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Utilisation of geospatial technology for characterization, classification and mapping of forest soils of central Brahmaputra valley zone of Assam

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Abstract
Typical pedons representing major landforms of Central Brahmaputra Valley Zone of Assam *viz*., rolling uplands, hill side slopes, alluvial plain, peidmont plains, hillocks and inselbergs developed from shale, quartzite, granite, gneiss and alluvium deposited by rivers occurring under forest cover were characterized, classified and assessed using geospatial technology, field survey and laboratory analysis. The soils were slightly deep to very deep, poorly drained to well drained, strongly acidic to slightly acidic in reaction, organic carbon content varied from low to high. Exchange sites were dominated by Ca^{2+} and Mg^{2+} followed by K^{+} and Na^{+}. CEC ranges from 0.1 to 15.66 Cmol(P^{+})/kg and base saturation varies from 14.56 to 73.20%. The soils were low to high in available N, low in available phosphorus and medium to high in available potassium content. The soils were classified as Aeric Endoaquents, Dystric Eutrudepts, Fluventic Dystrudepts, Fluventic Eutrudepts, Oxic Dystrudepts, Oxyaquic Dystrudepts, Typic Kanhapludalfs and Typic Udorthents. The soils were having hyperthermic temperature regime, mixed mineralogy and aquic to udic moisture regime. Alfisols were found to be the most dominant soil (57%) followed by Entisols (31%) and Inceptisols (12%). The study revealed that soil properties like profile development, texture, structure, colour, soil acidity, CEC, base saturation, *etc*. were influenced by landform.

Keywords: Forest soil, geospatial technique, soil classification, soil survey, soil map

Introduction
Soil is one of the world's most important natural resources. It is a non renewable finite resource which is required for production of food, feed, fibre, fuel and industrial raw materials as well as generation of energy resources. It is a highly valuable natural resource and therefore maintaining its productivity on sustainable basis is important for meeting the basic needs of the human and animals and knowledge of soils with respect to their extent, distribution, characteristics & potential use is important for optimizing land use. Soil Survey provides information on soils, their spatial distribution, their areal extent for sustainable land use planning and transfer of agro-technology (Kudrat *et al*. 2007). The remote sensing technology is found to be more efficient and economical than conventional survey (Somasundaram *et al*., 2000) [18]. Integration of Remote Sensing and GIS can decrease the cost, reduce the time and increase the detailed information gathered for soil survey (Bandyopadhyay *et al.*, 2009) [3]. Use of satellite remote sensing for soil survey and mapping received appreciation during early 1980s in India, and based on the potential of remote sensing techniques soil map of all the States and Union Territories of India on 1:250,000 scale was prepared by following a multi phased approach consisting of image interpretation, field survey, soil analysis, classification, cartography and printing (Velayutham, 1999) [20]. Indian Remote Sensing satellites (IRS-1A, 1B, 1C, 1D, RESOURCESAT-1and RESOURCESAT-2) provide state of the art database for natural resources inventories. Many research have been conducted to explore the potential of LISS-I and LISS-II data for soil resource mapping both at 1:250,000 and 1:50,000 scale (Manchanda *et al*., 2002) [10]. With the successful launching of a series of operational earth observation satellites *viz*., IRS satellites series (IA, IB, IC, ID, P3, P4-OCEANSAT/ P6-RESOURCESAT-1), CARTOSAT (1, 2, 2A) and most recently IMS-1, RISAT-1 and OCEANSAT-2, significant progress has been made in soil and land cover mapping, land degradation studies and soil and water resource development and management (Das *et al*., 2009). Several studies have been initiated on potential use of IRS-1C LISS-III and PAN data for mapping soils and it is expected that information on 1:25,000 to 1:12,500 scale could be generated through combination of these data (Kudrat *et al*., 2000) [9].

The soil information so generated is interpreted for various purposes like land capability classification, land irrigability assessment, crop suitability studies, management of watersheds, prioritization of watersheds etc. (Ali and Kotb, 2010, Das *et al*., 2014, Das & Sudhakar, 2014) [2, 6-7].
The most important land use land cover of Nagaon district of Assam is forest that covers about 42% of total geographical area (NRSC, 2014) [11]. The soils of the forest play a key role in sustaining a varied range of other ecosystem goods, services and values. Clean lakes and rivers and rich biodiversity are related to forest soil health. The knowledge on forest soils help the government's environmental policy and leads to improvement of forest management practices. Though knowledge on forest soil is very important to maintain a healthy forest ecosystem, till now very little effort has been made to study the soil characteristics, classification and evaluation of the soils in the area using geospatial technology. Therefore, the present study was carried out to study the soils in details.

Materials and Methods

Nagaon district is one of the largest districts falling under Central Brahmaputra Valley Zone of Assam. The district lies between 25°43' N to 26°43' N Latitude and 92°24' E to 93°18' E Longitude. The district is bounded by Sonitpur district and the Brahmaputra river on the north, west Karbi Anglong and Dima Hasao district on the south, East Karbi Anglong and Golaghat district on the east and Morigaon district on the west (Figure 1). Its major rivers include the Brahmaputra, Kolong, Sonai, Nanoi, Jamuna, Kopili and the Barpani. There are several *'beels'*, marshy lands and swamps in this district. The general slope of the district is towards the west. The eastern, north eastern and the south eastern parts are hilly terrains. The climate of the district is humid sub-tropical with mean annual rainfall of 1787.2 mm and mean annual temperature of 23.8°C. The maximum and minimum temperature of the district is 29.4°C and 19.5°C, respectively. The climate of the area is mainly influenced by south-west monsoon from Bay of Bengal and determined by surrounding hills of Assam. The pattern of rainfall is such that the south part of the district is usually dry and the north part is relatively humid.

