GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

MINISTRY OF ROAD TRANSPORT AND BRIDGES

ROADS AND HIGHWAYS DEPARTMENT (RHD)

Final Report
On
Preparation of soil maps for remaining divisions and compilation of soil maps prepared in the previous year under BRRL during the year 2016-2017.

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Implemented by

Bangladesh Road Research Laboratory (BRRL)
Mirpur-1, Dhaka-1216

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1. INTRODUCTION

1.1. Background

Roads and Highways Department is responsible for the construction and maintenance of the major road network of Bangladesh. The mission of the Roads and Highways Department is to provide safe, cost effective roads and bridges. To construct safe, cost effective roads and bridges, Engineering Soil Map may play important role as planning tool. If we have appropriate information regarding soils of Bangladesh, we can plan design and construct roads and bridges economically and provide safety during construction. To prepare an Engineering Soil Map of Bangladesh, it needs both time and manpower. Thus the Engineering Soil Map of whole Bangladesh cannot be made all at once. It is a continuous process and has to be made in phase. BRRL has prepared Engineering soil map of 49 districts of Bangladesh. As a part of the continuous process in financial year 2016-2017, an initiative has been taken to complete mapping of the remaining districts and compiling all the previous maps under the supervision of BRRL.

The Government of the People's Republic of Bangladesh has allocated public funds for the cost of "Preparation of soil maps for remaining divisions and compilation of soil maps prepared in the previous year under BRRL during the year 2016-2017". Therefore, Bangladesh Road Research Laboratory (BRRL) has taken an initiative to hire 01 (one) Geologist cum GIS Specialists hereinafter called Specialist as a junior consultant for 3 (three) months to carry out this study.

1.2. Scope of Work and Continuation

The aim of this work is to prepare Engineering Soil Map as per Soil Classification of Road Master Plan.

1. Collection of secondary boring data of the remaining divisions (Districts for which Engineering soil Map yet to be prepared).
2. To acquire around 50 no of secondary borehole data for each of remaining divisions.

3. With the help of secondary data to prepare soil maps of the remaining divisions.
4. Data Entry, GIS software & GIS Mapping.
5. Compilation of all the soil maps of previous and new (KML/KMZ file for Google earth presentation) to make it user friendly.
6. Demonstration of performed tasks, preparation and acceptance initiative of technical paper on the research findings in technical Journals.

1.3. Proposed Work Locations

Soil properties are subjected to high spatial and temporal variations. For accurate assessment of soil properties, high-density sampling will be required, but borehole sampling and other geophysical tests are costly.Therefore, the secondary boreholes data will becollected from government or non government organization. Regional Geomorphology will be also taken into consideration during soil mapping. Engineering soil map locations are given inFigure1-1.

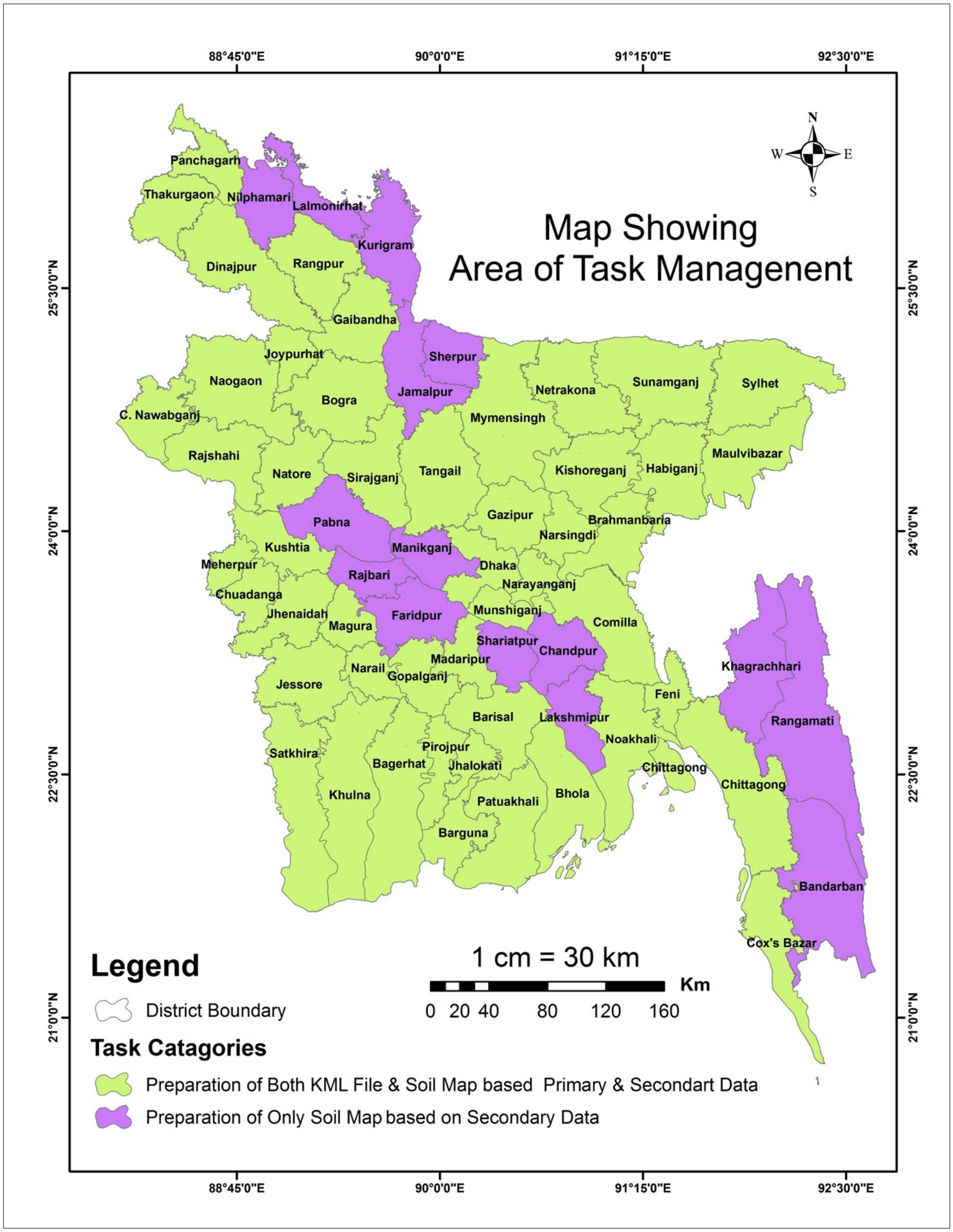

Figure 1-1 Engineering soil map locations

2. LITERATURE REVIEW

2.1. PREVIOUS WORK

To provide a safe, cost effective and well maintained road network, the Roads and Highways Department was founded in 1962. RHD is responsible for the construction and maintenance of the major road and bridge network of Bangladesh. The Roads and Highways Department has a sustainable capacity to plan, manage and deliver its full range of responsibilities in respect of the main road and bridge network and to be accountable for these duties. Since the Department was established the size of the major road network in Bangladesh has grown from 2,500 kms to the present network of 20,866.36 kms. This figure, for instance, reflects the significance of RHD in the context of national development. This department is playing a significant role and will continue its activity towards boosting the national economy by ensuring sustainable road network in Bangladesh.

BRRL is a wing in the context of technical service of Roads and Highway department. It is responsible to ensure the projects of RHD are utilizing most appropriate materials with maintaining the required quality. This circle provides soil investigation reports and conducts research related to construction material.

Earlier, Engineering soil maps have already been prepared for many areas in Bangladesh. Among them some are worthy to mentioning here.

Location of Soil Mapping (2013-2014):

1. Madhupur Clay : Dhaka, Ghagipur, Narsingdi, Narayanganj, Tangail, Jamalpur, Mymensingh, Kishoregonj.

2. Barind Clay : Dinajpur, Gaibandha, Jaipurhat, Bogra, Naogaon, Nator, Sirajgonj, Rajshahi, Nawabganj, Rangpur.

Location of Soil Mapping (2014-2015):

1. Dhaka, Comilla, Munshiganj, Narayanganj.
2. Barisal, Jhalokati, Pirojpur, Patuakhali, Barguna, Satkhira.
3. Madaripur, Gopalganj, Narail, Jessore, Bagerhat, Khulna.

Location of Soil Mapping (2015-2016):

1. Sylhet, Moulavi Bazar, Sunamgonj, Hobigonj, Brahmanbaria, Netrokona & Kishoregonj.
2. Noakhali, Feni, Bhola, Chittagong, Dohajari & Cox's Bazar.
3. Kushtia, Meherpur, Chuadanga, Jhenaidah, & Magura.
4. Panchgarh, Thakurgaon & Dinajpur.

The Government of the People's Republic of Bangladesh has allocated public funds for the cost of Engineering Soil Map of Bangladesh by sub-soil investigation under BRRL during the year 2013-16.The concerned authority of RHD, Bangladesh Road Research Laboratory intends to apply a portion of the fund to eligible private entity.

Engineering soil maps have already been prepared for 49 districts of Bangladesh (Figure-2-1). Those maps have been accomplished in a different financial year (Table-2-1). First of all, the Primary borehole data collection is very essential part to conduct this study successfully. All data are preserved in Bangladesh Road Research Laboratory's archive as well as assigned organization/consultancy firm. Initially,primary data and existing engineering soil maps need to be collected. After that borehole data will be summarized and prepared for GIS map presentation. Simultaneously, existing engineering soil maps will be compiled for demonstration.

Table 2-1 Previous financial year and the project area

Financial Year	Package	Districts/Divisions
2013-2014	1.Madhupur Clay	Dhaka, Ghagipur, Narsingdi, Narayanganj, Tangail, Jamalpur, Mymensingh, Kishoregonj.
	2.Barind Clay	Dinajpur, Gaibandha, Jaipurhat, Bogra, Naogaon, Nator, Sirajgonj, Rajshahi, Chapai Nawabganj, Rangpur.
2014-2015	1	Dhaka, Comilla, Munshiganj, Narayanganj.
	2	Barisal, Jhalokati, Pirojpur, Patuakhali, Barguna, Satkhira.
	3	Madaripur, Gopalganj, Narail, Jessore, Bagerhat, Khulna.
2015-2016	1	Sylhet, Moulavi Bazar, Sunamgonj, Hobigonj, Brahmanbaria, Netrokona & Kishoregonj.
	2	Noakhali, Feni, Bhola, Chittagong, Dohajari & Cox's Bazar.
	3	Kushtia, Meherpur, Chuadanga, Jhenaidah, & Magura.
	4	Panchgarh, Thakurgaon & Dinajpur.

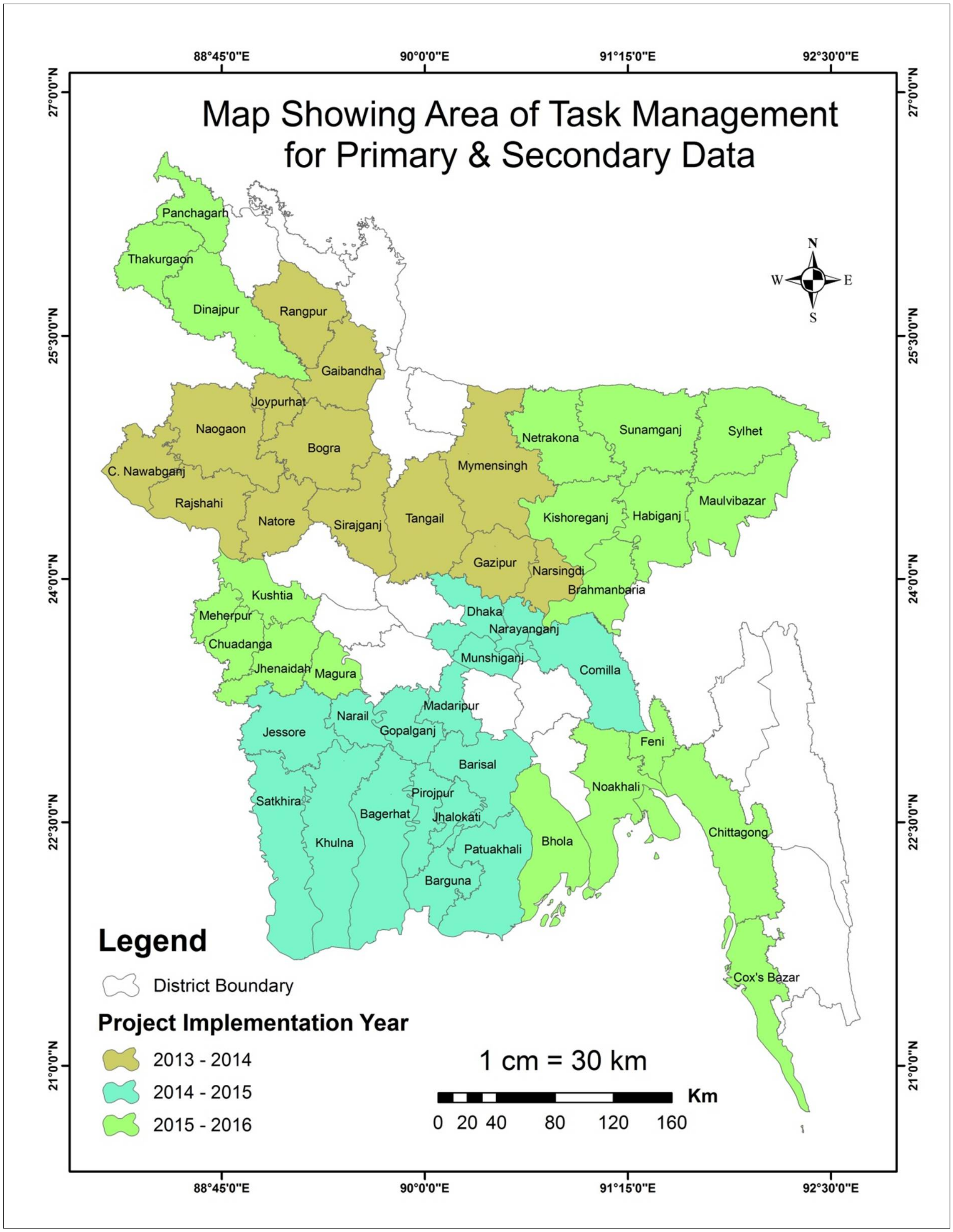

Figure 2-1 Engineering soil maps have been accomplished Previous financial year

2.2. REVIEW OF OTHER GOVERNMENT ORGANIZATIONS WORKS

Responsibilities Performed by Geological Survey of Bangladesh (GSB)

Geological Survey of Bangladesh (GSB), a government organization, is engaged in geoscientific activities throughout Bangladesh. Its beginning dates back to 1972 immediately after the liberation war of Bangladesh with the staff and facilities of the Eastern Division of the then Geological Survey of Pakistan (GSP) in Dhaka. At present GSB is an attached department of the Ministry of Energy and Mineral Resources.

Activities of GSB:

GSB conducts systematic geological mapping and geoscientific activities throughout the country from its headquarters in Dhaka and a camp office at Bogra.

To conduct systematic geological surveying of the country for preparing geological maps; to investigate in detail of such areas as are indicated by geological mapping to be favorite for accumulation of industrial rocks, minerals, fuels, groundwater, ground water arsenic contamination and other natural resources; to investigate in detail and conduct extensive geophysical, test drilling and geo-chemical operations in order to evaluate the known resources; to conduct stratigraphic studies to identify, correlate and determine the sequences of rock units in support of mapping and exploration programs including age determination by fossils and other geo-chemical methods; to conduct geological investigation into the construction of dams, canals, tunnels, highways, bridges, new townships and other public construction projects so as to advise the sponsoring agencies about geological feasibility of such construction projects; to carry out marine geological and geophysical investigations and geomorphological studies of river basins and deltaic region; to undertake systematic sampling of minerals, mineral fuels, surface and ground water resources and carry out the mineralogical and chemical analysis of the samples; to advise public and private organizations in all matters connected to geology and resources of the earth.

Divisions of GSB:

There are two divisions headed by two Deputy Director Generals and 17 branches under the divisions each headed by a Director. The branches are: (i) Planning and Implementation Unit, (ii) Editorial Service, (iii) Geological Mapping, (iv) Stratigraphy and Biostratigraphy, (v) Coastal and Marine Geology, (vi) Petrology and Mineralogy, (vii) Photogeology, (viii) Remote Sensing and Surveying, (ix) Geochemical Exploration, (x) Analytical Chemistry, (xi) Economic Geology, (xii) Geo-Technical, Engineering and Urban Geology, (xiii) Drilling, (xiv) Publication, Public Relation and Data Centre, (xv) Geophysical Mapping-1 (gravity and magnetic), (xvi) Geophysical Mapping-2 (seismic and electric) plus Laboratory and Geophysical Research, and (xvii) Operation and Coordination. The department has a computer cell with remote sensing and GIS (geographical information systems) facilities, a library with books and journals on earth science, a geological museum in Dhaka and a core library at Bogra.

Research facilities of GSB:

GSB is fully equipped with rotary conventional and wire line drilling units, and capable of drilling upto 2,000 meters. Analytical Chemistry Laboratory has been moderately upgraded with atomic absorption spectrometry. Laboratories of petrology and mineralogy, stratigraphy and biostratigraphy branches are equipped with X-ray diffractometer and scanning electron microscope. Engineering and Geo-technical Laboratory is well equipped to determine geo-technical characteristics of the soil and rock for civil constructions. Geophysical Mappings are being carried out with the help of gravity, magnetic, seismic and electrical methods. GSB has the capability of computerised data processing and well logging. The department is continually upgrading its capabilities through training of its geoscientific manpower and procuring the laboratory amenities to provide modern facilities.

Remarkable achievements of GSB so far:

As a result of the aforesaid activities and facilities GSB attained the following achievements: about 55,000 sq km areas of the country including coastal parts have so far been geologically mapped at the scale of 1:50,000. These mapping programs have been carried out in plain and hilly areas in different parts of the country.

The mapping works of the geo-technical and engineering and urban geology, at suitable scales, of important cities (eg Dhaka including surrounding areas, Chittagong, Rajshahi, Barisal, Rangpur, Bogra and Khulna have been completed. GSB has so far drilled 180 hole in the country with a total drilling depth of about 42,680m for mineral exploration, stratigraphic studies, testing and to gather other subsurface information.

GSB discovered good quality Gondwana coalfields at Barapukuria and Dighipara of Dinajpur district, Khalaspir of Rangpur district, and Jamalganj of Joypurhat district. Among these coalfields of Barapukuria is in mining stage. Besides the coal fields GSB discovered a good number of peat fields, limestone, white clays, glass sands, mineral sands, construction materials (gravels) and hard rocks. The subsurface hard rock at Maddhyapara of Dinajpur district is in mining stage.

Research outcomes of GSB:

GSB published a good number of reports on different branches of earth science. These works are based on their completed works carried out in different part of the country. Besides these, scientists of the department publish their research findings in seminars/symposia and journals in home and abroad.

Responsibilities Performed by Survey of Bangladesh (SOB)

Survey of Bangladesh (SOB) has started making 1:25,000 scale topographic map for entire Bangladesh and 1:5,000 scale topographic map for divisional cities by digital mapping system. Under the Improvement of Digital Mapping System of Survey of Bangladesh (IDMS) project technically assisted by JICA, Bangladesh digital topographic maps and digital geospatial data will be disseminated to the users in order to help them undertaking various development works.

Objectives of Improvement of Digital Mapping System (IDMS) Project

The following mapping and surveying activities will be accomplished:

- To Produce 1:5000 scale digital topographic map covering all Divisional cities and its digital database (approximately 160 sheets).
- To produce 1:25000 scale digital topographic map covering whole country and its digital database (approximately 960 sheets).
- To provide multiple products likes DEM, Orthophoto, maps etc. to the users for utilization in various socio-economic development activities and management of natural disaster.
- To strengthen the capability of production of digital topographic maps of Survey of Bangladesh.
- To establish a Digital Mapping Centre for Survey of Bangladesh (SOB) at Dhamalkote, Dhaka.

Responsibilities Performed by Bangladesh Space Research and Remote Sensing Organization (SPARSO)

The Bangladesh Space Research and Remote Sensing or SPARRSO, is a state agency concerned with astronomical research and the application of space technology in Bangladesh.

Broad Category of SPARRSO Activities

- Category 1: Operational Activities towards National Interest
- Category 2: Research & Technological Development Activities
- Category 3: Activities to Support National Development
- Category 4: Nation Building Mile Stone Activities of SPARRSO
- Category 5: Human Resource Development on RS & GIS Technology

This organization provides the following services:

- SPARRSO has been applying peacefully space and remote sensing technology, in the field of Agriculture, Forestry, Fisheries, Geology, Cartography, Water Resources, Land use, Weather, Environment, Geography, Oceanography, Science, Education, science-based Knowledge and other related space research areas. It also perform research activities for developing this technology and its practical application.

