited for crop intensification by growing 2-3 crops in a sequence round the year. However, significant area (>56%) falls under low to medium-low soil suitability zone and needs periodic nutrient replenishment, integrated nutrient management etc. for crop intensification.

Linkage between socio-economic status and land use pattern in Sibbari cluster

1. Primary data on annual household income reflected that nearly 43% of the total households fall under low category income group (<Rs.60, 000/ annum) while 40% were in medium category (60,000 to 1, 20,000) income group. Households with annual income > 1, 20,000/- were only 17%.
2. Average agricultural land holding per household was maximum with high income group (2.50 ha per household) followed by medium income group (1.49 ha/household) and low income group households (0.84 ha/household).
3. Majority of the low to medium-low suitability soil areas belonged to low income group households while medium income group had major share in medium-low to medium – high soil suitability class areas. More than 90% agricultural land area (198.4 ha of 214.4 ha) of the high income group fall under high to medium-high in soil suitability zone for crop intensification.

CHAPTER 5

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