A detailed soil survey was conducted in soils of forest areas of Nagaon district located in Assam Bengal plains and North Eastern Hills agro ecological zone under hot subhumid to humid and warm perhumid eco region. The study was carried out as per the procedure outlined in Soil Survey Manual (AIS & LUS, 1970) [1] using Resourcesat-2 LISS-IV, geo-coded satellite imagery for the period of 2013-14 and topo sheets of 1:25, 000 scale. Different thematic maps like lithology, phisiography and land use land cover were prepared from LISS IV image through on screen digitization by following visual interpretation technique. Slope and aspect map was derived from SRTM 30m DEM by using Spatial Analyst tools of Arc Tool box. Auger bores, mini pits, road cuts and 28 pedons located on plains, rolling uplands and hill side slopes were studied based on variations on physiography, lithology and slope. Soil correlation exercises yielded 15 typical pedons i.e. 4 in plains, 3 in rolling upland and 8 in hill side slopes (Table1). These 15 pedons were studied in detail and the morphological characteristics were presented in Table 2. The detailed morphological description of these pedons was studied in the field as per the procedure outlined by Schoeneberger *et al*., 2002 [15]. Later horizon wise samples were collected and characterized for important physical and chemical properties and available nutrient status using standard procedures. The soils were classified taxonomically following guidelines of Soil Survey Staff (2010) [17]. Soil boundary was delineated by following the soil landscape relationship. The soil map was prepared by using ArcGIS 10.2 software. The details of methodology is described as flowchart in Figure 2.

Table 1: Site characteristics of typical pedons

Lithology	Physiography	Slope (%)	Pedons
Gneiss (GN)	Inselbergs	0-3	P1
Alluvium (AL)	Piedmont Plains	0-3	P2, P3
Granite (GR)	Undifferentiated hills side slopes	>33	P5, P6, P9
Gneiss (GN)	Hillocks	15-33	P8, P12
Shale (SH)	Rolling Uplands	5-15	P10, P11, P12
Alluvium (AL)	Alluvial Plains	3-10	P4, P15
Quartzite (QZ)	Undifferentiated hills side slopes	10-25	P7, P14

Table 2: Morphological characteristics of the soils

Pedon	Drainage	Permeability	Erosion	Water table (m)	Surface			Subsurface		
					Thickness (cm)	Colour	Structure	Thickness (cm)	Colour	Structure
P1	Moderately well	Moderate	Slight	Deep	25	10YR 5/2	m	65	10YR 5/2	m
P2	Poor	Slow	Slight	Deep	25	7.5YR 4/4	sbk	160	7.5YR 5/4	sbk
P3	Imperfect	Moderately slow	Slight	Moderately deep	20	10YR 6/4	m	200	10YR 7/3	sbk
P4	Imperfect	Moderately slow	Slight	Moderately deep	13	10YR 3/2	sbk	106	10YR 4/3	sbk
P5	Imperfect	Moderately slow	Slight	Moderately deep	25	5YR 6/2	gr	120	5YR 6/2	sbk
P6	Moderately well	Moderate	Moderate	Deep	20	10YR 4/4	gr	145	7.5YR 5/6	sbk
P7	Well	Rapid	Moderate	Deep	15	5YR 3/4	gr	75	10YR 4/4	sbk
P8	Poor	Slow	Moderate	Deep	15	10YR 3/3	sbk	140	10YR 3/3	sbk
P9	Moderately well	Moderate	Moderate	Deep	30	7.5YR 4/4	gr	90	7.5YR 5/6	sbk
P10	Poor	Slow	Slight	Moderately deep	9	7.5YR 3/1	sbk	96	7.5YR 3/2	sbk
P11	Poor	Slow	Slight	Moderately deep	30	10YR 3/4	sbk	135	10YR 3/2	sbk
P12	Poor	Slow	Slight	Moderately deep	25	5YR 5/6	gr	105	5YR 6/6	sbk
P13	Poor	Slow	Slight	Moderately deep	20	10YR 5/3	sbk	175	7.5YR 5/6	sbk
P14	Poor	Slow	Slight	Moderately deep	25	10YR 5/8	sbk	15	7.5YR 5/6	sbk
P15	Moderately well	Moderate	Slight	Moderately deep	15	10YR 6/6	sbk	65	10YR 6/6	sbk