- Provides necessary information and disseminates research results to the Government and different relevant user agencies.
- It provides the Government about the development of space and remote sensing technology of different countries and gives advice for formulation of national policy to the Government.
- Conducts training, technical research, survey and monitor on space and remote sensing technology and cooperates national or international organization or institutes in the relevant matter.
- Framing development project to perform research activities on space and remote sensing technology and implement it taking prior approval from the Government.
- Take any measures regarding the above-mentioned work at any time as it feels necessary.

Divisions of SPARSO:

At present, there are total 17 working divisions in SPARRSO. They are: Atmospheric Division, Agriculture Division, Agro-hydrometeorology Division, Forestry Division, Water Resources Division, Oceanography Division, Fisheries Division, Cartography Division, Ground Station Division, Photographic Division, Ocean Physics Division, Instrumentation and Data Processing Division, Ground Truth Division, Geology Division, Rocket Technology Development Division, Space Physics & Rocket Dynamics Division and Regional Remote Sensing Center (RRSC).

Research conducted by SPARSO:

SPARRSO conducts research works on various aspects of geo-disciplinary subject areas of RS-GIS technologies. The research items include technological development on RS-GIS algorithms aims at better techniques for geoinformation retrieval along with effective approaches towards fruitful application of such technology.

3. GEOLOGY OF BANGLADESH

3.1. TECTONIC SETTING OF BANGLADESH

To understand the regional tectonic scenario it is important to understand the structural style of Bengal basin. The Bengal Basin includes Bangladesh and western part of West Bengal state and Tripura state of India. It is bounded by Shillong massif to the north, Frontal fold belt of Indo-Berman range to the east, Precambrian Indian shield to the west and open to the south for some distance to the Bay of Bengal. Bengal Basin being in the north-eastern margin of Indian plate experienced many deformation events due to tectonic instability as major deformations occurs at plate boundary zones. Geomorpho- structural features of the area indicate juxtaposition of active and passive margin setting of Indian plate. Passive marginal setting is defined by vertical upward and downward movement of blocks causing tensional horst-graben systems in the north-western part of Bangladesh which is attenuated toward south-east and is related to Cretaceous rifting of Indian plate from Antarctica (Murphy, 1988; Khan and Chouhan, 1996). Whereas active margins are related to formation of accretionary prism due to subduction of plate and the sedimentary layers are internally folded, faulted and thrusted.

Basin fill history of Bengal Basin is gradual in nature. It ranges from the pre collision marine phase to post collision fluvial phase. Sedimentation in the basin can be broadly subdivided into five major phases (Alam et al, 2003):

I. Permo-Carboniferous to Early Cretaceous.
II. Cretaceous to Mid-Eocene.
III. Mid-Eocene to Early Miocene.
IV. Early Miocene to Mid-Pliocene.
V. Mid Pliocene to Quaternary.

Pre-rift Gondwana sediments were deposited from Late Carboniferous to Late Jurassic. During Early Permian, after the formation of Intra-Cratonic rift basins sediments deposited in a uniform manner there. The basins subsided during Early Permian and surprisingly an oscillating fluvial environment largely controlled deposition. Gondwana deposits in Singra and Kutchma wells represent deposition in fluvial regime (Bangladesh Petroleum Potential and Resource Assessment Report, 2001 by HCU, Ministry of Energy and Mineral Resources Government of People's Republic of Bangladesh).

In Bangladesh, though sediments from Jurassic Upper Gondwana deltaic to shallow marine has not been drilled, from seismic survey their presence in the western shelf with southeast dipping wedge formation has been inferred before the final breakup of the continent.

The upper part of Gondwana succession is composed of Basaltic Lavas and associated volcanoclastic rocks of Jurassic age. In western shelf area, this unit has been drilled in several wells and it represents a wide spread volcanic as well as erosional event.

The Early Cretaceous (about 110 million years ago) is the time of final break up of Gondwanaland. After breaking up, Indian plate moved northward slowly. Due to the convergence of Indian plate with Eurasian plate, Tethyan Ocean gradually closed up which formerly located in the north part of Indian plate. From the shelf area, the breakup unconformity separating pre-rift Rajmahal and Gondwana succession from post rift Cretaceous sediments are seen in seismic section. Along the rifted, passive margin of Indian plate, a proto delta and fan began to develop at that time (Bangladesh Petroleum Potential and Resource Assessment Report, 2001 by HCU, Ministry of Energy and Mineral Resources Government of People's Republic of Bangladesh).

The Shipganj Trapwash covers a wide area and overlays the Jurassic to Early Cretaceous basaltic rocks. Besides of having derived from underlying Rajmahal rocks, it also contains granite wash i.e. clastic granite debris derived from Precambrian basement. This unit is assumed to be deposited in basin floor fans and wedges. It is tectonically important because it contains coarse grain size and content of rock fragments indicating activeness of neighboring areas.

A first transgression took place in Late Cretaceous, after a major break in the sedimentary succession. The post-rift pre-collision phase of basin development is represented by Cretaceous to Middle Eocene succession. Prior to maximum transgression during Middle Eocene, this succession shows progressive onlap of the rifted continental margin (Figure 3-1). During this time, most of the western shelf area of Bangladesh was covered by platform limestone of Sylhet formation. This limestone deposited in areas covering from western shelf to the south of Shillong plateau of India. In basin wards the formation passed into shale (Source: Bangladesh Petroleum Potential and Resource Assessment Report, 2001). At the end of Middle Eocene, the basin floor started subsiding beyond the shelf edge due to the considerable increase of sediments influx. From Early Cretaceous to Early Eocene, fluvio-deltaic slope and submarine fan sequences built out towards southeast (Source: Bangladesh Petroleum Potential and Resource Assessment Report, 2001).

Indian plate and Asian plate collided in stages began from Eocene (55 million years ago) with an initial uplift of Himalaya Molnar and Tapponier 1975, 1977; Curray et al. 1982).The first fall of sea level took place in Late Eocene and as a result erosion of limestone platform occurred and channels were formed cutting off the carbonate shelf edge. With further transgression Kopilli Formation onlapped the eroded surface comprising a thin drape of mudstone.

Since the Oligocene (35 million years ago), large river systems started to fill the basin by large sedimentary influx with the major rise of Himalayas. The western shelf Early Oligocene deposits contain a complex mixture of lithologies. It broadly grades up from inner shelf and delta front to a mixed energy carbonate rich delta plain and low energy delta front (Figure 3-1) (Bangladesh Petroleum Potential and Resource Assessment Report, 2001).

The landmass GBM delta started to build up in Neogene (25 million years ago). Himalayan orogeny rose rapidly as well as the basin in the south subsided rapidly resulting in deposition of huge sedimentary succession giving rise to mega delta development (Brunschweiler, R.O. 1980).

Middle Miocene sequence representing mixed energy delta front to inner shelf lithofacies indicates high amplitude shelf reflections when correlated with shelf wells.

This unit forms high quality reservoir sandstones. A speculative stratigraphic play may have formed due to the presence of canyon fill and upper fan valley sandstones in lower slope and inner fan environments (Source: Bangladesh Petroleum Potential and Resource Assessment Report, 2001).

Over shelf and slope deposition, prominent channeling events were formed by top of Middle Miocene deposition. Beneath this event, much of Middle to Lower Miocene shelf deposits has been removed by western shelf erosion. This can be correlated with prominent sea level low-stand.

The delta building activity was confined to the central part and the eastern part was folded into a mountain belt named Sylhet-Chittagong Hills. This is the western extremity of a more intense folded zone called Indo-Burman Range which was formed as a result of collision of Indian plate and Burma plate in the east (Imam, M.B., 1991)

Most recent phase of basin development is represented by Late Miocene to Plio-Pleistocene sequences. Because of the rapid progradation of delta slope fan systems southwards to the Bay of Bengal (Figure 3-1), the sequences are broadly regressive.

The Pliocene-Pleistocene deposits are entirely fluvial and ranges from meandering to braided river deposits. They are subdivided into three parts. Lithologically they are sand dominated in the bottom and the top with the middle part being shaly.

Generally the tectonic framework of Bangladesh can be broadly divided into two main subunits:

1. Stable Platform in the northwest including Bogra Shelf system and Paleocene-Eocene system.
2. Deep (Geosynclinal) Basin to the south east including Hatia tough system, Oligocene-Miocene system and Surma sub basin system.

The deepest part of the basin east and southeast is characterized by several troughs within an oceanic crustal basement for example, Surma trough, Hatia trough and Faridpur trough. Surma and Faridpur troughs are separated by Modhupur- Tripura threshold and Faridpur and Hatia troughs are separated by Barisal gravity high.

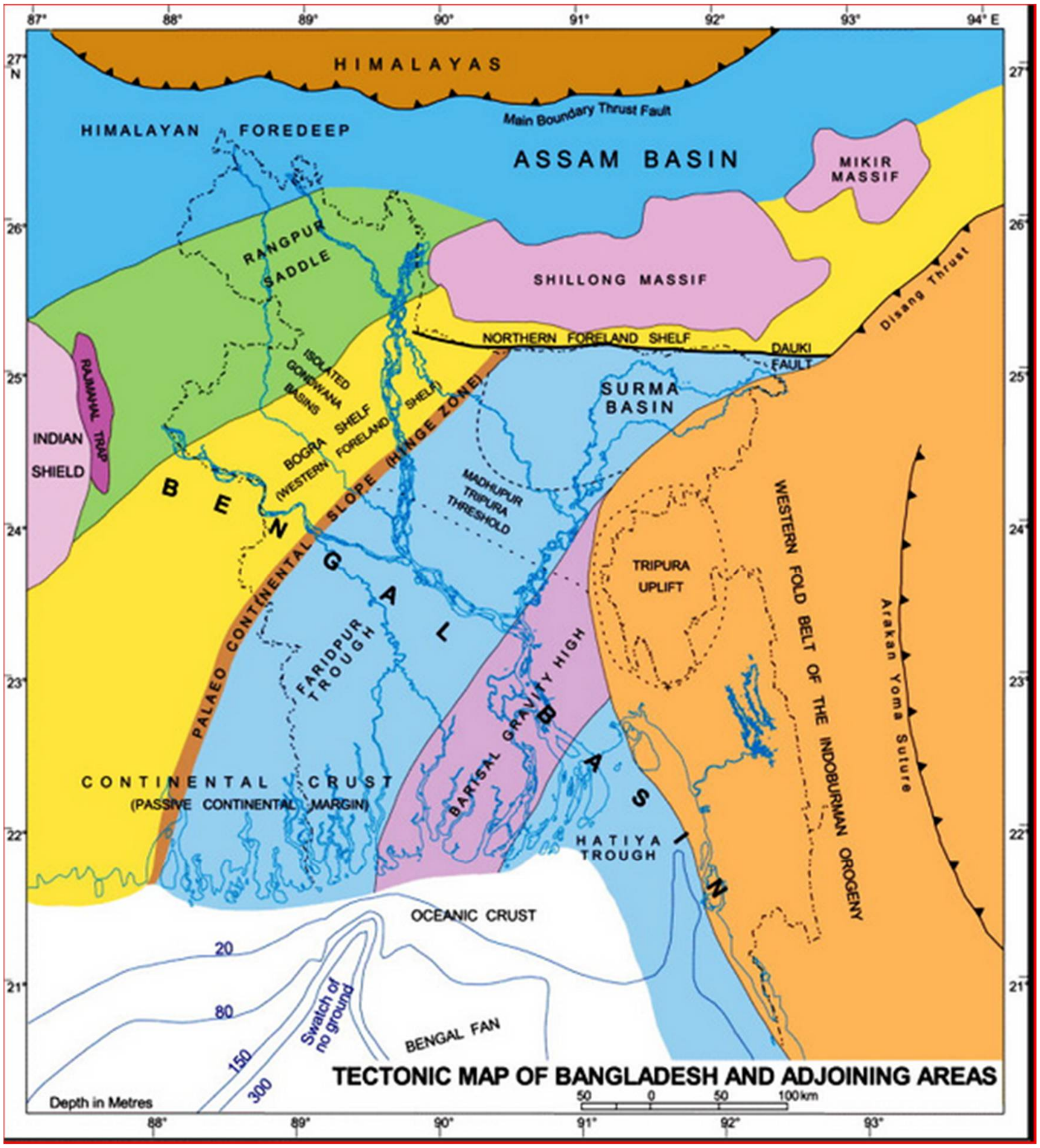

Figure 3-1 Tectonic Map of Bangladesh and Adjoining areas (After Guha 1978, GSB 1990, Reimann 1993).

3.2. SURFACE GEOLOGY OF BANGLADESH

Geology focuses on the nature and properties of rocks and sediments. A good knowledge on the geology of the rocks and sediments is indispensable to understand the nature and properties of the parent materials. It is essential to understand the processes of formation of major soils of the country. Geomorphological knowledge is also important to visualize the processes and methods well. Bangladesh lies in an active seismic location. Moreover being a riverine country, the sediments are much affected by the combination of river process and seismic activity. The rivers are the most significant features of Bangladesh geology. They constantly change course, sometimes so rapidly that it cannot be predicted. As a result the topological features of Bangladesh are ever changing and it gives a spectacular feature of Surface geology (Figure 3-2).

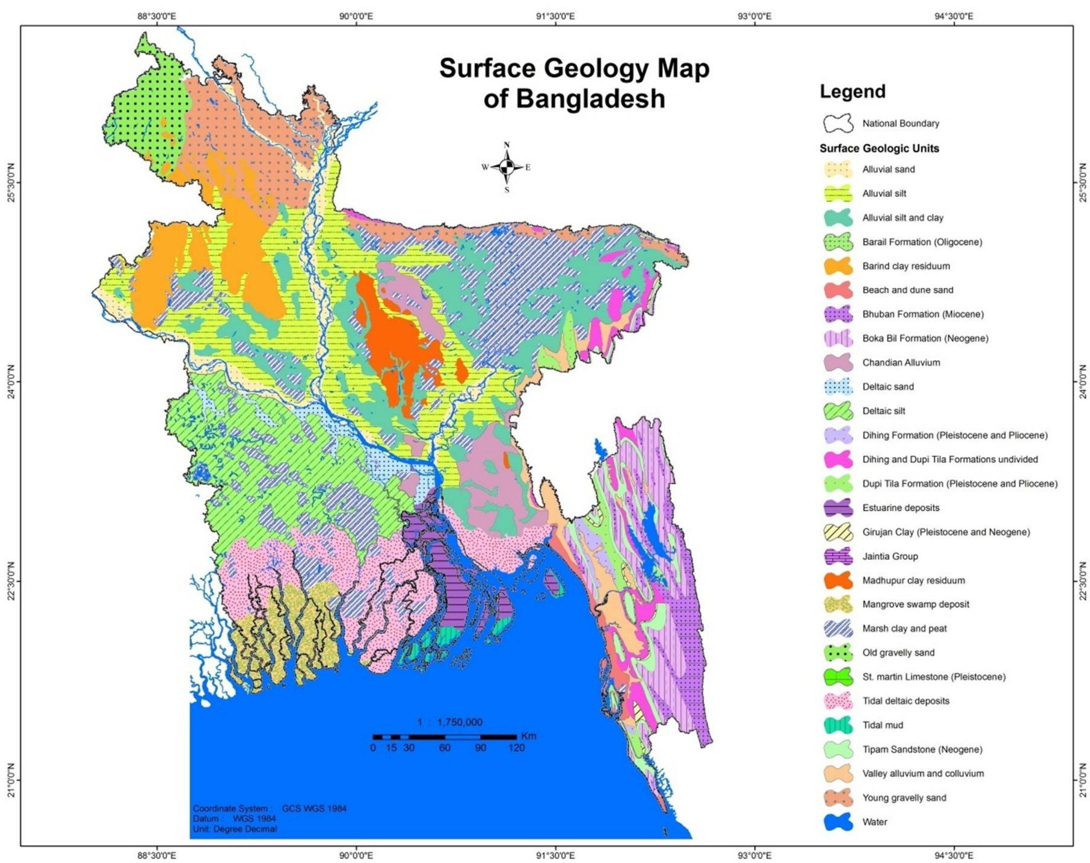

Figure 3-2 Surface Geology Map of Bangladesh (After modified from GSB 2001)

Alluvial Sand:

Alluvial deposits are materials formed by river deposition. It consists of sand, slit, clay and organic matters. The deposit may be sand or slit depending on the river water energy. It is very common in deltas around the world. Bangladesh contains the largest delta GBM delta that carries about 1.6 billion tons of sediment every year at present. Alluvial sand deposits are very common in the surface geology around the country.

Sands are particle sizes having 1/16 to 2 mm diameter. These are young soils formed on freshly deposited alluvium are stratified within 25-cm from the ground surface and contain lime. Soils are stratified or there is raw alluvium throughout or below the cultivated layer. They are calcareous throughout or part of it and lack a diagnostic subsoil horizon. Soils on the Lower Surma-Kushiara floodplain are slightly calcareous grey to olive, finely stratified silts. They are mainly calcaric fluvisols (Haque and Shoaib)

Alluvial Silt:

Sediment particles ranging from 0.004 to 0.06 mm (0.00016 to 0.0024 inch) in diameter irrespective of mineral type are called Silt. Silt is easily transported by moving currents but settles in still water. Hence river deposits are ideally rich in silty deposits. Energy content for silt deposition is slightly lower than sand body. However biologically it is the most important unit for plant root development.

Alluvial Silt and Clay:

These are also river bed deposits of low land areas. The energy content of river water fluctuates rapidly due to the difference in river discharge in monsoon and dry season. Hence with the fluctuation of the energy content silt and clay deposit form rapidly. Clay mineral**,** any of a group of important hydrous aluminumsilicates with a layer (sheet like) structure and very small particle size. They may contain significant amounts of iron, alkali metals, or alkaline earths. The term clay is generally either a natural material with plastic properties or particles of very fine size, customarily those defined as particles smaller than 2 micrometers or very fine mineral fragments or particles composed mostly of hydrous-layer silicates of aluminum, though occasionally containing magnesium and iron. The silt and clay layers together form a good biological setting to grow the plant roots.

The soil is sandy loam, very fertile and rich and is replenished every year by fresh deposits of silts carried down by the flood water. Almost all kinds of crops are grown of which jute and rice are the most important ones. The PH varies from 5.5 to 6.8. For low-lying areas, where broadcast winter paddy is grown, application of manures is unnecessary, but on high and medium lands good response is obtained from the application of nitrogenous and phosphatic fertilizers . The agricultural productivity of these soils ranges between moderate and poor. They are more productive and the potentiality is higher than the non-calcareous alluvium.

Chandian Alluvium:

The soil type usually is grey where rice is grown, brown where other crops are grown, and dark grey where sugarcane or other vegetables are heavily manured. Most top soils are calcareous, but some are non-calcareous. The reaction usually is moderately alkaline, but may be slightly acidic to mildly alkaline, if the topsoil is decalcified. The subsoil is olive-brown. The prismatic structure is developed in relatively heavier soils and thin, grey, subsoil coatings are sometimes found. Soil texture on the higher ridges usually is silt loam and occasionally sandy loam. Lower sites usually have silt loams or silty clay loams with a finer texture in the top soil than in the subsoil. The agricultural potential of these soils ranges from high to low. The potentiality is highest in deep loamy soils where irrigation is available, and lowest in shallow ridge soils and in soils affected by salinity or strong alkalinity. Most of these soils belong to chromic–calcaric gleysols (Haque and Shoaib).

Barail Formation:

Barail Group an Oligocene lithostratigraphic unit comprising several formations. P Evans (1932) named the rock unit as the Barail Series after the Barail Range of Assam. It was later emended by B Biswas to the Barail Group. It represents the geosynclinal development of Oligocene. It is well developed in the Surma valley. The unit comprises arenaceous and in places shaly and carbonaceous rocks. It is composed of alternating sandstone, siltstone, shale and occasional carbonaceous rich layers. It has three formations, from bottom to top: the Laisong Formation (sand rich or arenaceous), Jenam Formation (clay rich or argillaceous) and Renji Formation (sand rich or arenaceous).

Surma Group:

Surma Group unconformably lies over Barail group and conformably underlies by Tipam group.This group is subdivided into two units. The lower, sandier unit is known as Bhuban Formation and the upper, shalier unit is Bokabil Formation.The Bhuban Formation was deposited in an environment ranging from a shallow inner neritic to a lower deltaic plain, and that for the Bokabil Formation was in a range from marine at the bottom to transitional marine at the top. Both the formations show extensive lateral facies change. Sand shale ratio also varies in the formations from place to place. For this the correlation of the units in basinal scale is difficult. The top of the Bokabil Formation is also known as Upper marine shale (UMS) representing the last widespread marine transgression over the Bengal Fore deep. During this period, a large Delta complex started to build on the northeast side of the Bengal Basin. Smaller deltas were possibly building on the eastern side of the basin, presently occupied by Tertiary Hills of Chittagong and Chittagong Hill Tracts (Alam, 1989).

Bhuban Formation:

Bhuban Formation a Miocene body of rock identified by its lithic characteristics. The lower unit of P Evans (1932) Surma Groupwas designated by him as the Bhuban Stage after the Bhuban Range of Assam, India (Source: Banglapedia).