M- massive, sbk- sub angular blocky, gr- granular

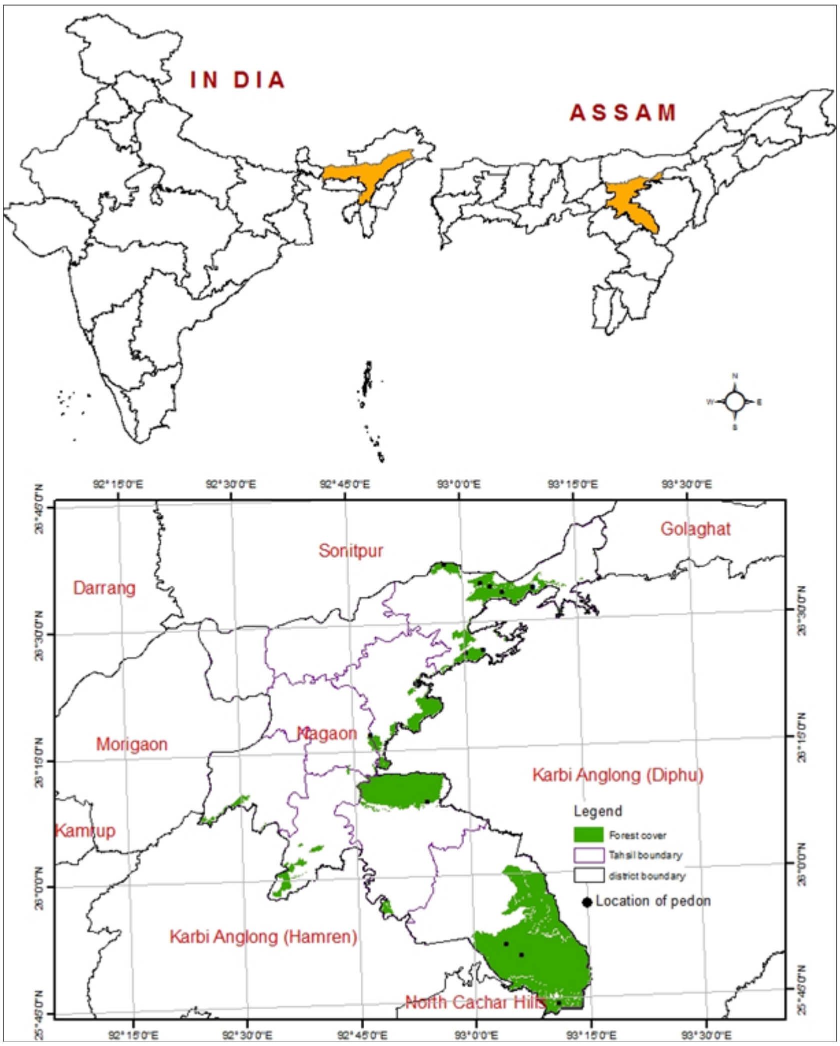

Fig 1: Location map of the study area

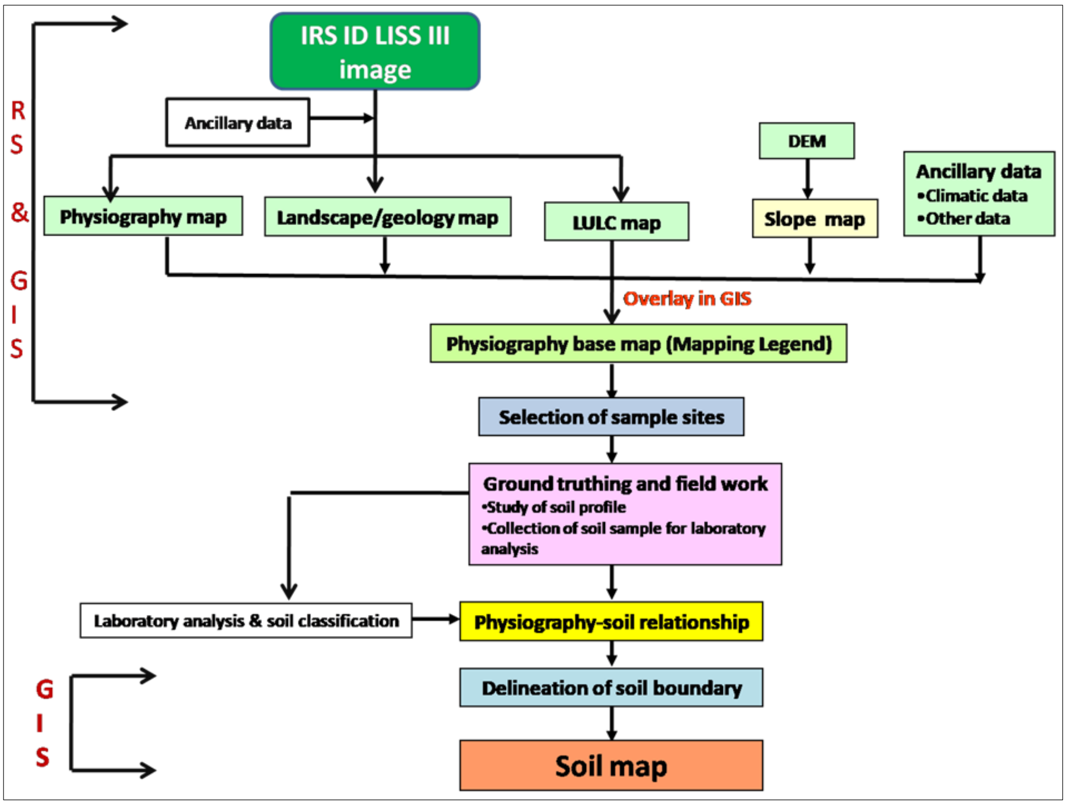

Fig 2: Flowchart of the methodology of soil mapping

Results and Discussion

Physiography and Lithology

Major physiography of the study area is the rolling uplands that cover 57% area followed by undifferentiated hill side slopes (27.72%), alluvial plain (5.46%), peidmont plains (4.28%), hillocks (4.20%) and inselbergs that covers only 1.41% area. Forest soils of Nagaon district are developed from shale, quartzite, granite, gneiss in the hills and alluvium deposited by rivers on the plain areas (Figure 3). It is observed that shale is the most dominant rock type found in the rolling uplands that covers 57% area under forest cover. Quartzite is the second dominant rock type (23.51%) from which soils are developed on undifferentiated hill side slopes. Inselbergs and hillocks of the study area are formed from gneiss that covers 5.61% area under forest cover. About 4.21% area is developed from granite rocks on undifferentiated hill side slopes. Soils developed on alluvium deposited by river Brahmaputra that covers about 9.74% area which is under forest cover.

Land use land cover

Most of the areas of Nagaon district are under agriculture (45.87%) followed by forest (41.94%), grassland (3.62%) and wastelands (1.19%). Water body and built-up areas covers about 5.82% and 1.55% respectively. From the field verification it was found that the mixed forest is the most dominant vegetation cover followed by Teak and Gomari plantations (24%), Shrubs mixed with arecanut plantation (4%) and pure Teak forest that covers 0.6% area.