Bhuban subgroup is further divided into three subdivisions in the Bengal Basin .they are:

i. Upper Bhuban Formation: This formation underlies conformably the Boka Bil Formation. The contract in most cases is gradational. Consists of massive, brownish, soft friable, medium grained sandstone with some fragments of shales.

ii. Middle Bhuban Formation: It overlies the Upper Bhuban Formation conformably the contract being graditional.The rock formation is predominantly argillaceous sandstone with shale, mudstone and siltstone.
iii. Lower Bhuban Formation: It comprises mostly of grayish, fine to very fine grained well bedded,compact,massive sandstone interbedded with thinner bands of siltstone and shale.

The oldest rocks, the Lower Bhuban Formation are outcropped in the cores of the easternmost anticlines near the Indian border. Based on foraminifera test and hystrichospherids encountered in the shaly sequences of this member indicate deposition in a marine to brackish environment. Rocks of the Middle Bhuban Member are also confined to the cores of the anticlines in the eastern part of the Chittagong Hill Tracts indicating a deltaic to near shore depositional environment. The Upper Bhuban Member crops out in most of the anticlines throughout the Chittagong Hill Tracts. The study area does not have such extensive exposure of the unit. The Upper Bhuban Member is dominated by gymnospermous pollen. This indicates that the orogenies in the region were already so highly elevated that the climatic conditions were favorable for the growth of gymnospermous plants in this zone.

Bokabil Formation:

The Bokabil Formation conformably overlies the Bhuban Formation and is unconformably overlain by the Tipam Sandstone Formation. It was named by Evans (1932) as Bokabil stage after a locality in the Hailakandi valley, northern Cachar, Assam, India (Source: Banglapedia). The unit is mainly composed of silty shale, shale, siltstone and sandstone. The silty shale is gray to bluish, laminated to thinly bedded, compact and highly jointed. The shale is Greenish gray to bluish gray, very thinly to thickly laminated. Siltstone is predominantly yellowish gray to bluish gray, moderately hard,laminated,sometimes shows ripple marks. Sandstone is gray to yellowish gray, moderately hard and compact, thin to thick bedded and medium to fine grained. Sandstone commonly shows planar cross-bedding with abundant flaser lamination.(Ismail Hossain,Md.Sultan-Ul- Islam,2013).

The formation is exposed in the hill ranges of greater Sylhet, Chittagong district and the Chittagong Hill Tracts. From the Boka Bil Formation, more than 100 fossil species have so far been identified from two localities of the Garo Hills. Most of them belong to Pelecypoda and Gastropoda. Different species of Foraminifera have been recorded, such as Chiloguembelina globigera; Globigerina bulloides;G, falconensis-G, cf bradyi and G.quinqueloba. In the Sitakunda hills the Bokabil Shale contains Ostrea digitalina, O. gryphoides and numerous plates of Bolanus, fragments of Arca, Pecten, Trochus, Oliva and Corals. The formation may have been deposited under shallow marine to deltaic and estuarine environments. (Banglapedia).

Dihing and Dupitila Formation Undivided:

Dupitila Formation is a predominantly sand rich unit of Pliocene- Pleistocene age. Minor interbedded claystone are also present in this unit. The sandstone is red to brown in color, medium to coarse grained, cross bedded, loosely compacted. It occasionally contain pebble and woody fragments as well as petrified woods. The formation was river plain or fluvial deposit mainly of Braided type river deposit.

Dihing Formation is a Pleistocene rock unit. It has scattered occurrence in the Bengal Basin and is merely of local importance. FR Mallet gave this name after the Dihing river near Jaipur in Assam. The distribution of the formation in Bangladesh is not homogenous rather has a patchy nature. It consists of yellow and grey, medium-grained, occasionally pebbly sandstone and clayey sandstone with interbeds of mottled clay. The rocks are in most part poorly consolidated. The unit lies unconformably between Dupitila and alluvium. At places the unit is reported to contain white clay at the base. [Sifatul Quader Chowdhury, Mujibur Rahman Khan and Md Nehal Uddin]. The gravels or pebbly sandstones are mainly igneous and metamorphic in nature. The origin is from Shillong massif indicated by the similarity of composition of gravels and pebbles with Shillong rocks. However this situation indicates the mighty rivers of Bangladesh have weatherd the Shillong Plateau in high discharge time (monsoon season) and deposited the pebbles at the foothill or down slope area.

The Dupitila and Dihing formation cannot be separated as the formation is mainly sandy with nature of Dupitila with signatures of Dihing Formation, the igneous metamorphic gravel beds.

Jaintia Group:

Jaintia group is the Eocene deposit. The thickness of the group in the study area is much more than other districts. The formations of the Tertiary age were initially deposited in an open marine to shallow marine environment followed by marginal marine or transitional zone and continental environments.

The Jaintia group were deposited under open marine environment. It is divided into 3 formations: Tura Formation, Sylhet Limestone and Kopili Shale form bottom upward.

Tura sandstone is predominantly whitish sandstone with a minor amount of clay. Occasionally coal beds (peat coal) are found in the top of the section. It is lower Eocene in age. The formation lies unconformably over the Shibganj Formation and conformably under the Sylhet limestone. In Bangladesh the formation crops out at Takerghat in the Sylhet district, which is adjacent to the Bangladesh-India border. The unit has also been reported to be present in the subsurface of Bogra and Rajshahi districts. The lithology consists of sandstone with subordinate shale and marl with occasional carbonaceous shale. The sandstone is light grey, white, dirty white and light brown. It is fine to coarse-grained and even pebbly at places. Cross bedding is also found. The shale occurs as thin beds in the sandstone and is of grey to greyish brown in color. The marl bed is greyish brown and fossiliferous. The carbonaceous beds locally developed in the coal seams. (Source: Banglapedia).

The overlying formation Sylhet Limestone is a fossiliferous (nummulitic) limestone unit of Middle Eocene age. It is the marker horizon in the northwestern part of the country. But here in Sunamganj district it is exposed. Scattered small outcrops of Sylhet Limestone Unit are present along the northern Sylhet- Sunamganj border with Meghalaya. This formation is the most fosiliferous unit if Bangladesh with numerous marine fossils including Nummulites, Discocyclina, Alveolina etc. indicating the deposit is marine in origin (Imam, 2013).

The Kopili formation overlies the Sylhet Limestone conformably. It is composed of dark to black fossiliferous shale with minor amount of limestone beds. The unit marks the end of open marine condition of deposition (Imam, 2013).

Tipam Sandstone Formation:

The Tipam Sandstone Formation is mainly coarse-grained sandstone. It is composed of mainly grey-brown to pale-grey, coarse-grained, cross bedded, massive sandstone alternation with grey shale. The sandstones are mainly lithic arkose, arenaceous in nature. Sandstone composed of quartz. Tipam Sandstone deposits occur throughout the Frontal Fold Belt of Bengal Basin. From the southern part of Chittagong hill tracks to the western part of Indian state Mizoram and Tripura. In the Frontal Folded Belt area this formation is often seen in the anticlinal trends, forming steep cliffs (Source: Banglapedia). But in the study area small strips are exposed.

On the Surma basin of Sylhet area Tipam sandstone is divided into three parts: Lower, Middle and Upper Tipam Sandstone. Lower Tipam is usually Yellowish brown to dark brown with very little gray colored clay. Middle Tipam alteration of grayish fine grained ripple laminated sandstone with grey colored parallel laminated silty shale. The Upper Tipam is consists of grey colored medium to very fine grained sandstone with siltstone, silty shale and shale.(Dhiman kumar Roy,Md. Mostafizur Rahman, Sarmin Akter,2006).

Girujan Clay:

Girujan Clays constitute a distinct lithological unit in the Tipam group of Pleistocene and Neogene age). Mainly consists of mottled clay intercalations of sand bands. Sometimes some coal streaks are also found. Fossil wood and lignite are also present in the unit. The term ‘Girujan Clay’ first introduced by P Evans (1932) for a thick mottled clay formation exposed in Girujan stream near ‘Digboi’ in Assam.(Source: Banglapedia). It is a useful stratigraphic marker in the delimitation of the Tipam Series because of its mottling and argillaceous nature. It is deposited mainly in the large valleys in the synclinal trends of frontal fold belt.

The Girujan Clay Formation represents lacustrine floodplain and over bank deposits. The sedimentation took place under sub aerial conditions. (Banglapedia). It is stratigraphically very important unit as where it is not present the distinction between Dupitila and Tipam Formation is difficult.

Barind Clay Residuum:

These soils are the residual of Barind Clay. The parent material of the soil is the Barind clay covering the Barind Pleistocene terrace. Barind clay is of reddish t brownish color with subordinate silt (Imam, 2013). It generally occurs at uplifted terraces as well as subsurface (Morgan and McIntyre 1959, Monsur et al 2003). The formation is remarkably homogeneous in appearance, both vertically and laterally. It comprises a layer of unconsolidated clay, about 10 m thick near Dhaka, but apparently thinner to the east and possibly much thicker in the west of the Rajshahi district. The formation is generally almost horizontal, but has been broken into a number of fault blocks, some of which are slightly tilted. Extensive areas of the Barind Tract and parts of the Madhupur Tract have almost level terracelike topography. The western part of the Barind Tract and considerable parts of the Madhupur Tract are closely dissected.

Barind residuum soil occurs on level terrace sites on the north and east of the Barind Tract. These soils are brown and red mottled, strong to extremely acidic, friable clay loam to clay soils over deeply weathered, red-mottled, Madhupur clay (Haque and Shoaib). They are moderately to imperfectly drained. The topsoil is 10–15-cm thick. The color is predominantly brown, with grey and stronger brown mottles. The soil is silt loam or loam in texture, and usually very strongly acidic in reaction. A strong plowpan is present in soils used for transplanted rice. They have been classified as ferric Luvisols and Alisols. The subsoil usually is 40–60-cm thick. The subsoil comprises brown or yellow-brown, friable, porous, clay loam to clay. The reaction is medium to very strongly acidic. The substratum usually is red, mottled with pale brown, friable, porous clay, and usually very strongly acidic in reaction. These soils have low agricultural potential for both dry land crops and for paddy cultivation. They are classified as orthi-ferric Luvisols (Haque and Shoaib).

Madhupur Clay Residuum:

These soils are the residual of Pleistocene Madhupur Clay. The parent material of the soil is the Madhupur clay covering the Madhupur Pleistocene terrace. Madhupur clay is of reddish t brownish color with subordinate silt (Imam, 2013). It generally occurs at uplifted terraces as well as subsurface (Morgan and McIntyre 1959, Monsur et al 2003). This formation is remarkably homogeneous in appearance, both vertically and laterally. It comprises a layer of unconsolidated clay, about 10 m thick near Dhaka, but apparently thinner to the east and possibly much thicker in the west of the Rajshahi district. The formation is generally almost horizontal, but has been broken into a number of fault blocks, some of which are slightly tilted. Extensive areas of the Barind Tract and parts of the Madhupur Tract have almost level terracelike topography. The western part of the Barind Tract and considerable parts of the Madhupur Tract are closely dissected.

These soils occur on level terrace sites on the north and east of the Barind Tract, the Madhupur Tract, and the Akhaura terrace. These soils are brown and red-mottled, strong to extremely acidic, friable clay loam to clay soils over deeply weathered, red-mottled, Madhupur clay. They are moderately to imperfectly drained. The topsoil is 10–15-cm thick. The color is predominantly brown, with grey and stronger brown mottles. The soil is silt loam or loam in texture, and usually very strongly acidic in reaction. A strong plowpan is present in soils used for transplanted rice. They have been classified as ferric Luvisols and Alisols. The subsoil usually is 40–60-cm thick. The subsoil comprises brown or yellowbrown, friable, porous, clay loam to clay. The reaction is medium to very strongly acidic. The substratum usually is red, mottled with pale brown, friable, porous clay, and usually very strongly acidic in reaction. These soils have low agricultural potential for both dryland crops and for paddycultivation. They are classified as orthi-ferric Luvisols.

Marshy Clay and Peat:

Peat soils and Marshy clays in the surface geology of the area is indication of swampy and humid environment of present active river plain deposits. In these soils, partially or wholly decomposed organic matter are present. These soils have a low infrastructure and of low quality on engineering value. Peat and muck layers are black to dark brown, strongly reduced, and neutral in reaction under persisting conditions. When these layers are allowed to dry, they become extensively acidic. The unit is seasonally flooded by both increased river water and rainwater hence, remains wet around this time. During the dry season where mineral topsoil is present they become dry. Under dry condition mineral top-soils are mainly grey or dark grey and become strongly acidic. The soil has generally low agricultural productivity. The land is used for reed production and fishing under natural conditions.

Valley Alluvium and Colluvium:

Valleys are low-lying areas within uplifted lands. Usually rivers run through the valleys. River deposits are generally found in valleys. Colluvium is a general term applied to any loose, heterogeneous, and incoherent mass of soil material or rock fragments deposited by rain-wash, sheet-wash, or slow, continuous downslope creep, usually collecting at the base of gentle slopes or hillsides. Here the colluviums in this zone is associated to river borne or rain wash deposit.

Alluvium and Colluvium deposits are a mixture of sand, silt and clay sized loose materials deposited mainly by river borne deposit. They are recent one and hence not compacted and unconsolidated. The sediments are mainly gray colored with less micaceous substance and clay rich dominantly. Easily weathered materials are altered to clay in this deposit (Feldspar to clay).

Jaintia Group:

Jaintia group is the Eocene deposit. The thickness of the group in the study area is much more than other districts. The formations of the Tertiary age were initially deposited in an open marine to shallow marine environment followed by marginal marine or transitional zone and continental environments.

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The Kopili formation overlies the Sylhet Limestone conformably. It is composed of dark to black fossiliferous shale with minor amount of limestone beds. The unit marks the end of open marine condition of deposition (Imam, 2013).

Old Gravelly Sand

These soils occur in some central and western parts of the Barind Tract, locally on the Madhupur Tract, in the northeast of the Barind Tract and on parts of the piedmont plain in the north of the Mymensingh region. These soils are shallowly flooded with rainwater or raised groundwater. The topsoil is dark grey and silt loam or silty clay loam. Yellow-brown or strong brown mottles are found along root channels and cracks. Gravels are the predominant feature of the soil. The reaction is medium to strongly acidic when moist or dry, but neutral when submerged. The subsoil is grey, mottled yellow-brown, red and sometimes black, friable, highly porous, and silty clay loam to silty clay. The substratum is generally friable, porous, clay, and weakly structured. Thick grey coatings occur on pedological faces and in pores in the lower parts of the subsoil and in the substratum. These soils have low agricultural potential. These soils are better suited for paddy cultivation than for dry land crops and are classified as chromi-albic gleysols (Haque and Shoaib).

Young Gravelly Sand:

Most soils are shallowly flooded by rainwater or by a raised groundwater table. The topsoil is 10–15-cm thick, which is grey and silty with gravel beds along with cracks and root channels. It is strongly to very strongly acidic when dry, but neutral in reduced condition. A compact plowpan occurs below the cultivated layer. The thickness of the subsoil varies between zero and about 50 cm.

The dominant lithology is grey, highly porous, silt loam to silt clay loam. The reaction is medium or strongly acidic throughout. The substratum has grey color mottled olive or red, heavy silty clay or clay texture and a strong blocky or wedge-shaped structure. The soils have low permeability because of the presence of compact plowpan. Lime nodules are found in some soils. These soils have moderate agricultural potentiality. The soils are well suited for transplanted paddy, especially with irrigation, but are poorly suited for dry land crops and for tree crops. They have been classified as chromi-eutric Planosols.

Tidal Deltaic Deposits :

Among tidally influenced sedimentary environments, tide-dominated deltas are perhaps the most variable and difficult to characterize. This variability is due in part to the major role that fluvial systems play in defining their delta, with rivers differing widely in discharge, sediment load, seasonality, and grain size. Tide dominated deltas also tend to be large systems that can extend hundreds of kilometers across and along the continental margin. The associated sediment transport regimes are typically high energy, but they vary considerably at the scale of tidal cycles and seasonal river discharge. As a consequence of varying transport energy, the sedimentary successions formed in tide-dominated deltaic settings tend to be heterolithic, with interbedded sands, silts, and clays and both fining- and coarsening-upward facies associations.

Mangrove Swamp Deposits :

Alluvial deposits are geologically very recent and deep. The soil is a silty clay loam with alternate layers of clay, silt and sand. The surface is clay except on the seaward side of islands in the coastal limits, where sandy beaches occur. In the eastern part of the Sundarbans the surface soil is soft and fertile, whereas it is harder and less suitable for tree growth in the west (Choudhury, 1968). The pH averages 8.0 (Christensen, 1984).

Estuarine Deposits :

A sedimentary deposit laid down in the brackish water of an estuary, characterized by fine-grained sediments (chiefly clay and silt) of marine and fluvial origin mixed with a high proportion of decomposed terrestrial organic matter; it is finer grained and of more uniform composition than a deltaic deposit.

Tidal Mud Deposits:

They consist mainly of soft mud, but in places contain admixtures of sand. As a general rule, mud is deposited near highwater mark, silty or sandy mud in areas of intermediate water, and fine sand near the position of the water at low tide. In some places the sediments are laminated and cross-bedded. Lenticular bedding is a structure of the muddy heteroliths facies displaying 2.5-7 m thick of alternating layers mud and sand. The ripples and sand lenses in lenticular bedding are discontinuous and isolated. The common environments of the occurrences of lenticular bedding are subtidal zones (Reineck, 1963a; Reineck et al. 1968) and intertidal zones (Hantzschel, 1936a; Van Straaten, 1954a). The genesis of lenticular bedding is related to the tidal rhythm (tidal currents alternating with periods of quiescent or slack water).

Deltaic Sand :

A triangle shape Marginal Marine floodplain deposits mainly consists of sand with silt and clay.

Deltaic Silt :

A triangle shape Marginal Marine floodplain deposits mainly consists of silts with clay.

3.3. DISCUSSION ON ROAD ABOVE SOFT SOIL

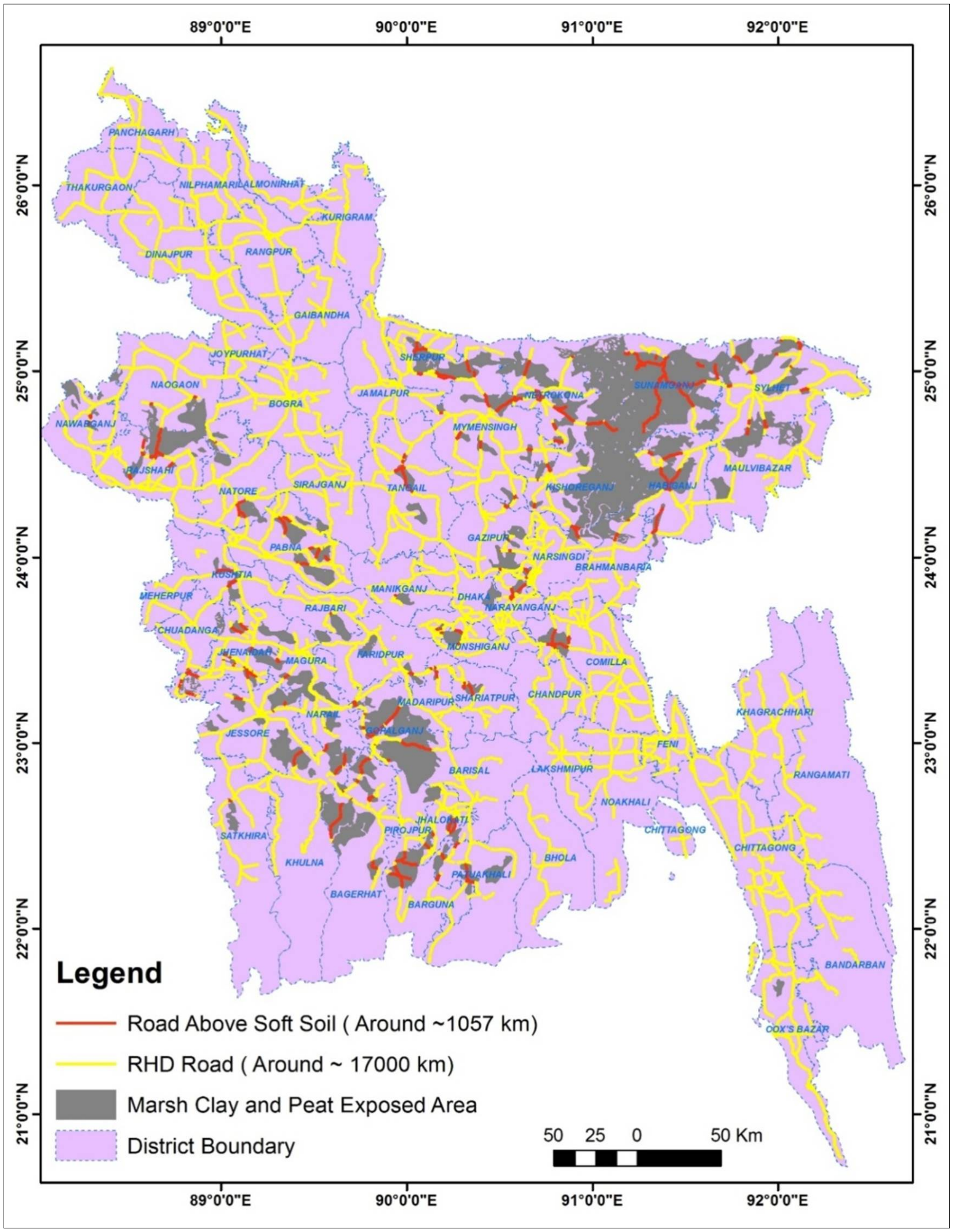


Figure 3-3 Road Above soft Soil

The above figure 3-3 manifests roads of Bangladesh along the characteristic consistency of soils they are lying upon. Can be observed from the map that about

17,000 Km road-network of RHD. On top of that, there can be seen around 1057 Km of roads lying on soft soil. Besides, locations where marshy clay and peat are exposed and the road thereby can also be seen on this map.

Peaty soils and marshy clays in the surface area is indication of swampy and humid environment of present active river plain deposits. In these soils, partially or wholly decomposed organic matter are present. These soils have a low infrastructure and of low quality on engineering value. Peat and muck layers are black to dark brown, strongly reduced, and neutral in reaction under persisting conditions. When these layers are allowed to dry, they become extensively acidic. The unit is seasonally flooded by both increased river water and rainwater hence, remains wet around this time. During the dry season where mineral topsoil is present they become dry. Under dry condition mineral top-soils are mainly grey or dark grey and become strongly acidic. The soil has generally low agricultural productivity.

On the map, marshy clay and peat deposits are seen exposed largely in the north, east, and south of Sylhet division. To the west, some northern areas of Mymensingh district are also seen have these depostios exposed on the surface. Moreover, a number of road are seen running on these deposits. These deposits are also seen exposed in small areas around Dhaka division, across which also there are roads running. Marshy clay and peat deposits are also exposed in Rajshahi division. They are located in northeast, middle part and south of the division. A number of roads are seen running through these soils. These type of deposits has also been found sporadically in small discrete locations of Khulna division. But they are concentrated in the north, and middle part of the division. There, roads are also running on these type of soils. These deposits are also present in the western and southwestern part of Barisal division, where there roads have been constructed as well.

As marshy clay and peat are very low in consistency, they have much lower engineering value for building civil infrastructure and critical lifeline like roads, etc. on them. Roads on these type of soils have very poor longevity, so should be avoided for maximum economic benefit. Otherwise, ground improvement measures should be taken if in case cannot be avoided for any constraint. Before construction of road in any locality, detailed survey should be taken for exploring such weak soils.

4. SEISMICITY OF BANGLADESH

4.1. INTRODUCTION

Seismic hazard is a broad term used in a general sense to refer to the potentially damaging phenomena associated with earthquakes, such as ground shaking, liquefaction, landslides, and tsunami. In the specific sense, seismic hazard is the likelihood or probability of experiencing a specified intensity of any damaging phenomenon at a particular site or over a region in some period of interest. The methodology for assessing the probability of seismic hazards grew out of an engineering need for better designs in the context of structural reliability (Cornell, 1968; Cornell, 1969), since such assessments are frequently made for the purpose of guiding decisions related to mitigating risk. However, the probabilistic method has also proven to be a compelling, structured framework for the explicit quantification of scientific uncertainties involved in the hazard estimation process. Uncertainty is inherent in the estimation of earthquake occurrence and the associated hazards of damaging ground motion, permanent ground displacements, and in some cases, seiche and tsunami.

The process begins with the characterization of earthquake occurrence using two sources of data: observed seismicity (historical and instrumental) and geologic. The occurrence information is combined with data on the transmission of seismic shaking to form the seismotectonic model. Since uncertainty is inherent in the earthquake process, the parameters of the seismotectonic model are systematically varied via logic trees, Monte Carlo simulation, and other techniques, to provide the probabilistic seismic hazard model's results. The results may be disaggregated (also known as deaggregation) to identify specific contributory parameters to the overall results. The results must also consider the site-specific soil properties.

The final outcome of seismic hazard assessment in this project is a seismic micro-zoning map or hazard map of the area, in which incorporated are characterized seismic sites, constrained from the aforementioned simulations of earthquake ground motion. The mapped hazard refers to an estimate of the probability of exceeding a certain amount of ground shaking, or ground motion, in 50 years. This map can be used to create building code at the area to help establish construction requirements necessary to preserve public safety.

4.2. SEISMIC HAZARD PROFILE OF BANGLADESH

Bengal Basin is one of the largest sedimentary basins of the world and Bangladesh covers a major part of this Basin (Alam, 1972). The northward collision of the Indian Plate with the Eurasian Plate created the Himalayan Ranges and subsequent generation of huge river network forms the Bengal Basin in the eastern part of the Indian Plate (Curray and Moore, 1974; Curray et al., 1982; Acharyya, 1998; Alam et al., 2003; Aitchison et al., 2007). Due to the complex interaction of Eurasian plate, Indian Plate and Burmese plate, Bangladesh is surrounded by Plate Boundary Fault-1 in the South-East, Plate Boundary Fault-2 in the East, Plate Boundary Fault -3 in the North-East and thrust faults (Main Boundary Thrust, Central Boundary Thrust & Himalayan Frontal thrust) associated with the formation of Himaya in the North (CDMP, 2009). Apart from these faults there exists two major intracontinental faults named Dauki Fault and Madhupur Fault located in Northern Sylhet and Western Part of Dhaka respectively (CDMP, 2009). Historically, many major earthquakes have occurred from these faults and the location of epicenters is also shown in Figure 4-1.

Seismic hazard in and around Bangladesh is high, as manifested by the number of large earthquakes that have occurred during historic time (Table 4-1). Moreover, a number of tremors with moderate to severe intensity had already taken place within Bangladesh territory in recent past (5.6M Sylhet Earthquake in 1997, 6.0M Bandarban Earthquake in 1997, 5.1M Moheshkhali Earthquake 1999, 5.5M Rangamati Earthquake in 2003) (Choudhury, 2005).

Table 4-1 List of major historical earthquakes occurred in and around Bangladesh.

Date	Earthquake	Magnitude
2 April 1762	Chittagong-Arakan Earthquake	>8.5
30 June 1868	Sylhet Earthquake	7.5
10 Jan 1869	Cachar Earthquake	7.5
14 July 1885	Bengal Earthquake	7.0
12 June 1897	Great Indian Earthquake	8.3
8 July 1918	Srimongal Earthquake	7.6
3 July 1930	Dhubri Earthquake	7.1
15 January 1934	Nepal-Bihar Earthquake	8.1
15 August 1950	Assam-Tibbet Earthquake	8.6
26 December 2014	Sumatra Earthquake	9.1
25 April 2015	Gorkha, Nepal Earthquake	7.8

Table 4-2 Earthquake occurrence in Bangladesh within last 20 years (Source: Dhaka University Earth Observatory (DUEO).

Date	Magnitude	Source location	Impact
8 May 1997	6	Sylhet	Wall cracks
21 Nov. 1997	6.1	Myanmar border	Collapse of a building in Chittagong city (18 deaths)
22 July 1999	5.2	Moheshkhali Island	Serious damage and collapse of mud-walled house, serious damage to a cyclone centre column
31 Dec 1999	5.4	Off-shore Kutubdia Island	Rattled SE Bangladesh and small tidal surge — 4ft in Cox's Bazar
19 Dec 2001	4.2	Near Dhaka city	Panic and injuries
July 2003	5.6	Borkol	Serious damage to brick masonry buildings and mud-walled houses. Power supply disrupted. Major cracks in a building in Chittaging
August 2006	4.2	Narail	Panic and injuries
July 2007	4.8	Borkol	Panic and injuries
20 March 2008	4.4	Tangail	Panic
05 July 2008	4.1	Rajshahi	Panic
27 July 2008	5.1	Mymensingh	Panic and injuries
25 August 2008	5.1	Chittagong hill tracts	Panic and injuries
September-October 2008	2-4.4	Chandpur, Comilla	Panic
09 October 2009	4.8	Chandpur, Comilla	Panic and injuries

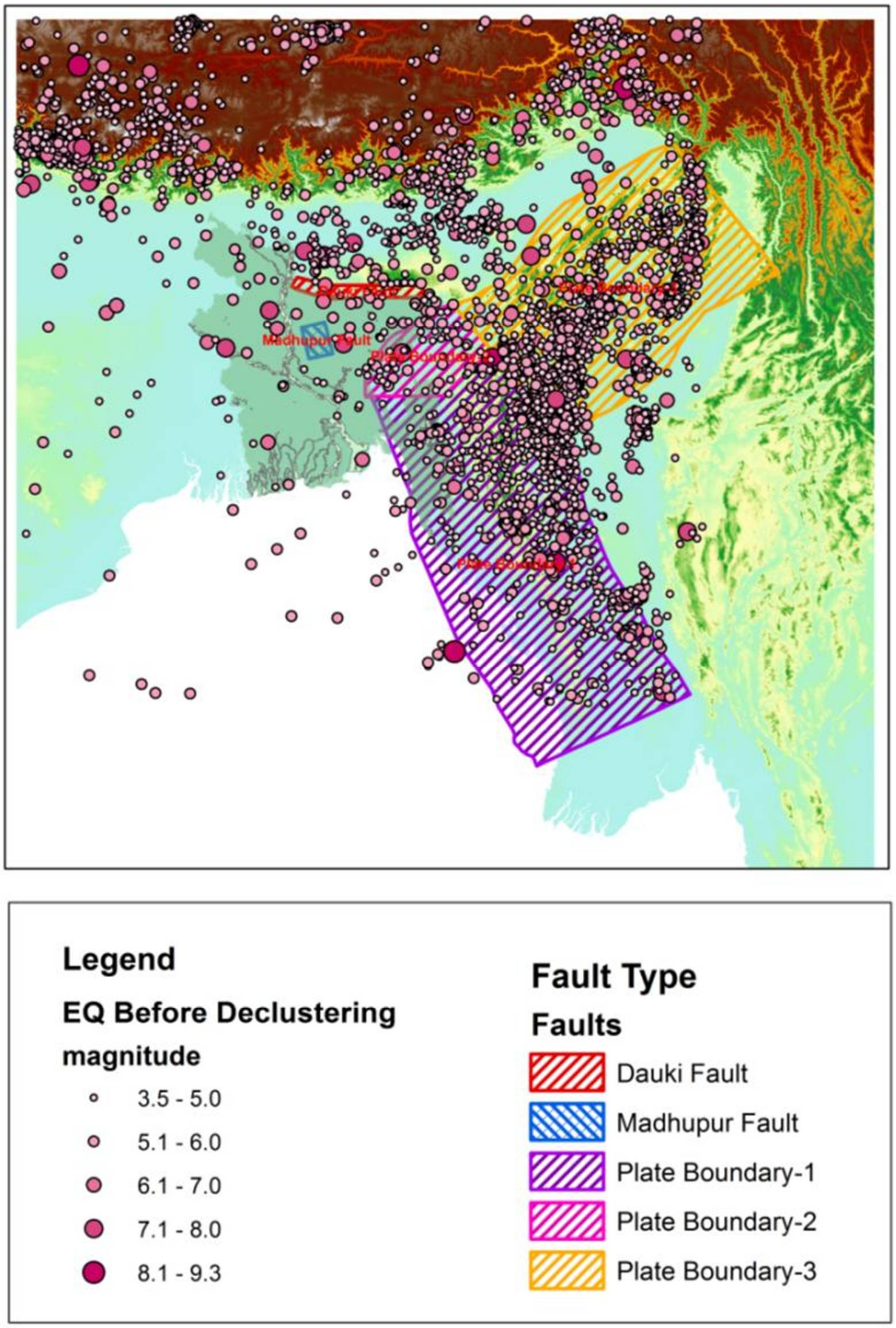


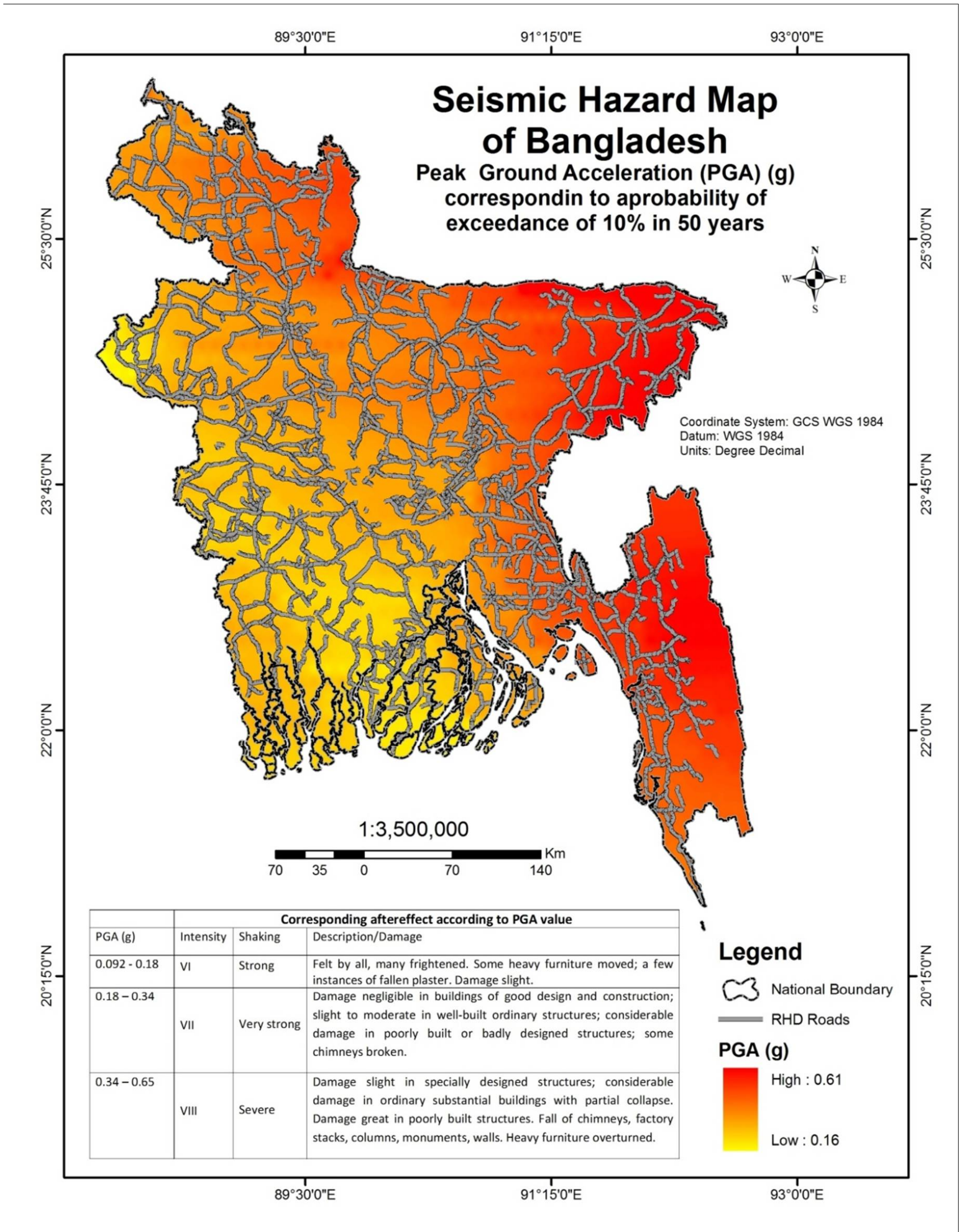
Figure 4-1 Major active faults in and around Bangladesh and the location of earthquake epicenters data of past hundred years (1822-2016)

4.3. SEISMIC HAZARD ASSESSMENT

The approaches of earthquake motion estimation in hazard analysis are roughly classified into two groups. One is called “Deterministic study” and the other is called “Probabilistic study”. Result by the deterministic study is the seismic motion distribution in case a certain scenario earthquake may occur. Output of the probabilistic analysis is expressed as, for example, the seismic motion distribution with 10% probability of exceedance in 50 years exposure time. The goal of many earthquake engineering analyses is to ensure that a structure can withstand a given level of ground shaking while maintaining a desired level of performance. But what level of ground shaking should be used to perform this analysis? There is a great deal of uncertainty about the location, size, and resulting shaking intensity of future earthquakes. Probabilistic Seismic Hazard Analysis (PSHA) aims to quantify these uncertainties, and combine them to produce an explicit description of the distribution of future shaking that may occur at a site. The probabilistic distribution of earthquake motion is, unlike that in the case where certain earthquakes actually occur, a compilation on a drawing of evaluated earthquake motion for each point. The probabilistic study results can be applied to seismic microzoning map and seismic regulation for building or facility construction such as building codes,

The source of most earthquakes is fault except the volcanic earthquakes; however the earthquake fault can’t always be found because the fault is sometimes deep and hidden or small and not reached the rupture to the ground surface. The smaller earthquakes are usually not associated with the faults. In probabilistic analysis, the effects of all the earthquakes affecting the study site should be considered. The source model of faults with the location, length, width, depth, magnitude and activity rate is desirable and may bring more accurate result but the faults of most earthquakes are not known. To cope with this limitation of the data of faults, probabilistic analysis usually introduces the concept of area source model. The earthquakes, which can be associated with the active faults and the necessary parameters are available, are treated as the fault source model and the rest are treated in area source model. The area source model, i.e. the back ground source model is based on the activity in the earthquake catalogue not associated with the fault activities. In this study, the larger events in the magnitude range and higher are assumed to occur related to the scenario earthquake faults.

In this study, the probabilistic analysis was performed using the CRISIS2007 developed by Mario Ordaz et Al 2007), Engineering Institute, National Autonomous University of Mexico (UNAM). This program calculates seismic hazard using the standard methodology for probabilistic seismic hazard analysis. Earthquake data of past hundred years and characteristics of tectonically active faults in and around Bangladesh were considered for this analysis.



	Corresponding aftereffect according to PGA value		
PGA (g)	Intensity	Shaking	Description/Damage
0.092 - 0.18	VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
0.18 – 0.34	VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
0.34 – 0.65	VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

Figure 4-2 Seismic Hazard Mapof Bangladesh(Exhibits Peak Ground Acceleration (PGA) value).

4.4. DISCUSSION ON SEISMIC HAZARD PROFILES

Bangladesh is located in the tectonically active Himalayan orogenic belt that developed by the collision among the Indian, Arabian, and Eurasian plates over the last 30-40 million years (Ma), (Aitchinson et al.2007). Moderate to large earthquake magnitudes are common in this region and will continue to occur as long as the tectonic deformation continues. Some of these earthquakes caused serious damage to buildings and infrastructures through strong ground shaking and also, in some cases, faults rupturing the ground surface. The destructive and deadly hazards associated with earthquakes pose a real and serious threat to the life of people, property damage, economic growth and development of the country. A proper understanding of the distribution and level of seismic hazard throughout the country is therefore necessary. In order to perform rigorous seismic hazard analysis, all available knowledge of the historical earthquake, tectonic environment, and instrumental seismic data are required to predict the strong ground shaking in future earthquakes. The section provides appropriate earthquake ground motion parameters for seismic mitigation based on current existing data and most recent geological data interpretation.

All results presented in maps are developed for bedrock site condition. In general, seismic hazard is representing by Peak Ground Acceleration (PGA) value. Peak ground acceleration (PGA) is equal to the maximum ground acceleration that occurred during earthquake shaking at a location. PGA is an important parameter (also known as an intensity measure) for earthquake engineering, the design basis earthquake ground motion is often defined in terms of PGA. Here, Peak Ground Acceleration (PGA) is calculated by the corresponding to a probability of exceedance of 10% in 50 years.

The United States Geological Survey developed an Instrumental Intensity scale, which maps peak ground acceleration (PGA) on an intensity scale similar to the felt Mercalli scale. These values are used to create shake maps by seismologists around the world. This Instrumental Intensity scale is given below table.

Table 4-3 Instrumental Intensity Scale.