Soil morphology

The solum depth varied from slightly deep to very deep. The soils were poorly drained to well drained. Soil colour developed from granite rocks in the undifferentiated hill side slopes (P5, P6 and P9) ranged from brown (7.5YR 4/4) to dark yellowish brown (10YR 4/4) at surface and from strong brown (7.5YR 5/6) to reddish yellow (5YR 6/6) at sub-surface horizon. The surface soil colour of the hillocks of gneissic rocks (P8 and P12) was dark brown (10YR 3/3) to yellowish red (5YR 5/6), whereas the sub-surface soil colour varied from reddish yellow (5YR 6/6) to yellow (10YR 7/6). The surface and subsurface soil colour developed from gneissic rocks on inselbergs (P1) was grayish brown (10YR 5/2). Soils developed from quartzite rocks on undifferentiated hill side slopes (P7 and P14) varied in colour from yellowish brown (10YR 5/8) to dark reddish brown (5YR 3/4) on the surface and subsurface color ranges from strong brown (7.5YR 5/6) to dark yellowish brown (10YR 4/4). In case of rolling upland pedons (P10, P11 and P13) developed from shale, surface soil colour varied from brown (10YR 5/3), to dark yellowish brown (10YR 3/4), while in their subsequent subsurface horizon it became more brownish in colour ranging from strong brown (7.5YR 5/6) to dark brown (*Soil morphology*
The solum depth varied from slightly deep to very deep. The soils were poorly drained to well drained. Soil colour developed from granite rocks in the undifferentiated hill side slopes (P5, P6 and P9) ranged from brown (7.5YR 4/4) to dark yellowish brown (10YR 4/4) at surface and from strong brown (7.5YR 5/6) to reddish yellow (5YR 6/6) at sub-surface horizon. The surface soil colour of the hillocks of gneissic rocks (P8 and P12) was dark brown (10YR 3/3) to yellowish red (5YR 5/6), whereas the sub-surface soil colour varied from reddish yellow (5YR 6/6) to yellow (10YR 7/6). The surface and subsurface soil colour developed from gneissic rocks on inselbergs (P1) was grayish brown (10YR 5/2). Soils developed from quartzite rocks on undifferentiated hill side slopes (P7 and P14) varied in colour from yellowish brown (10YR 5/8) to dark reddish brown (5YR 3/4) on the surface and subsurface color ranges from strong brown (7.5YR 5/6) to dark yellowish brown (10YR 4/4). In case of rolling upland pedons (P10, P11 and P13) developed from shale, surface soil colour varied from brown (10YR 5/3) to dark yellowish brown (10YR 3/4), while in their subsequent subsurface horizon it became more brownish in colour ranging from strong brown (7.5YR 5/6) to dark brown (7.5YR 3/2) to very dark grayish brown (10YR 3/2). Surface soil colour of Piedmont Plains (P2 and P3) varies from brown (7.5YR 4/4) to light yellowish brown (10YR 6/4) where as subsurface soil colour ranges from brown (7.5YR 5/4) to very pale brown (10YR 7/3). The soil colour of alluvial plains (P4 and P15) varies from very dark grayish brown (10YR 3/2) to brownish yellow (10YR 6/6). Mottles were commonly observed in the pedons developed on alluvium due to the prevalence of excessive wet environment under fluctuating ground water condition as commonly found in waterlogged soil in North Eastern Region (Bhattacharyya *et al.* 2003) [4]. The structure was predominantly sub-angular in all pedons which might have been attributed due to the presence of higher quantities of clay fraction (Sharma *et al.* 2004) [16]. The detailed morphological characteristics of soils were presented in Table 2. The moist consistency of the soils of hills areas was found to vary from firm to friable whereas it was found to be firm to very firm in valley areas. Soils of rolling upland had thin to moderately thick argillans in sub-surface horizons. The soils of hills of granite and gneiss and piedmont plains had the altered sub-surface cambic horizons whereas the soils of the alluvial plain and hills of quartzite rocks did not show any characteristic horizons which qualified for A-C horizon.

Physical and Chemical Characteristics

The particle size analysis revealed that the clay content varied from 1.5 to 44%. The increase in clay content in subsurface horizon in P10, P11 and P13 was primarily due to vertical migration or translocation of clay within the solum (Rao *et al.*, 2008) [13]. The enrichment of clay in subsurface horizon of P2, P3, P4, P5, P6, P8, and P12 was due to weathering of parent material. More or less, a decrease in clay content with depth was noticed in P1, P7, P9, P14 and P15 which might be due to variability of weathering in different horizons. Silt fraction ranged from 9.9 to 32.2% and silt content in general exhibited an irregular trend with depth. This irregular distribution of silt might be due to variation in weathering of parent material or *in-situ* formation (Satish kumar and Naidu, 2012) [14]. Sand constitutes the bulk of mechanical fractions in most of the pedons, which could be attributed to siliceous nature of parent material (Devi *et al*., 2015) [18]. The soils of forest areas showed wide textural variations ranging from loamy sand to clay. The wide textural variations might be due to variation in parent material (alluvium, granite, gneiss, quartzite and shale), topography, *in-situ* weathering and translocation of clay by eluviations and age of soils.

The pH of the soils ranges from 4.4 (strongly acidic) to 6.3 (slightly acidic). Slightly acidic soils were found in P3, P4, P7 and P13 while strongly acidic soils were found in pedon P9. Soil pH of other pedons were moderately acidic (4.5-5.5). It was observed that soils developed from shale, quartzite and alluvium parent material are slightly acidic whereas soils on granite and gneiss are strongly to moderately acidic. Organic carbon content was found to vary from 0.12 (low) to 1.55% (high) and it decreases along the control section unless there is fluventic effect. Exchangeable Ca, Mg, Na and K content in pedons varied from 0.56 to 10.81, 0.36 to 1.98, 0.03 to 5.7 and 0.10 to 2.54 Cmol(P^+)/kg, respectively. Exchange sites were dominated by Ca^{2+} and Mg^{2+} followed by K^+ and Na^+. CEC ranges from 0.1 to 15.66 Cmol(P^+)/kg and base saturation varies from 14.56 to 73.20%.

Available N varied from 50.46 to 173.02 kg ha^{-1} and was found to be higher in surface horizons compared to underlying horizons; due to decreasing trend of OC with depth (Prasuna Rani *et al.*, 1992) [12]. The available P_2O_5 content ranges from 10.50 to 235.90 kg/ha and was generally decreased with depth. Available K_2O content varies from 171.90 to 403 kg/ha. The highest available K content was observed in the surface horizons and showed a decreasing trend with depth which might be attributed to more intense weathering and release of labile K from organic residues (Thangasamy *et al*. 2005) [19].

Soil Classification

The soils were classified following comprehensive classification system (Soil Survey Staff, 2010) [17]. The soils were classified into 3 orders, 5 suborders, 6 great groups, 8 subgroups, 5 families and 12 soil series based on soil genesis (Table 4). The soil temperature regime, mineralogy and moisture regimes were found to be hyperthermic, mixed and udic & aquic, respectively. The soils of P10, P11 and P13 located on the rolling upland were classified as Udalfs due to presence of Udic moisture regime and classified as Typic Kanhapludalfs due to presence of kandic horizon.