PGA (g)	Intensity	Shaking	Description/Damage
< 0.001	I	Not felt	Not felt except by a very few under especially favorable conditions.
0.0017-0.014	II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
0.0017 - 0.014	III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
0.014- 0.039	IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
0.039- 0.092	V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
0.092 - 0.18	VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
0.18 - 0.34	VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
0.34 - 0.65	VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
0.65 - 1.24	IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
> 1.24	X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

In Bangladesh PGA values are found 0.16g to 0.61g. According to the Mercalli scale intensity scale, Bangladesh fall VI to VIII intensity, which implies strong, very strong, and severe after effects respectively. Further, by clustering PGA value ranges Bangladesh could be divided into five zones where values that range from 0.16 to 0.27 g, 0.28 to 0.34 g, 0.35 to 0.42 g, 0.42 to 0.49 g, and 0.50 to 0.61 g. Among them, areas with PGA value range from 0.16 to 0.27 g in the western and southwestern region of Bangladesh: more specifically these include westernmost part of the Rajshahi Division, Khulna division, and a small part of Barisal division in the southwest (Figure 4-2). PGA values suggest that these areas would suffer strong to very strong effect (Mercalli scale intensity VI and VII) of earthquake. PGA value range from 0.28 to 0.34 g prevails easterly to the previous zone and continuously from the north to south as a long strip i.e., in the northernmost and northwestern corner, and diagonally from west to south. Districts of the northernmost and northwestern area includes Panchagarh, and western part of Rangpur and Dinajpur. Others are a part of Rajshahi division, a part of Dhaka division in the middle of Bangladesh, and Barisal and Chittagong division in the south. Apart from these, a discrete zone in the southwestern area of Bangladesh, within the westernmost part of Khulna division, is also seen with this value range. This value range indicates very strong after effect (Mercalli intensity scale VII) of earthquake. Areas with value range of that of 0.35 to 0.42 g is seen further east from the previous zones and occurs in parallel fashion as a long strip from the north to the south, covering Rangpur division, Mymnsingh division, Dhaka division, and a small area of Chittagong division in the south. This zone is again repeated in the southern end of the southeastern Bangladesh. i.e., Teknaf thana, and there occupies a comparatively small area. Severe earthquake effect can be assigned to these areas as intensity scale is VIII. Zone with PGA value range from 0.42 to 0.49 g also occurs parallel to the previous one and easterly from north to south (Figure 4-2). This zone also appears as a long narrow strip. In the northernmost area of Bangladesh this zone is seen at the eastern portion. Such PGA values are also seen at the northernmost part of the easternmost Bangladesh i.e., Rangamati district, where occurs at a comparatively small area. In a thumbnail, soils with such PGA value range occurs in Rangpur division, Mymensingh division, Dhaka division, and Chittagong division from north to south. According to

Mercalli intensity scale, severe after-effect (intensity scale VIII) is expected in areas with such PGA value range. Areas with PGA value ranging from 0.50 to 0.61 are occupying the northeastern corner of Bangladesh, i.e., northeastern part of the Sylhet division and a portion in the easternmost corner of Bangladesh i.e., Khagrachari and Bandarban district. Severe earthquake effect in such areas can be estimated from Mercalli earthquake intensity scale as it stands VIII. It can be said from the seismic hazard map of Bangladesh that largely both PGA value and intensity of earthquake effect increase gradually from southwest to east. Sylhet division and Chittagong division can be the worst hit of earthquake. But Dhaka division is also vulnerable because of enormous unplanned settlements there.

5. ELEVATION MODEL OF BANGLADESH

5.1. INTRODUCTION

A digital elevation model (DEM) is a digital model or 3D representation of a terrain's surface — commonly for a planet (including Earth), moon, or asteroid — created from terrain elevation data.

A Digital Elevation Model (DEM) is a digital cartographic/geographic dataset of elevations in xyz coordinates. The terrain elevations for ground positions are sampled at regularly spaced horizontal intervals. DEMs are derived from hypsographic data (contour lines) and/or photogrammetric methods using USGS 7.5-minute, 15-minute, 2-arc-second (30- by 60-minute), and 1-degree (1:250,000-scale) topographic quadrangle maps.

Many DEMs provided by the USGS use a 30-m grid. In other words, the area covered in the DEM is split into squares with 30-m sides. Hills or valleys smaller than the 30-m cells will not show up. In an effort to improve the data available for the Lake Tahoe region, the USGS Western Geographic Science Center has created a set of DEMs with 10-m cells. These 10-m DEMs come from the same source data, the hypsographic DLGs, which have 40 ft contours. No new elevations have been included, but elevation information has been interpolated to a finer resolution. However, 30-m DEM has been collected from USGS database (open source) for elevation model.

Methodology

Mappers may prepare digital elevation models in a number of ways, but they frequently use remote sensing rather than direct survey data. One powerful technique for generating digital elevation models is interferometric synthetic aperture radar where two passes of a radar satellite (such as RADARSAT-1 or TerraSAR-X or Cosmo SkyMed), or a single pass if the satellite is equipped with two antennas (like the SRTM instrumentation), collect sufficient data to generate a digital elevation map tens of kilometers on a side with a resolution of around ten meters. Other kinds of stereoscopic pairs can be employed using the digital image correlation method, where two optical images are acquired with different angles taken from the same pass of an airplane or an Earth Observation Satellite (such as the HRS instrument of SPOT5 or the VNIR band of ASTER).

Older methods of generating DEMs often involve interpolating digital contour maps that may have been produced by direct survey of the land surface. This method is still used in mountain areas, where interferometry is not always satisfactory. Note that contour line data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs, but may be considered digital terrain models. A DEM implies that elevation is available continuously at each location in the study area.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Several factors play an important role for quality of DEM-derived products:

terrain roughness;

sampling density (elevation data collection method);

grid resolution or pixel size;

interpolation algorithm;

vertical resolution;

terrain analysis algorithm;

Reference 3D products include quality masks that give information on the coastline, lake, snow, clouds, correlation etc.

Common uses of DEMs include:

Extracting terrain parameters for geomorphology

Modeling water flow for hydrology or mass movement (for example avalanches and landslides)

Modeling soils wetness with Cartographic Depth to Water Indexes (DTW-index)

Creation of relief maps

Rendering of 3D visualizations.

3D flight planning and TERCOM

Creation of physical models (including raised relief maps)

Rectification of aerial photography or satellite imagery

Reduction (terrain correction) of gravity measurements (gravimetry, physical geodesy)

Terrain analysis in geomorphology and physical geography

Geographic Information Systems (GIS)

Engineering and infrastructure design

5.2. DISCUSSION ON ROAD NETWORK ELEVATION

The map shows road-network around Bangladesh with respect to elevation (Figure 5-1). The map also indicates roads in flood prone areas while others are not much prone to the disaster. It can be seen that around 2480 Km roads lye on lowly elevated areas, and around 17,000 Km roads lye on areas with comparatively high elevation.

Bangladesh is a flood prone country where this natural hazard strikes as disaster in almost every year. Alike most common natural hazards it also causes loss of life, properties and infrastructures. Roads are one of the worst hits of flood, causing economic loss by interrupting normal transport systems and for maintenance. That is why development of database about flood prone areas should be one of the top most elements while planning for establishing road-network in any location of Bangladesh: so that runoff areas during flood can be avoided, or proper measures can be taken if unavoidable anywhere. From this point of view, this project also aims at delineating the location wise status of flood effect all around Bangladesh. The above elevation map of the country has been used here as a mean of anticipating flood hazard effect all over. It seems from the map that the northern most area of Bangladesh, i.e., Panchagarh district, is less likely for being affected by flood for its elevation of about 162.1 to 197 m. The adjacent areas, further south, also have a considerably good elevation, i.e., 130.1 to 162 m, for not being flood prone, which include Rangpur, Dinajpur, Lalmonirhat, Nilfamari, and Thakurgon districts in the northern portion of Rajshahi division. Elevation continues to decrease further south of the division—74.01 to 101 m—and so also less likely to be flood prone. But, the Padma and the Jamuna River floodplain areas are always in risk of heavy flood. Khulna division is further south of Rajshahi division and the Padma River. Northerly Meherpur, Kushtia, Chuadanga, and Jhenaidah districts of Khulna division have elevation as that of adjacent part of Rajshahi division, i.e., 74.01 to 101 m. These areas may experience low effect of flood. Elevation in this division becomes lower southerly from 26 to 74 m and thus can be moderately affected. Coastal areas have much less elevation: 11 to 26 m. These areas can be severely affected during flood. Coastal areas very close to the Bay of Bengal have elevation from -24 to 11 m; these areas may suffer severe tidal surge. Barisal division is situated to the east of Khulna division, and has nearly similar topographic pattern, so has moderate to severe flood threat from north to south. Northern part of the Mymensingh has elevation from 130.1 to 162 m, so could be excluded from monsoonal flood risk. Elevation decreases to 101 to 74.01 m southward, where risk of the said natural hazard might be low. But the areas within the Brahmaputra River and the Jamuna River floodplain could be of moderate to severe risk. To the east of Mymensingh division is situated Sylhet division. Sylhet division also has higher topography in the northern extreme—elevation ranging from 130.1 to 162 m. So, these areas are less risky for monsoonal flood hazard. Elevation decreases from 101 to 74.01 m towards south, so could be of low risk. Dhaka division is situated in the central Bangladesh. In Dhaka division elevation varies from 49.01 to 74 m in the middle part, Dhaka and Gazipur districts, so this locality is moderate to low flood prone. Tangail and Munsiganj districts in the east and south of Dhaka division, respectively, are near the Meghna River and the Jamuna River, where elevation is 26.01 to 46 m and moderate to severe risk of river flooding. Narshingdi and Narayanganj districts lye in the east of Dhaka division, where elevation is 11.01 to 26 m and thus have low to moderate flood risk. Brahmanbaria district of Chittagong division is situated in east-central Bangladesh, where elevation varies from 11.01 to 26 m. So, this area might have low to moderate flood risk. To the south of this district is situated Komilla district, where elevation is same and so the flood risk. Chadpur and Laksmipur districts are situated in southern Bangladesh and in the east of Chittagong division. These districts have elevation from 11 to 26 m, rendering low to moderate flood risk. Noakhali and Feni might be equally flood prone. But areas adjacent to coast would suffer severe tidal surge. Elevation in the areas of eastern part of Chittagong division is very high, 130.1 to 1,021 m, so these localities are devoid of flood risk. But flash flood may occur during monsoon. But in the southern part of Chittagong district elevation is low, i.e., less than 11 m, where severe tidal surge may take place.

As a whole, it can be concluded that areas within the river flood plain are low in elevation and could be affected by flood during monsoon. Moreover, coastal regions are really lowly elevated and tidal surge can cause significant damage to road network these localities.

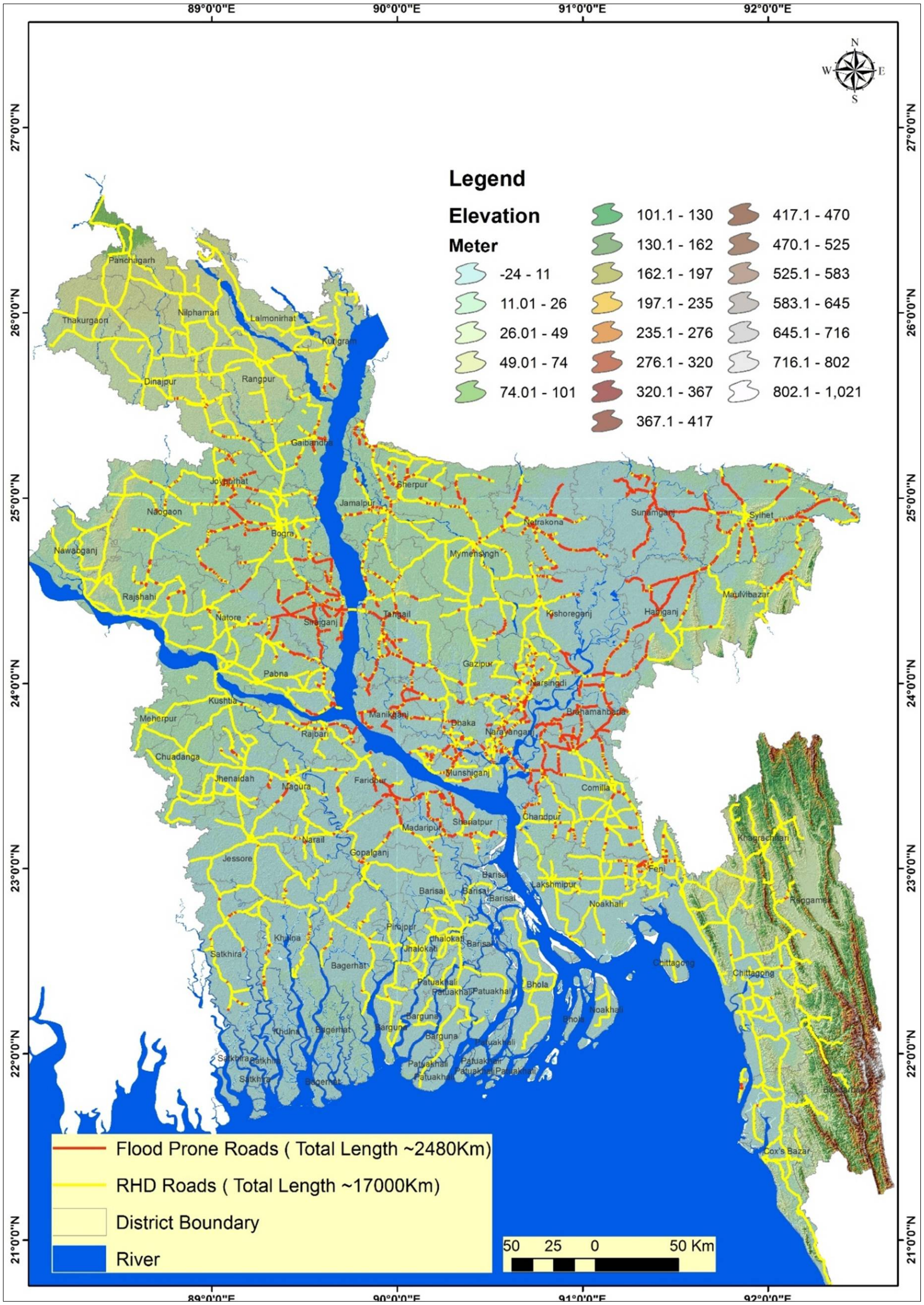


Figure 5-1 Elevation Map with RHD Road-Network (represent flood prone roads)

6. ENGINEERING SOIL MAPPING FOR REMAINING DIVISION

6.1. INTRODUCTION

Secondary data refers to data that was collected by someone other than the user. Secondary data are available from other sources and may already have been used in previous research, making it easier to carry out further research. It is time-saving and cost-efficient.Secondary data can provide a baseline for primary research to compare the collected primary data results to and it can also be helpful in research design.

This task emphasizes on to collect around 50 numbers of borelog data that cover most of the area of each remaining fifteen (15) division (Figure 6-1). Secondary data can be collected from different sources like as Geological Survey of Bangladesh (GSB), Roads and Highways Department (RHD), Water development Board, and other government or non government organization. Though all of the departments are collected and preserved data for their particular purpose, those data have been supported to conduct engineering soil maps for remaining division.

The preparation of detailed engineering soil maps has become routine in BRRL for last three years; particularly on bridge, road and dam construction projects. Very recently BRRL has taken an initiative to prepare engineering soil maps for the rest of the division of Bangladesh. However, nowadays ArcGIS is an important tool for interpreting and representing engineering soil maps. Initially, the SPT-N value at different depth needs to be calculated. It is known that the samples are usually being collected at 1.5m interval in the standard penetration test. After that, interpolation technique will be used. Eventually, the map will be prepared which will show SPT-N value distribution. The purpose of providing these maps is to get a comprehensive idea about the resistance of the subsurface soil.

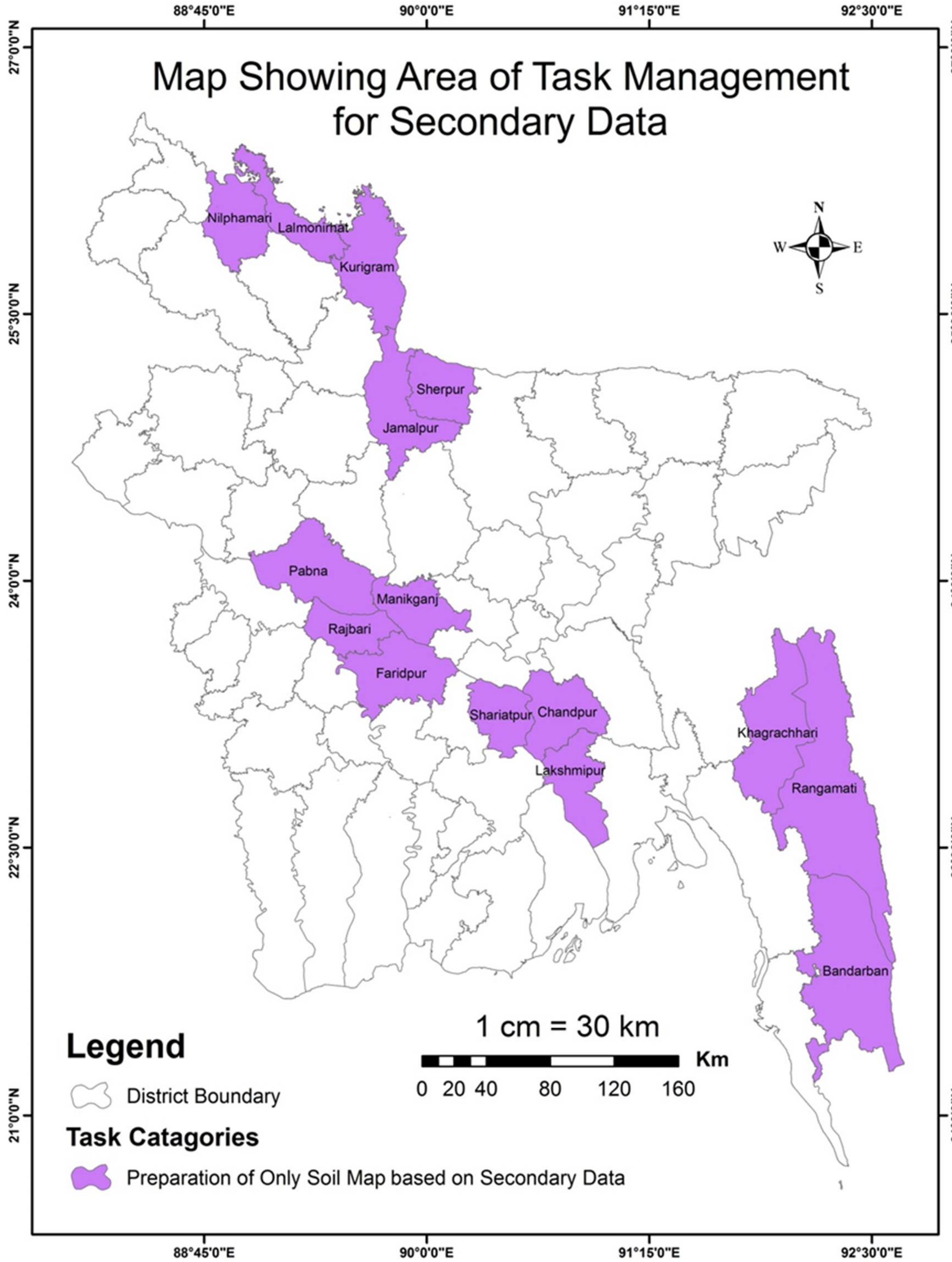


Figure 6-1 Engineering soil maps for remaining division

6.2. ENGINEERING SOIL MAPPING

Chandpur District

Chandpur District is bordered by Comilla and a part of Munshiganj district to the north, Noakhali, Lakshmipur and Barisal districts to the south, Comilla district to the east, Shariatpur, Munshiganj districts and mighty Meghna River to the west.The area of Chandpur is 1645.32 Sq Km. The Geo position of the district is between 23˚29’ to 24˚04’ North latitudes and between 90˚06’ to 91˚09’ east longitude (Figure 6-2).