On the other hand soils of P2, P3, P4, P5, P6, P8 and P12 were placed under Inceptisols because of presence of cambic (Bw) sub-surface diagnostic horizon and Udepts due to presence of Udic moisture regime. The soils of P2, P3, P6, P8 and P12 were classified as Dystrudepts due to absence of sulfuric horizon, duripan, fragipan and having less than 60% base saturation. Again, P3 and P6 have irregular distribution of soil particles & organic carbon content and hence classified as Fluventic Dystrudepts. Soils of P4 and P5 were placed under Eutrudepts due to presence of base saturation of more than 60%. The soils of P5 was classified as Fluventic Eutrudepts due to irregular distribution of soil particles & organic carbon content.

The soils of P1, P7, P9, P14 and P15 did not exhibit any diagnostic horizon and hence were classified as Entisols. The soils of P15 have aquic moisture condition for some period of normal year. The soils of P10 have irregular distribution of soil particles & organic carbon content and have Udic moisture regime; therefore placed under Udifluvents the soils of P1, P7, P9 and P14 were classified as Orthents due to absence of aquic, psammentic & fluventic conditions.

Soil mapping

The soil map was prepared by delineating the soil boundary on LISS IV images considering soil physiography relationship. Seven dominant soil series had been identified (Figure 4). From the soil map it has been observed that Alfisols is the most dominant soil that covers 57% area followed by Entisols (31%) and Inceptisols (12%). Alfisols were found to be developed from shale on rolling uplands. Inceptisols were found on piedmont plains and hills. This has been observed that the Inceptisols (4%) of piedmont plains are developed from deposition of alluvium and colluviums material. Inceptisols of hills were developed from granite and gneiss (8%). Entisols were found on alluvial plains (6%), Inselbergs of gneiss (1%) and hills of quartzite (24%).

Table 3: Physical and chemical properties of the soils

Pedon	Depth (cm)		Gravel	Sand	Silt	Clay	Texture	pH	EC	OC	P_2O_5	K_2O	Ca	Mg	Na	K	CEC
	Min	Max	(%)	(%)	(%)	(%)				(%)	Kg/ha	Kg/ha	Cmol(P^+)/kg				
P1																	
A	0	25	0.0	62.6	32.0	5.4	Sandy loam	5.2		0.48	43.6	223.5	0.5	0.7	7.2	2.5	17.0
AC	25	90	0.0	66.4	32.2	1.5	Sandy loam	4.7		0.39	35.9	309.7	0.6	0.5	5.7	2.5	12.8
P2																	
A	0	25	0.0	47.7	18.6	33.7	Sandy clay loam	4.9	0.1	0.87	19.2	330.8	0.8	0.4	0.5	2.4	12.0
AB	25	45	0.0	43.9	19.6	36.5	Sandy clay	4.8	0.1	0.63	15.4	289.2	0.6	0.2	0.6	1.5	8.4
Bw1	45	65	0.0	39.2	18.3	42.5	Clay	4.8	0.1	0.57	12.8	266.1	0.5	1.1	0.5	2.1	13.2
Bw2	65	90	0.0	36.7	23.2	40.1	Clay	4.7	0.1	0.24	11.8	364.5	1.2	1.2	0.6	1.9	19.6
Bw3	90	125	0.0	40.1	25.6	34.4	Clay loam	4.5	0.1	0.24	10.3	281.4	1.0	1.8	0.5	2.0	19.2
Bw4	125	185	0.0	43.8	20.1	36.1	Clay loam	4.3	0.0	0.18	7.7	361.7	1.0	2.2	0.6	2.0	15.2
P3																	
Ap	0	20	0.0	43.8	32.1	24.1	Loam	5.8	0.1	0.54	28.2	312.4	0.5	1.2	0.3	0.5	8.2
B1	20	70	0.0	42.3	29.9	27.9	Loam	5.8	0.2	0.30	23.1	260.2	0.4	1.6	0.3	0.9	6.7
B2	70	115	0.0	41.3	26.3	32.4	Clay loam	5.8	0.0	0.24	18.0	292.3	1.0	1.2	0.2	2.0	10.4
B3	115	160	0.0	40.8	27.6	31.6	Clay loam	6.6	0.0	0.24	18.0	238.2	1.2	0.3	0.2	0.8	7.2
B4	160	180	0.0	46.5	23.8	29.7	Sandy clay loam	6.6	0.0	0.21	38.5	203.3	1.7	2.3	0.1	0.5	9.8
c	180	220	0.0	47.5	27.8	24.8	Sandy clay loam	6.6	0.1	0.21	33.3	174.1	1.6	1.0	0.1	2.2	12.0
P4																	
A1	0	13	0.0	58.2	24.8	17.0	Sandy loam	6.3		1.38	56.0	254.8	1.1	2.0	0.3	0.3	7.2
A2	13	39	0.0	54.2	25.9	19.9	Sandy loam	5.8		0.67	37.7	228.2	1.2	2.3	0.3	0.4	7.9
Bt1	39	66	0.0	47.2	24.1	28.7	Clay loam	5.8		0.32	19.6	229.6	1.3	2.9	0.3	0.4	8.2
Bt2	66	119	0.0	45.2	26.2	28.6	Clay loam	5.6		0.26	15.1	245.1	1.1	3.1	0.4	0.5	8.8
P5																	
A	0	25	0.0	58.4	17.6	24.0	Sandy clay loam	4.9	0.1	0.90	35.9	344.1	2.4	2.4	0.9	3.0	12.0
AB	25	50	0.0	58.2	18.5	23.3	Sandy clay loam	4.8	0.1	0.63	28.2	328.6	2.8	2.4	0.9	2.2	10.6
Bw	50	75	0.0	51.7	23.9	24.3	Sandy clay loam	4.6	0.1	0.57	25.7	373.4	2.8	2.0	0.9	2.3	11.2
C1	75	115	0.0	54.3	36.8	8.9	Sandy loam	4.1	0.1	0.54	23.1	289.2	1.6	2.0	0.9	2.1	10.4
C2	115	145	0.0	88.3	5.6	6.1	Loamy sand	4.5	0.1	0.36	18.0	266.8	3.2	1.6	0.6	2.5	10.8
P6																	