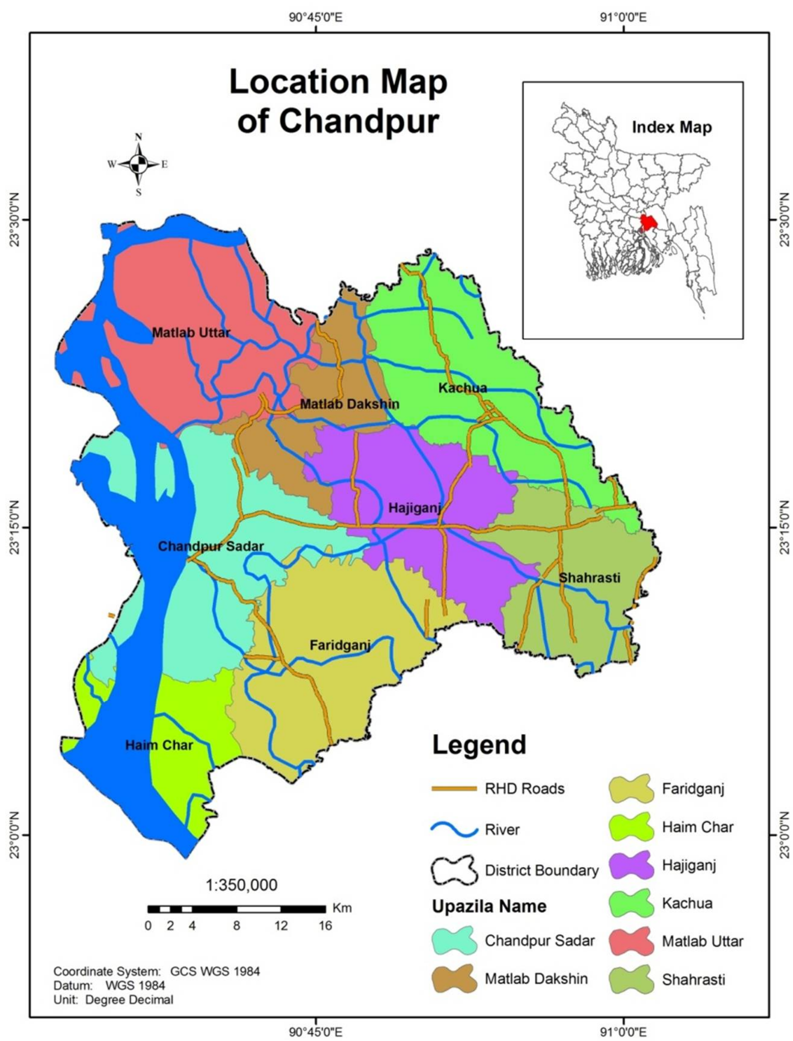


Figure 6-2 Location Map of Chandpur

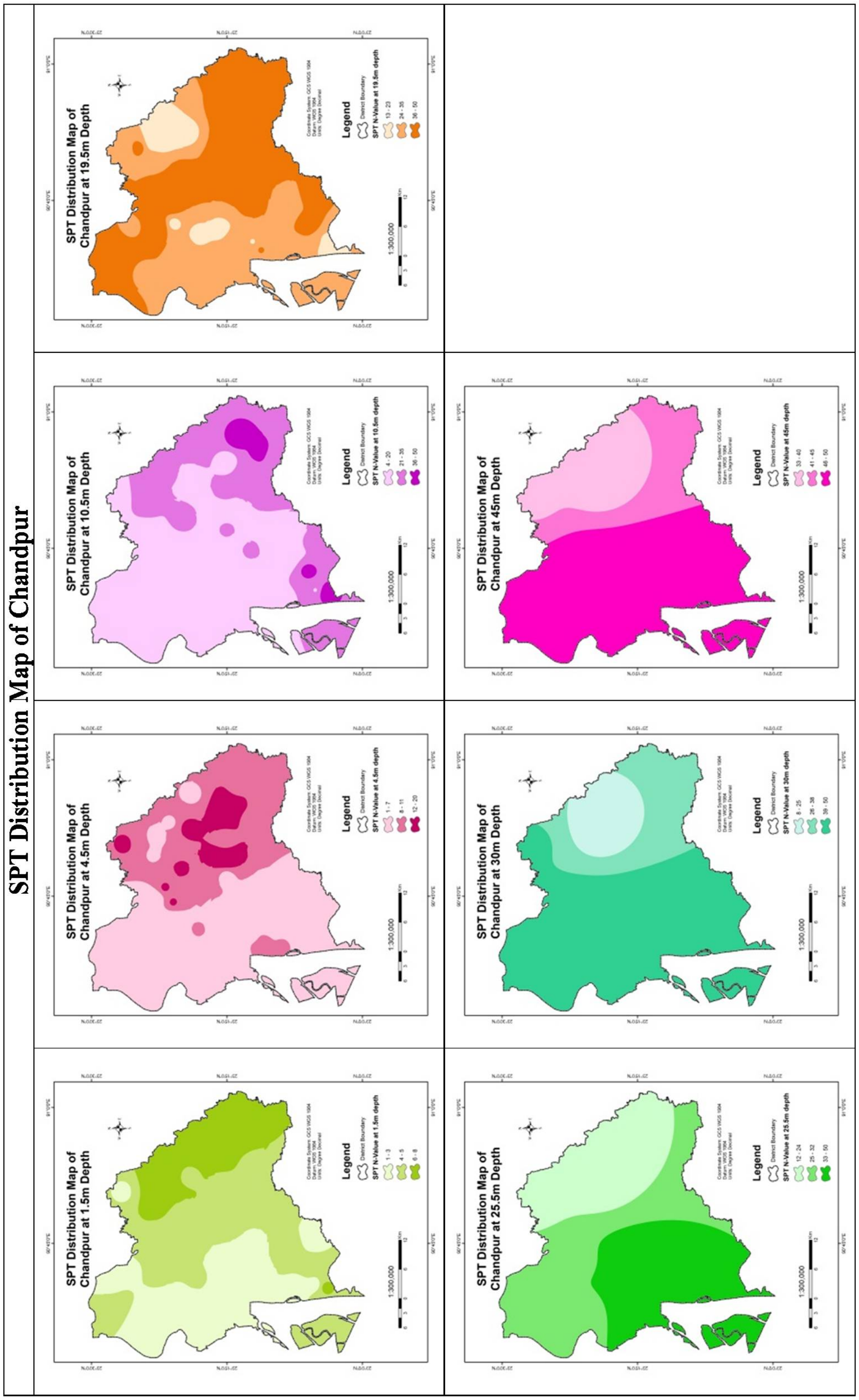


Figure 6-3 Distribution Map of Chandpur

The above figure 6-3 represent SPT N value distribution at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, 30 m, and 45 m depth of Chandpur.

It can be said from SPT distribution map 1.5 m depth that soils with SPT values from 1 to 3m are clustered largely throughout the western part to the middle part of the project area. At the middle part of the district soils have values of that from 4 to 5. At the eastern portion of the district soils have SPT values from 6 to 8 at 1.5 m depth.

At 4.5 m depth of the western zone of the district, soils have SPT N values from 1 to 7, and it is seen throughout half of the area easterly of the the middle part as well. Soils with values of that from 4 to 11 are seen in most of the area of eastern region of Chandpur. At the middle part of central-east area SPT values from 12 to 20 has been found.

At 10.5 m depth, SPT values from 4 to 20 was found were found in most of the area, except values of that from 21 to 25 northernmost corner and easternmost corner, andn 26 to 50 at two very small zones in the north and a small zone at central-east.

SPT borehole investigation at 19.5 m depth of Cahndpur revealed that at depth those values from 19 to 23 are concentrated manily at the middle part of central-east and central-west. SPT values from 24 to 35 have been found in the east and west. Moreover, SPT values from 36 to 50 were found throughout the moddle portion of the area.

At 25.5 m depth soils have SPT values from 12 to 24 at the eastern portion of the district. Throughout the middle part of the area values of that from 25 to 32 were found. SPT values from 33 to 50 were found in the east.

At 30 m depth soils have SPT values from 8 to 25 at a small zone of central-east in the easternmost corner. SPT values from 26 to 38 were found at east. Values from 39 to 50 were found in rest of the area throughout middle and eastern part.

SPT values from 33 to 40 were found at 45 m depth in the east. Values of that from 41 to 45 were found from north to sounth in the middle portion of Chandpur. Values from 46 to 50 were found in rest of the eastrn and middle part of the project location.

Faridpur District

Faridpur District, lies between latitude 23°10' to 23°40' and longitude 89°30' to 90°10', is located in the central part of Bangladesh with an area of 2052.86 sq km (Figure 6-4). Faridpur District is bordered by Manikganj and Rajbari districts to the north, Gopalganj district to the south, Munshiganj, Madaripur and a part of Dhaka district to the east, Magura, Narail and Rajbari districts to the west.

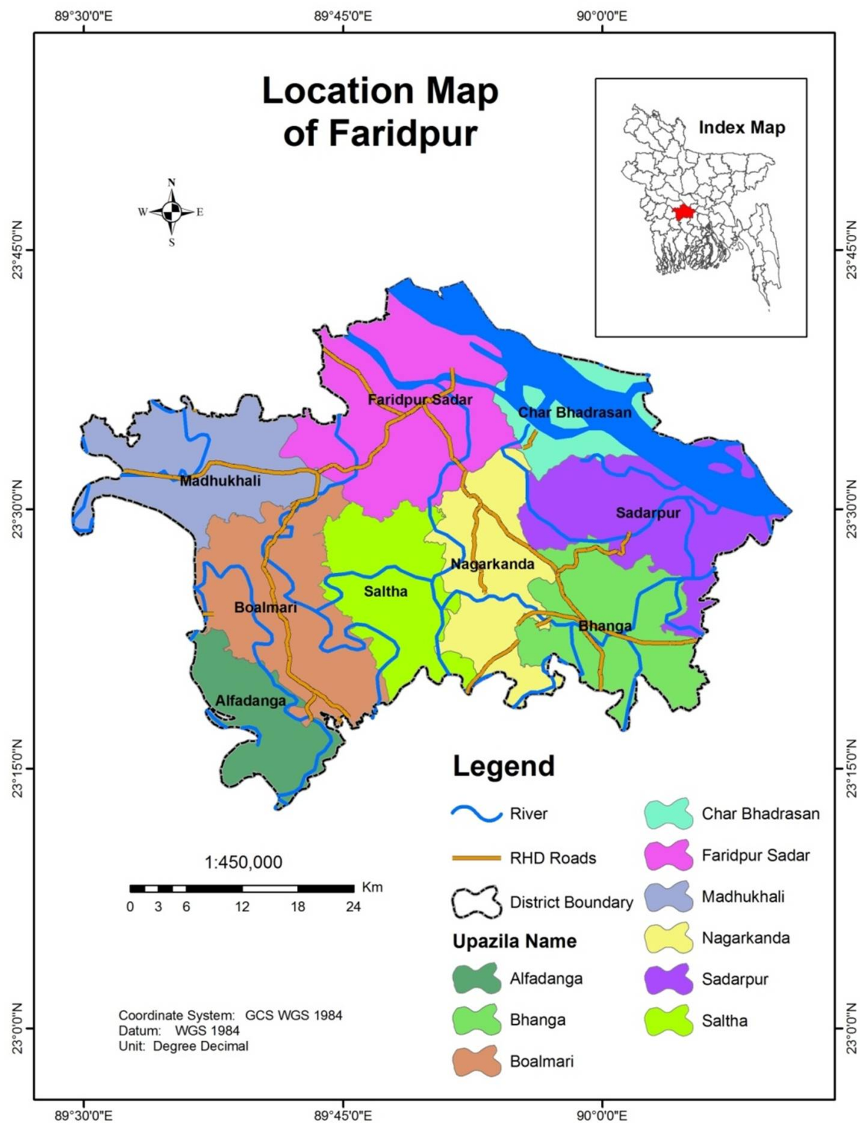


Figure 6-4 Location Map of Faridpur

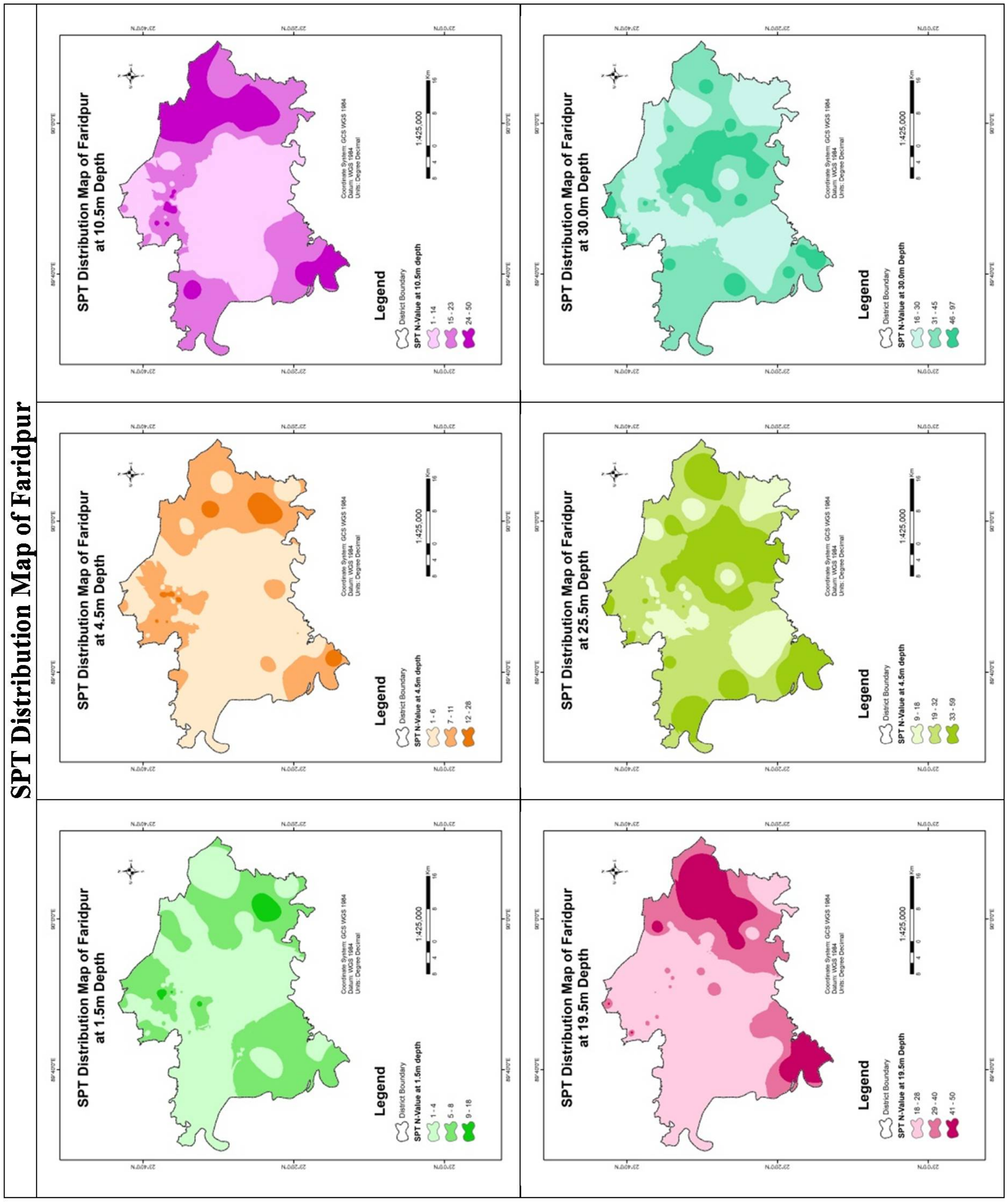


Figure 6-5 Distribution Map of Faridpur

At 1.5 m depth of Faridpur district, SPT N values from 1 to 4 were found in most of the area, except at a small location with values of that from 5 to 8 southernmost region, northernmost region, and east., and 9 to 18 at a small location in southeast corner (Figure 6-5).

SPT values from 1 to 6 were observed in most of the middle and eastern portion of the project area at 4.5 m depth. Values that from 7 to 11 were found at a small location at southernmost corner, easternmost part and northern area. Values from 12 to 28 were found at some small location s in east and south.

Most of the middle and eastern part at 10.5 m depth of the project area are occupied by soils with SPT N value from 1 to 14. At northeast, southeast and in some areas 15 to 23. Values of that from 24 to 50 were found at northeast, southwest, and at a small location at northwest.

At 19.5 m depth of Faridpur district, most of the area has SPT values from 18 to 28, except 29 to 40 at some areas in east and south, and 41 to 50 at some areas of east and south.

At 25.5 m depth values from 9 to 18 prevail at northwest, northwest, and southeast as small zones. Otherwise, values from 19 to 32 has been found in the most of the locations except 33 to 59 at east of the middle part and in some areas at southwest, central-west, north-west in the west, and central-east in the easternmost corner.

At 30 m depth SPT N values from 16 to 30 have been found in most of the middle part from south to north and northeast. Values of that from 31 to 45 prevail throughout west, in some northernmost areas, and easterly from the middle part to central-east. Values from 46 to 97 were observed at eastern portion of the middle part of Faridpur.

Jamalpur District

Jamalpur District is bordered by Kurigram and Sherpur districts and Meghalaya (Indian State) to the north, Tangail district to the south, Mymenisigh and Sherpur districts to the east, Bogra district and Jamuna River to the west. The Geo position of the district is between 24˚40' to 25˚20' North latitudes and between 89˚40' to 90˚10' east longitude. The area of Jamalpur is 2115.16 Sq Km (Figure 6-6).

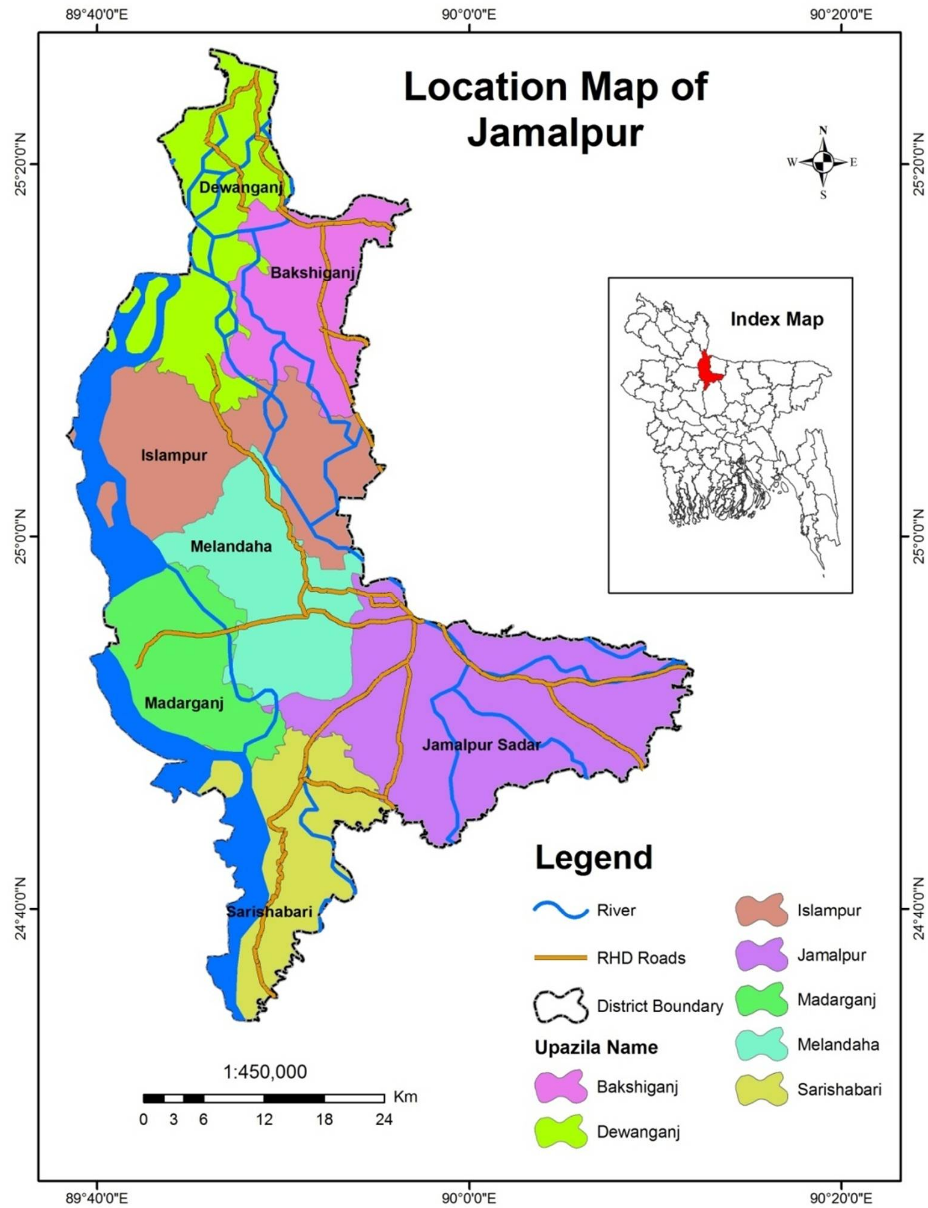


Figure 6-6 Location Map of Jamalpur

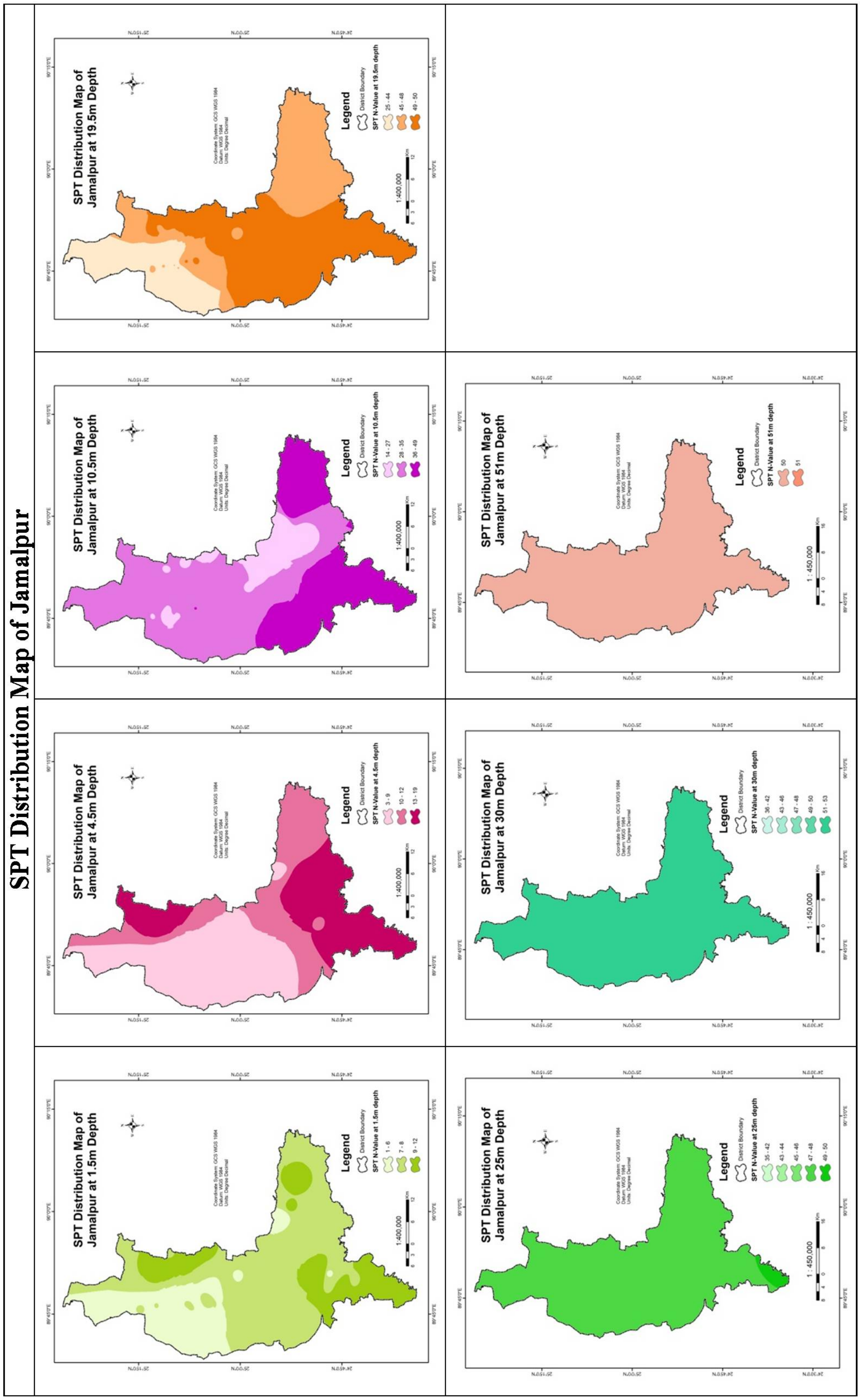


Figure 6-7 Distribution Map of Jamalpur

The above figure 6-7 manifests SPT N value distribution maps of Jamalpur district at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25 m, 30 m, and 51 m.

SPT N value distribution map at 1.5 m exhibits that soils with values that ranging from 1 to 6 prevails predominantly at an area from central-west to northwest, upto the northernmost portion of the district. Values of that ranging from 9 to 12 are seen at an area in the southernmost portion of the district, at a small area as N-S elongated in the northeast, and discretely as very small zones throughout. Rest of the area of the district is occupied by soils with SPT value ranging from 7 to 8.

At 4.5 m depth of the district soils with SPT N value from 3 to 9 are present throughout the area from central-west to northwest. Values ranging from 10 to 12 at this depth have been found as two continuous areas, one is as a long N-S trending strip on the northestar portion of the area and another is southerly from the middle part of the investigated district, which extends from west to east and southeast. SPT value range from 19 to 13 has been observed at an area in the southernmost zone and at a relatively small area at the northeast in the northernmost part of Jamalpur district.

At 10.5 m depth of of the project area soils with SPT N value ranging from 14 to 27 lye as discrete zones around the central-east portion. Four separate zones are seen there, among which one is comparatively large and trend N-S from the central-east to the south. Two other such zones are present in north-west as well. Values of that ranging from 28 to 35 is seen most of the area, from north to south. Another SPT N value range, i.e., from 36 to 49, has been found at southwest corner and southeast corner of the study area.

SPT distribution map at 19.5 m depth of the study area represents that soils with the value of that ranging from 25 to 44 prevails in the northern portion, extending from the North to the central-western portion as a long, rough strip. SPT N value range from 45 to 48 has been found in two locations: one occurs as a long narrow strip, extending diagonally from central-west to northeast on the map, and another zone is located at the southeast corner of Jamalpur district. The rest of the area, i.e., from the south throughout the middle part of the city to northeast in the north, is occupied by soils of SPT value from 49 to 50.

Bandarban District

Bandarban District is bordered by Rangamati district to the north, Arakan (a state of Mayanmer) and the Naf River to the south, Indian Border and Rangamati district to the east, Chittagong and Cox's Bazar districts to the west. The area of Bandarban is 4479.01 Sq Km.The Geographical position of the district is between 21˚11' to 22˚22' North latitudes and between 92˚40' to 92˚41' east longitude (Figure 6-8).

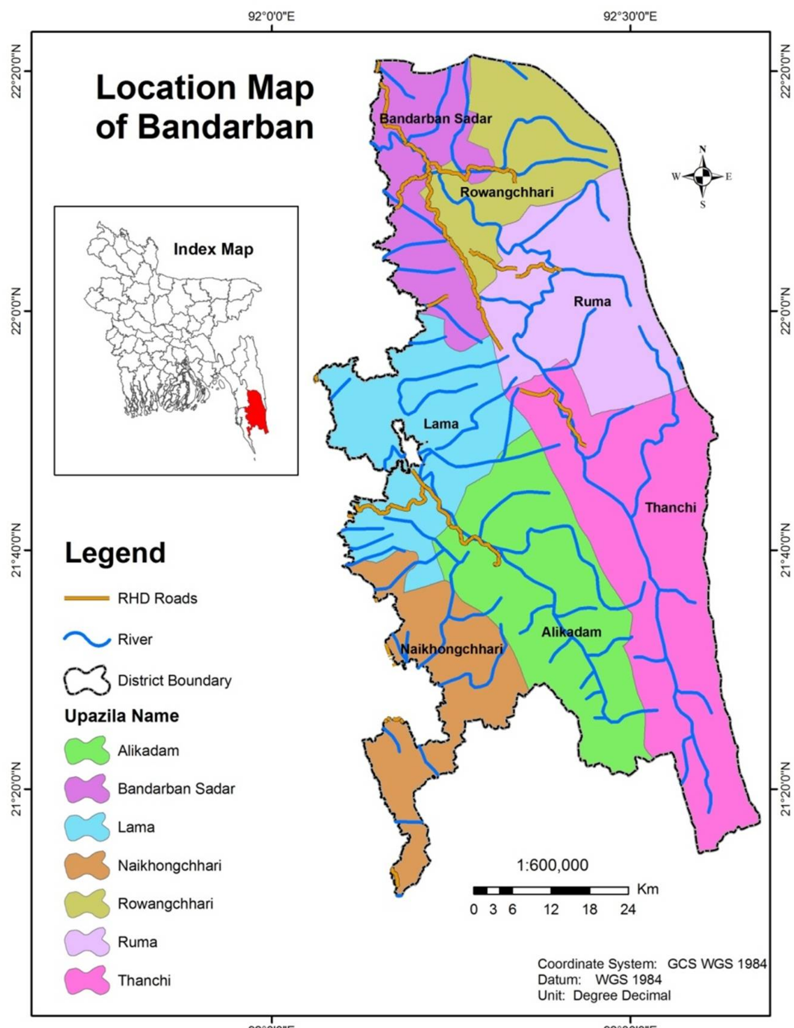


Figure 6-8 Location Map of Bandarban

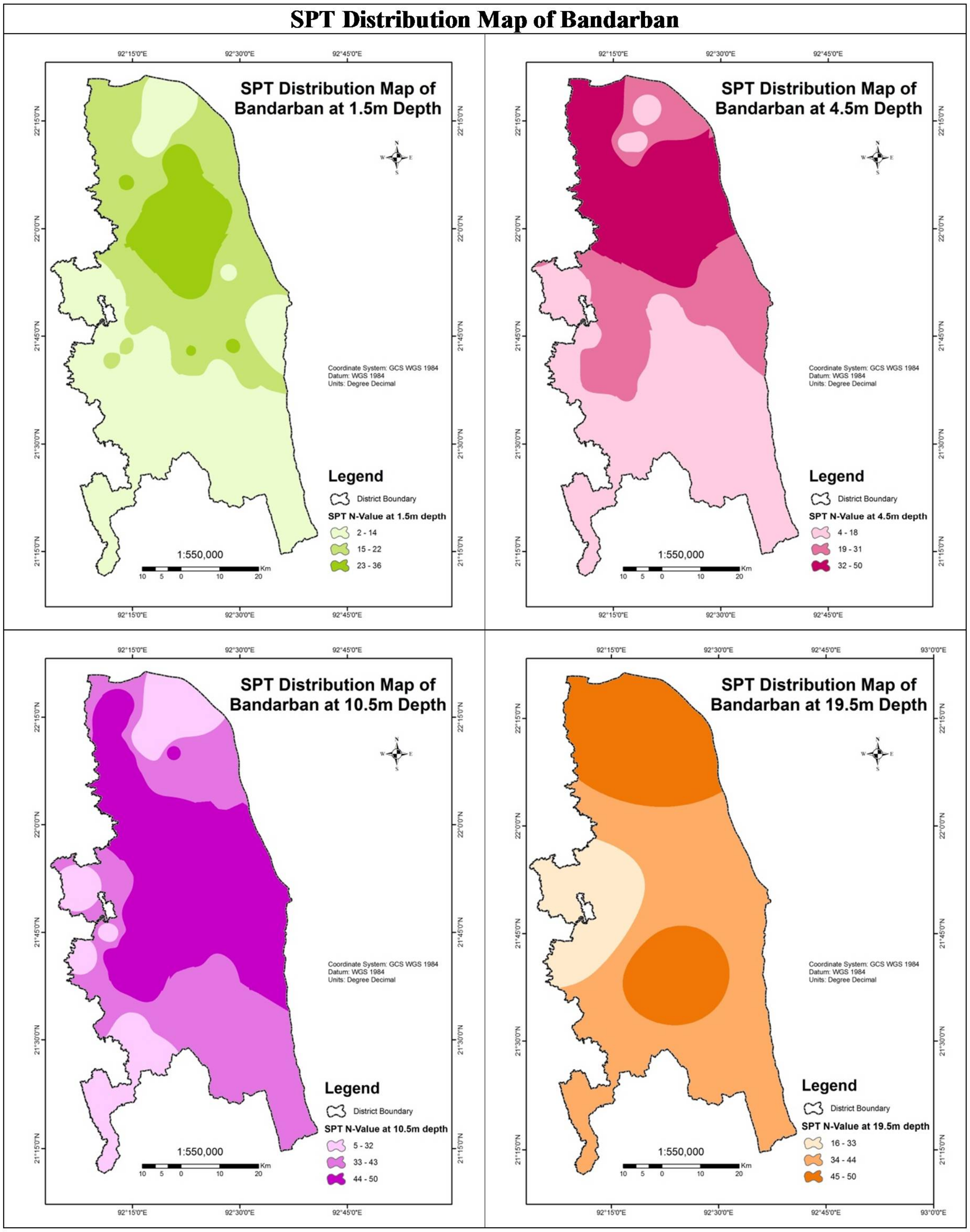


Figure 6-9 Distribution Map of Bandarban

The maps in the above figures show SPT N value distribution of Bandarban district at 1.5 m, 4.5 m, 10.5 m, and 19.5 m (Figure 6-9).

SPT N value distribution map at 1.5 m southern half portion of Bandarban district has value of that ranging from 2 to 14. A small area in the north of the district also has such values. Northern half of the district predominantly contains SPT value from 15 to 22 but within this portion there is a zone having values of that ranging from 23 to 36. The later values are further seen discretely as very small localized zones.

SPT N value distribution map at 4.5 m represents that southern half portion of the district has values of that ranging from 4 to 18. Area with values of that ranging from 19 to 31 are seen continuously at the middle part of the district and at a small area in the northern part. SPT values ranging from 32 to 50 has been found throughout the northern portion of the district.

SPT value distribution map at 10.5 m depth represents that soils with values of that ranging from 5 to 30 prevails in the northern and southern most areas of the districts as small zones, and also as three discrete zones in the central-west part of the district. Moreover, soils with SPT values from 33 to 43 are present as two continuous zones—one is in the northernmost area, spreading continually from northwest to east and another continually from central-west to the southernmost portion of the district. Besides, SPT values from 44 to 50 is seen in the soils locating at the middle part of the district and continually towards northwest.

At 19.5 m depth SPT values ranging from 45 to 50 are seen at a small area in the northern most part of the district and just to the south of the middle portion. Values of that ranging from 16 to 33 are seen only at an area in the central-west part of the project area. Other areas of study area is occupied by soils with SPT N value ranging from 34 to 44.

Khagrachhari District

Khagrachhari District is bordered by Tripura (Indian State) to the north, Rangamati and Chittagong district to the south, Rangamati district to the east, Chittagong district and Tripura (Indian State) to the west. The area of Khagrachhari is 2749.16 Sq Km. The Geo position of the district is between 22˚38’ to 23˚44’ North latitudes and between 91˚42’ to 92˚11’ east longitude (Figure 6-10).

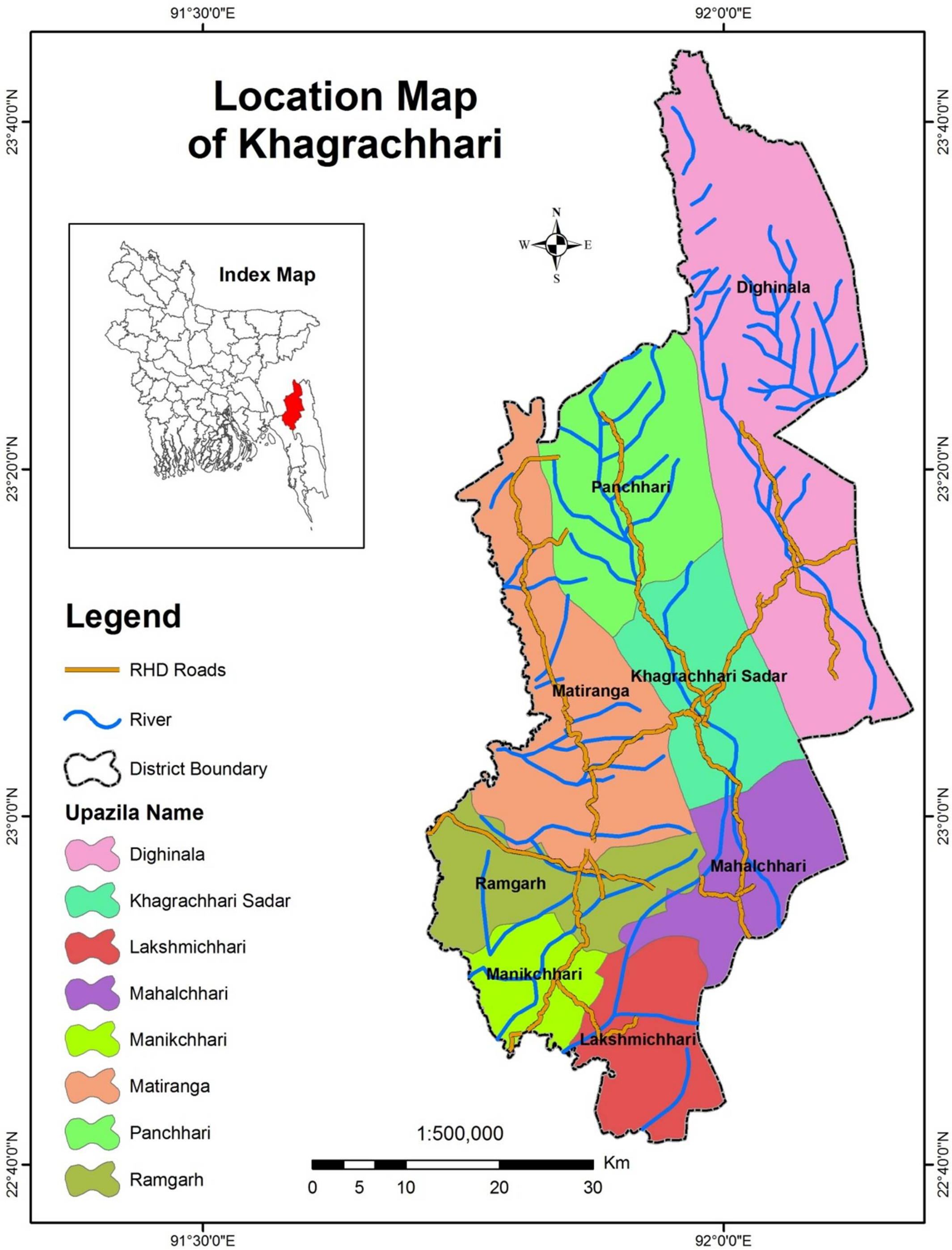


Figure 6-10 Location Map of Khagrachhari

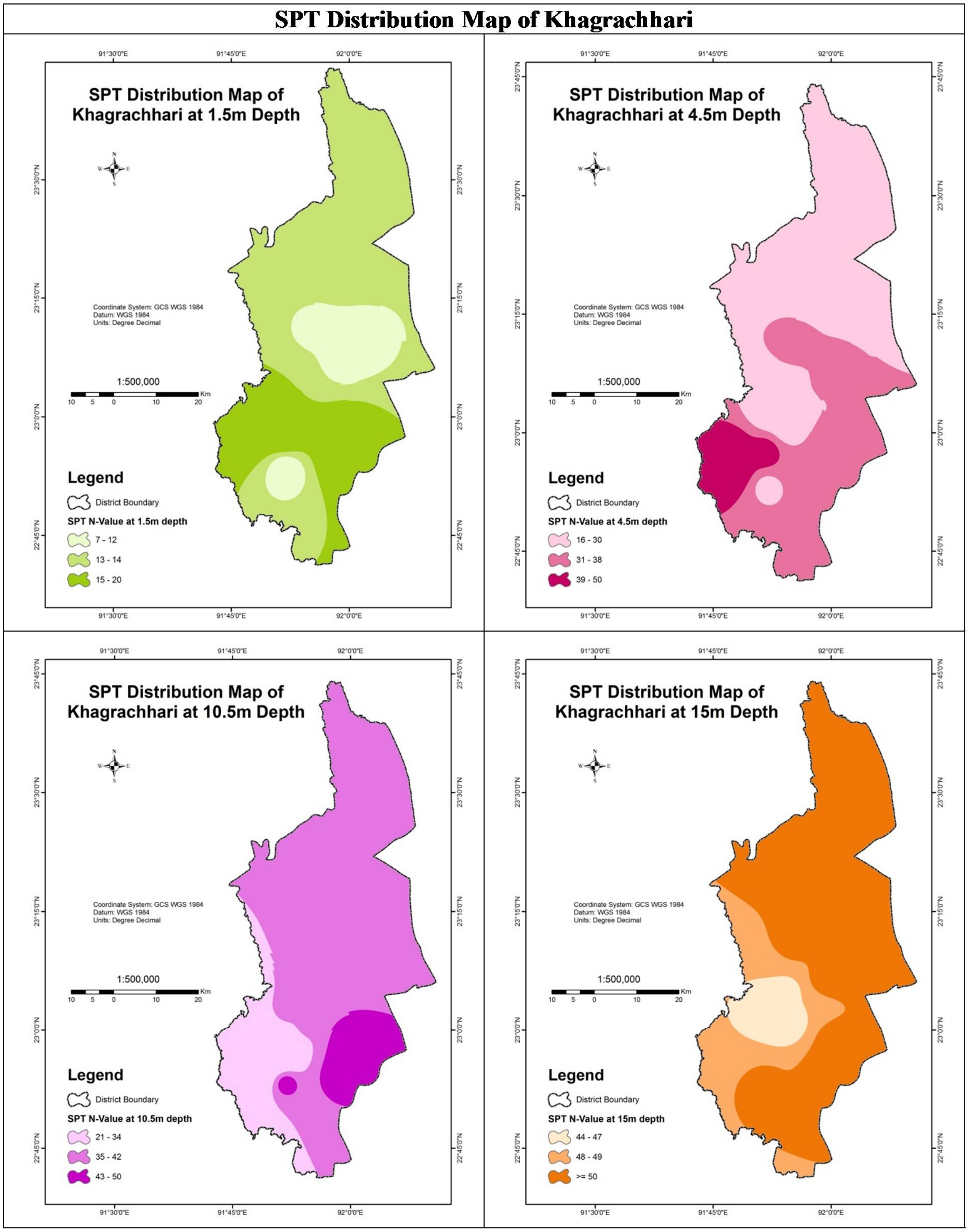


Figure 6-11 Distribution Map of Khagrachhari

SPT N value distribution map at 25 m, 30 m, and 51 m depth exhibit that soils of those respective depths have values of that from 49 to 50, 51 to 53, and 51 (Figure 6-11).