A	0	20	0.0	70.8	13.6	15.6	Sandy loam	4.8	0.2	0.69	20.5	392.0	2.8	1.2	0.4	1.6	13.0
Bw	20	65	0.0	64.4	14.4	21.2	Sandy clay loam	4.6	0.1	0.54	19.2	287.9	0.8	1.6	0.4	1.4	9.6
BC	65	110	0.0	79.7	6.1	14.3	Sandy loam	4.4	0.1	0.36	18.0	226.3	1.6	1.6	0.4	1.4	11.0
C	110	145	0.0	83.8	9.5	6.6	Loamy sand	4.5	0.1	0.30	15.4	235.6	0.4	0.4	0.4	1.2	8.0
P7																	
A	0	15	85.9	65.0	31.4	3.6	Sandy loam	5.5		0.36	23.1	184.4	0.8	0.8	0.2	0.2	6.8
AC	15	35	59.0	60.7	32.5	6.8	Sandy loam	5.5		0.21	15.4	166.0	1.0	0.8	0.2	0.2	6.0
C	35	90	83.0	66.5	30.7	2.8	Sandy loam	5.5		0.15	12.8	174.1	0.4	0.2	0.3	0.2	6.5
P8																	
Ap	0	15	0.0	40.4	24.0	36.0	Clay loam	5.4	0.1	0.24	23.1	196.5	1.1	0.1	1.7	1.3	5.5
AB	15	30	0.0	40.7	28.0	31.3	Clay loam	5.3	0.0	0.21	18.0	217.7	0.8	0.5	1.5	0.7	7.4
Bw1	30	80	0.0	36.9	23.1	40.0	Clay loam	5.1	0.1	0.15	15.4	273.5	0.6	0.7	1.1	1.1	7.4
Bw2	80	105	0.0	47.9	12.6	39.4	Sandy clay	6.0	0.0	0.12	13.4	300.4	0.5	0.7	1.7	1.8	7.2
C	105	155	0.0	50.4	28.1	21.9	Sandy clay	6.4	0.1	0.12	12.8	346.1	0.6	0.6	1.5	1.9	8.6
P9																	
A	0	30	0.0	77.2	10.9	11.9	Sandy loam	4.6	0.1	0.66	35.9	253.9	3.2	1.2	0.7	1.5	12.8
AC	30	45	0.0	77.4	7.3	15.3	Sandy loam	4.6	0.1	0.51	28.2	274.9	2.0	1.2	0.7	1.4	10.0
C1	45	80	0.0	81.6	11.0	7.4	Loamy sand	4.5	0.1	0.42	25.7	238.6	4.0	2.4	0.7	1.4	14.4
C2	80	120	0.0	84.8	9.9	5.3	Loamy sand	4.3	0.1	0.15	25.7	138.4	3.2	1.6	0.8	1.3	12.4
P10																	
Ap	0	9	0.0	35.4	26.0	38.6	Clay	4.9		1.55	45.1	233.1	3.6	4.9	0.3	0.2	17.9
Bwg1	9	20	0.0	47.1	16.0	36.9	Sandy clay	5.0		1.32	40.4	147.0	3.3	4.2	0.5	0.1	14.5
Bwg2	20	37	0.0	39.4	28.0	32.6	Clay	5.3		0.66	23.5	183.8	2.4	4.3	0.4	0.1	13.0
Bwg3	37	61	0.0	37.4	24.0	38.6	Clay	5.3		0.81	19.2	179.5	4.5	5.1	0.6	0.1	16.1
Bwg4	61	105	0.0	36.7	26.0	37.3	Clay	5.5		0.45	12.6	205.9	3.1	4.7	0.4	0.1	14.3
P11																	
A	0	30	0.0	24.7	26.7	48.6	Clay	4.5		1.23	35.1	369.0	5.1	7.1	0.2	0.9	22.5
Bw1	30	75	0.0	19.4	32.0	48.6	Clay	4.7		0.99	27.7	331.0	4.2	7.9	0.2	0.8	21.8
Bw2	75	116	0.0	27.4	28.0	44.6	Clay	4.8		0.56	31.2	308.0	4.8	7.0	0.2	0.7	20.1
Bw3	116	165	0.0	37.4	42.0	20.6	Clay	5.1		0.35	18.9	250.0	3.7	5.1	0.1	0.5	14.5
P12																	
A	0	25	0.0	66.8	20.9	12.3	Sandy loam	5.0	0.1	0.69	46.2	339.2	0.8	1.2	0.6	2.8	10.0
Bw1	25	55	0.0	41.8	27.4	30.8	Clay loam	5.3	0.1	0.57	38.5	333.7	1.2	0.8	0.5	1.7	13.6
Bw2	55	105	0.0	43.0	23.8	33.2	Clay loam	5.0	0.1	0.45	33.3	220.4	0.6	2.2	0.6	1.7	17.2
Bw3	105	130	0.0	44.5	30.5	25.0	Loam	5.5	0.0	0.42	28.2	213.7	0.8	0.8	0.6	1.9	14.0
C	130	165	0.0	55.2	15.7	29.1	Sandy clay loam	5.2	0.1	0.33	25.7	252.4	0.0	0.0	0.6	2.0	13.0
P13																	
Ap	0	20	0.0	53.9	16.8	29.4	Sandy clay loam	6.8	0.3	0.84	28.2	250.0	0.9	0.6	0.1	0.4	4.0
Bt1	20	45	0.0	46.2	12.4	41.4	Sandy clay loam	6.7	0.2	0.39	23.1	237.5	1.1	1.1	0.0	0.3	4.4
Bt2	45	80	0.0	38.8	20.0	41.2	Clay	5.9	0.1	0.27	20.5	400.9	0.8	0.6	0.0	0.6	4.5
C	80	195	0.0	35.0	32.0	33.0	Clay loam	5.3	0.1	0.33	7.7	440.2	0.6	0.7	0.0	0.7	5.3
P14																	
A	0	25	0.0	22.0	46.0	32.0	Silty clay loam	4.5	0.0	0.54	23.1	462.1	2.4	1.6	0.5	1.6	9.2
AC	25	40	0.0	28.6	27.4	44.0	Clay	5.1	0.0	0.45	15.4	289.2	1.6	1.6	0.8	0.7	10.0
P15																	
A	0	15	0.0	68.6	15.1	16.3	Sandy loam	4.6		0.42	28.2	366.2	1.6	2.0	0.6	1.6	12.0
AC	15	40	0.0	72.3	15.4	12.3	Sandy loam	4.5		0.36	25.7	293.9	1.2	1.2	0.6	1.3	13.0
C1	40	110	0.0	71.4	17.2	11.4	Sandy loam	4.5		0.30	20.5	251.1	0.8	0.4	0.6	1.3	19.0
C2	110	135	0.0	80.4	11.0	8.6	Loamy sand	4.9		0.30	14.1	219.7	0.8	2.4	0.6	1.5	18.0
C3	135	195	0.0	85.2	9.6	5.2	Loamy sand	4.3		0.24	12.8	237.1	0.4	0.8	0.6	1.5	7.2

Table 4: Classification of Soils as per the guidelines of Soil Survey Staff, 2010 [17]

Sub order	Great group	Sub group	Family Class	Series
Aquents	Endoaquents	Aeric Endoaquents	Coarse Loamy, Mixed, Hyperthermic, Aeric Endoaquents	Silimkhowa
Orthents	Udorthents	Typic Udorthents	Coarse Loamy, Mixed, Hyperthermic, Typic Udorthents	Amguri
	Udorthents	Typic Udorthents	Fine, Mixed, Hyperthermic, Typic Udorthents	Salbari
	Udorthents	Typic Udorthents	Loamy Skeletal, Mixed, Hyperthermic, Typic Udorthents	Doboka
	Udorthents	Typic Udorthents	Sandy, Mixed, Hyperthermic, Typic Udorthents	Fuloguri Hill
Udalfs	Kanhapludalfs	Typic Kanhapludalfs	Fine, Mixed, Hyperthermic, Typic Kanhapludalfs	Lumding Bidhan Pally
	Kanhapludalfs	Typic Kanhapludalfs	Fine, Mixed, Hyperthermic, Typic Kanhapludalfs	Lumding Bidhan Pally
	Kanhapludalfs	Typic Kanhapludalfs	Fine, Mixed, Hyperthermic, Typic Kanhapludalfs	Lumding Bidhan Pally
Udepts	Dystrudepts	Fluventic Dystrudepts	Coarse Loamy, Mixed, Hyperthermic, Fluventic Dystrudepts	Dersu Hill
	Dystrudepts	Oxic Dystrudepts	Fine, Mixed, Hyperthermic, Oxic Dystrudepts	Kukrakota
	Dystrudepts	Oxic Dystrudepts	Fine, Mixed, Hyperthermic, Oxic Dystrudepts	Kukrakota
	Dystrudepts	Oxyaquic Dystrudepts	Fine, Mixed, Hyperthermic, Oxyaquic Dystrudepts	Amsoi
	Eutrudepts	Dystric Eutrudepts	Fine Loamy, Mixed, Hyperthermic, Dystric Eutrudepts	Dasgram
	Dystrudepts	Fluventic Dystrudepts	Fine Loamy, Mixed, Hyperthermic, Fluventic Dystrudepts	Burigaon
	Eutrudepts	Fluventic Eutrudepts	Fine Loamy, Mixed, Hyperthermic, Fluventic Eutrudepts	Deosur Hill

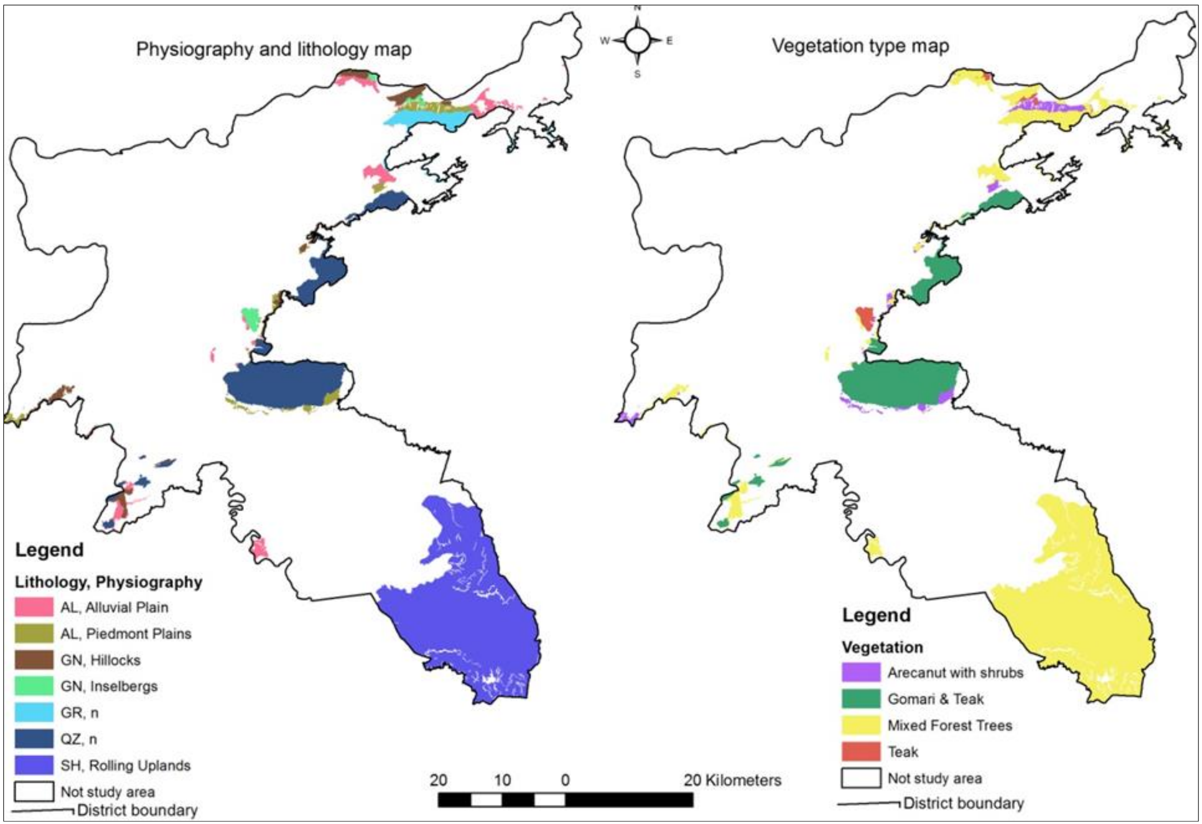

Fig 3: Physiography, lithology and vegetation type map of the study area

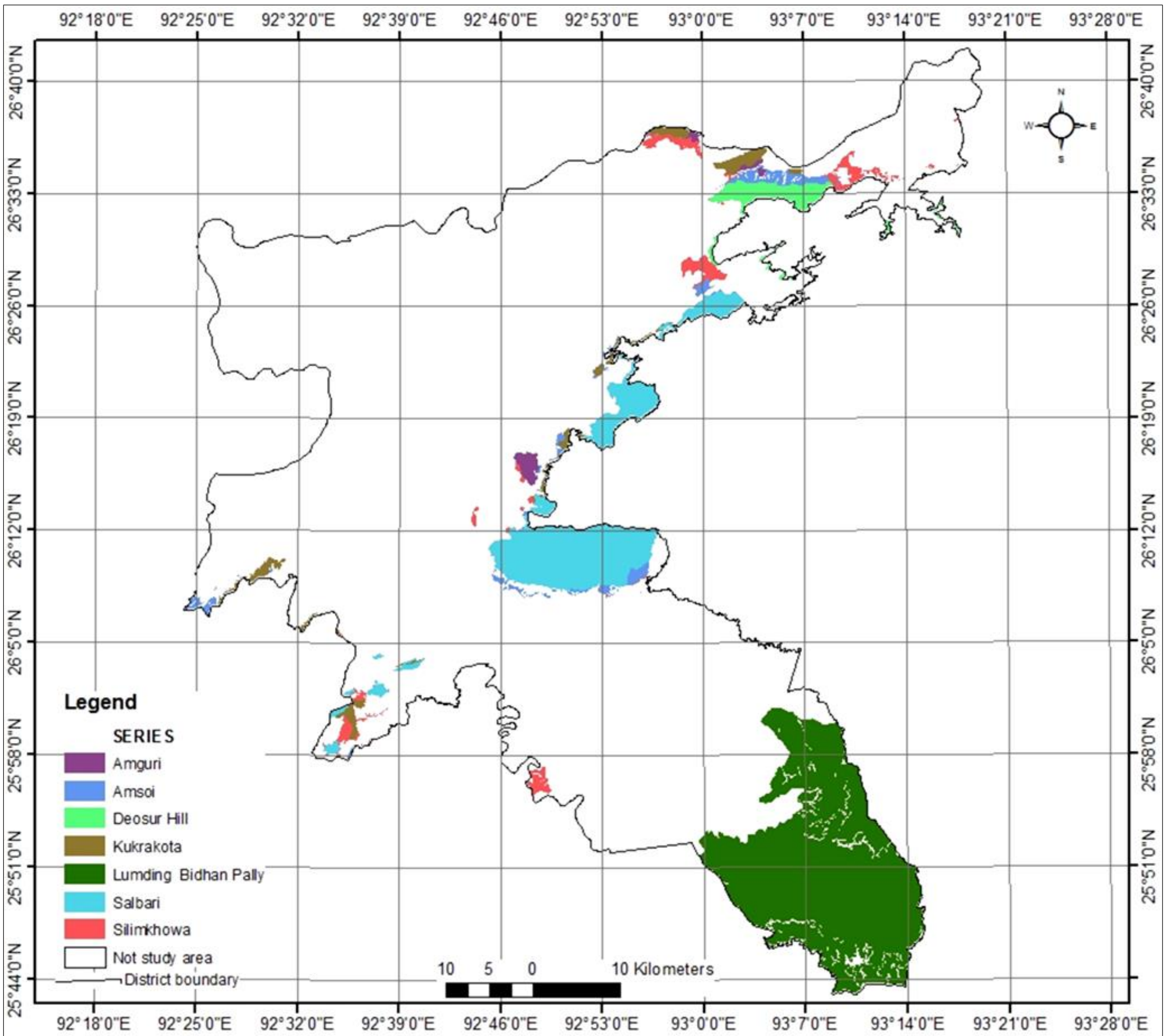

Fig 4: Soil map of the study area

Conclusions
The morphological, physical, chemical and taxonomical study of soils revealed that the soils of forest areas of Nagaon district were strongly acidic to slightly acidic in reaction and low to high in organic carbon. Exchange sites were dominated by Ca^{2+} and Mg^{2+} followed by K^{+} and Na^{+}. CEC was found to vary from 0.1 to 15.66 Cmol(P^{+})/kg and base saturation varied from 14.56 to 73.20%. The soils were low to high in available N and most of the soils were having low phosphorus content followed by medium and high. The available potassium content varied from medium to high. The soils were classified as Aeric Endoaquents, Dystric Eutrudepts, Fluventic Dystrudepts, Fluventic Eutrudepts, Oxic Dystrudepts, Oxyaquic Dystrudepts, Typic Kanhapludalfs and Typic Udorthents. The soil temperature regime, mineralogy and moisture regime were found to be hyperthermic, mixed and udic & aquic, respectively. Alfisols were found to be the most dominant soil which occupied 57% area followed by Entisols (31%) and Inceptisols (12%). The study revealed that soil properties like profile development, texture, structure, colour, soil acidity, CEC, base saturation, *etc*. were related to landform. The formation of the diverse group of soils could be attributed to the effect of topography, parent material, vegetation and climate leading to various pedogenic processes.

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