It is seen from the above maps that SPT N value distribution at 1.5 m depth of Khagrachari district can be presented by clustering into three zones based on that value range. From central portion to the north of the district is mainly SPT values from 13 to 14. This value range is further seen as a small at the southernmost porat of the study area. Within these zone there are two small zones with value ranging from 7 to 12: one is at the centraleast portion and another is in the southern part. In the south, there are soils with values of that ranging from 15 to 20, and they extend from east to west, including some portions of the southeast anfd southwest.

At 4.5 m depth of the stdy area, soils have SPT N value rnage rfom 16 to 30 from central-west to northernmost part. Soils with values of that ranging from 31 to 38 have been found from central-east to southernmost portion of the study area. Just south of central-west, there is a zone with SPT values from 39 to 50.

SPT N value distribution at 10.5 m depth of Khagrachari district is as such that values of that ranging from 35 to 42 has been found throughout the area from north covering continuously the middle part to the southeast. SPT value from 21 to 34 is seen from southeast in the south upto central-east towards north. The highest SPT value range found here is 43 to 50, and is situated at a small area just south from the central-eastern portion of the district.

SPT N value distribution at 15 m depth of Khagrachari district is as such that values of that greater than 50 has been found throughout the area from north covering continuously the middle part to the southeast. SPT values from 44 to 47 was found as a small zone at the central-west part of the study area. SPT N value range from 48 to 49 is seen throughout an area extending from central-west in the north throughout southwest in the south.

Lakshmipur District

Lakshmipur District, lies between latitude 22°30' to 23°10' and longitude 90°40' to 91°00', is located in the central part of Bangladesh with an area of 1440.39 sq km (Figure 6-12). Lakshmipur District is bordered by Chandpur district to the north, Bhola and a part of Noakhali district to the south, Noakhali district to the east, Bhola and Barisal district to the west.

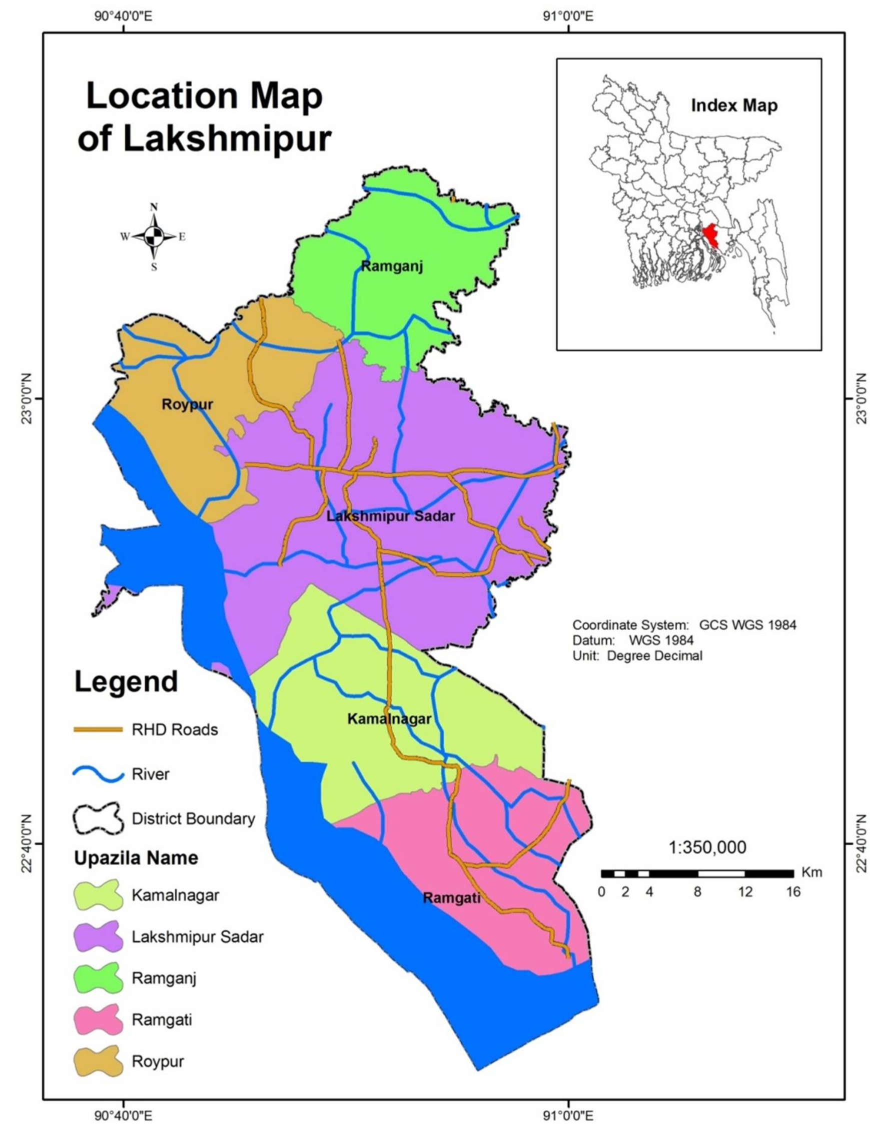


Figure 6-12 Location Map of Lakshmipur

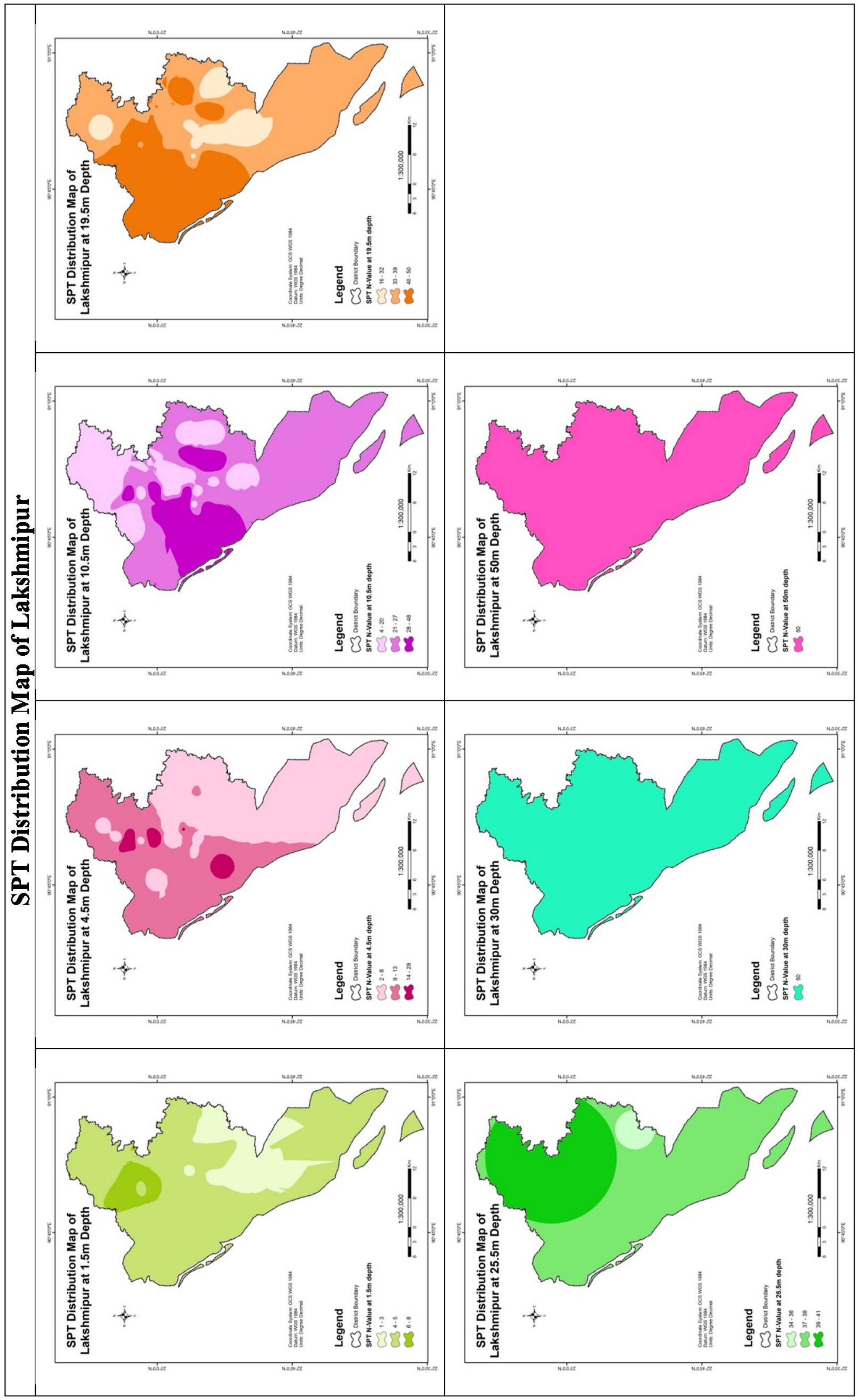


Figure 6-13 Distribution Map of Lakshmipur

The above figure 6-13 represents SPT N value distribution mp of Lakhsmipur district at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, 30 m, and 50 m depth.

SPT N value distribution map at 1.5 m depth exhibits that values of that ranging from 1 to 3 prevail at southeast, extending from mid-east to southeast to the south. SPT value ranging from 4 to 5 is predominant throughout the area from the north to the south. Within this is present a zone containing values from 6 to 8 at a small area in northwest.

Soils at 4.5 m depth have SPT value from 3 to 8 continually in the east and southeast from mid-east to south, amd also discretely as localized in the northwest part of Lakhsmipur district. Rest of the area, i.e., southwest to northwest and north, predominantly consists of soils with values of that ranging from 9 to 13. Within this area there are three very small zones with soils of SPT value from 14 to 29. Among them, one zone is at the central-west, other two are in the north just from the middle part of the project area.

SPT distribution at 10.5 m depth of the said area is as such that soils with values of that ranging from 4 to 20 are present at the northernmost zone, at a small zone at the middle part, at a zone in the central-east, and at a zone easterly just north of the middle part of the area. At an area just north of the central-west, and an area extending from south to the middle part of the study location soils have SPT N value range from 21 to 27. Within this zone, there are also soils with SPT value from 28 to 48 at the mid-west and mid-east.

At 19.5 m depth soils with SPT N values of 16 to 32 are seen mainly in three small zones within the study area. One is located in the northern portion, one is at the middle part of the study area and the other one is in the central-east portion. SPT N value range from 33 to 39 has been observed from to north to south, except in the westernmost central-western portion of the study area where there soils have values of that ranging from 40 to 50.

SPT N value distribution at 25.5 m depth reveals that soils with values of that ranging from 34 to 36 is present only at a very small and localized area in central-east of the project area. Soils with SPT range from 37 to 38 covers the entire middle portion and southern portion continually throughout the study area, and also present at a very small area at the northernmost part. SPT value from 39 to 41 has been at this depth in the northern part, just to the north of the middle portion of Lakhsmipur district.

Both at 30 m and 50 m depth SPT N value range is 50 throughout the district.

Lalmonirhat District

Lalmonirhat District is bordered by Kuchbihar and Jalpaiguri district of West Bengal (Indian State) to the north, Rangpurdistrict to the south, Kurigram district and Kuchbihar district of West Bengal to the east, Rangpur and Nilphamary districts to the west. The area of Lalmonirhat is 1247.37 Sq Km. The Geo position of the district is between 25˚48’ to 26˚27’ North latitudes and between 88˚38’ to 89˚36’ east longitude (Figure 6-14).

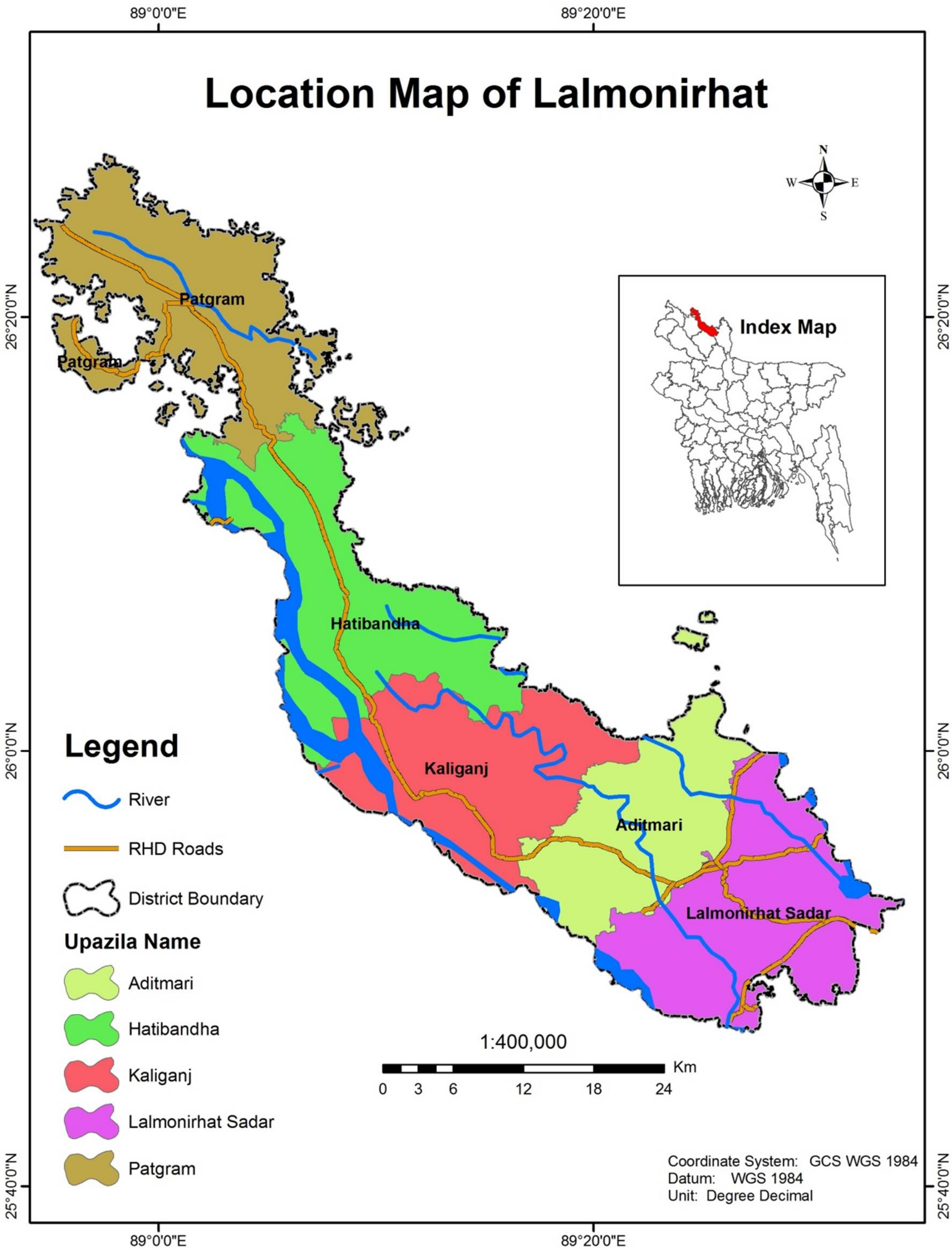


Figure 6-14 Location Map of Lalmonirhat

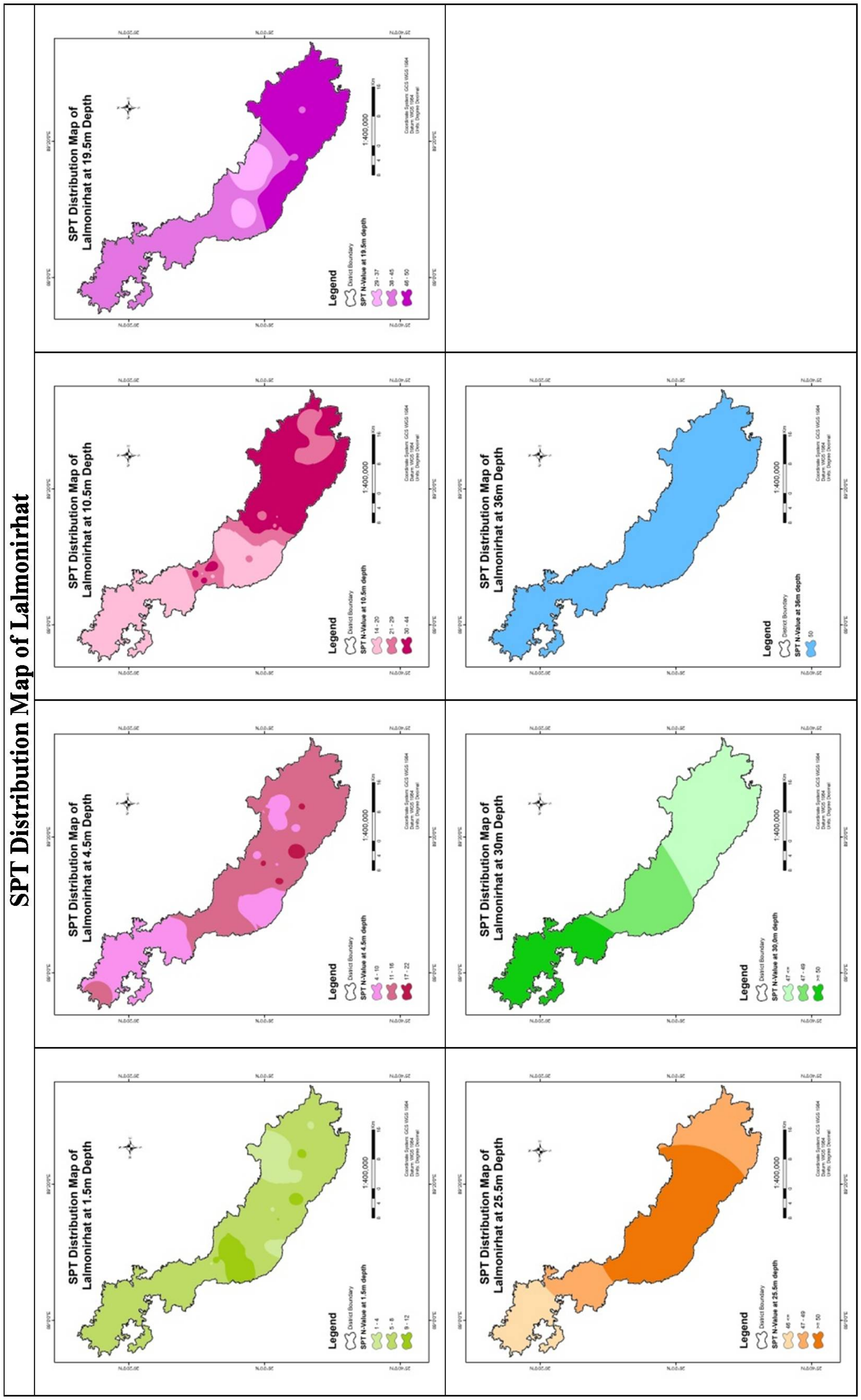


Figure 6-15 Distribution Map of Lalmonirhat

At 1.5 m depth of Lalmonirhat district SPT N values from 1 to 4 were found near the western portion of central-west and southwest. SPT values from 9 to 8 were found in rest of the area, except 9 to 12 just north of central-west (Figure 6-15).

SPT values forom 4 to 10 at 4.5 m depth were found in most of the northern portion and at the westernmost portion in central-west. Values tof that from 11 to 16 were observed in rest of the area and at a very small area in northernmost part. But values from 17 to 22 were found discretely as very small zones in the central and southern portion of Lalmonirhat.

At 10.5 m depth values from 14 to 20 are clustered in northern half of the middle part and in most of he northern portion of Lalmonirhat. 21 to 29 have been identified as a narrow E-W trending strip at the middle art of the area, at a smalla area just north of the central portion, and at a small area near the southern end. SPt values from 30 to 44 are seen in southern half of the middle portion of Lalmonirhat and continually in most of the southern part.

At 19.5 m depth soils with SPT values from 29 to 37 were found at two small zones in the middle of the middle part of Lalmonirhat. Values from 38 to 45 is possessed by soils in ret of the middle part to all of the northern portion. 46 to 50 values were observed in central-west to throughout south.

At 25.5 m depth SPT values less than 46 were found in the northernmost region of Lalmonirhat. Values of that from 47 to 49 in southern half portion of the northern zone and in the southernmost portion. Values greater than 50 prevail throughout the middle part to some potion of the northern half of the southern part.

At 30 m depth SPT values less than 46 were found in the south to southern half of the middle part part of Lalmonirhat. Values of that from 47 to 49 in southern half portion of the northern zone to northern half of the middle part of the study location. Values greater than 50 prevail throughout the middle part northern part of the project area.

Soils at 35 m possess SPT N value 50 throughout Lalmonirhat district.

Kurigram District

Kurigram District is bordered by Kuchbihar district of West Bengal (Indian State) to the north, Gaibandha district to the south, Assam (Indian State) to the east, Rangpur and Lalmonirhat district and West Bengal to the west. The Geo position of the district is between 20˚03' to 26˚03' North latitudes and between 89˚27' to 89˚47' east longitude. The area of Kurigram is 2245.04 Sq Km (Figure 6-16).

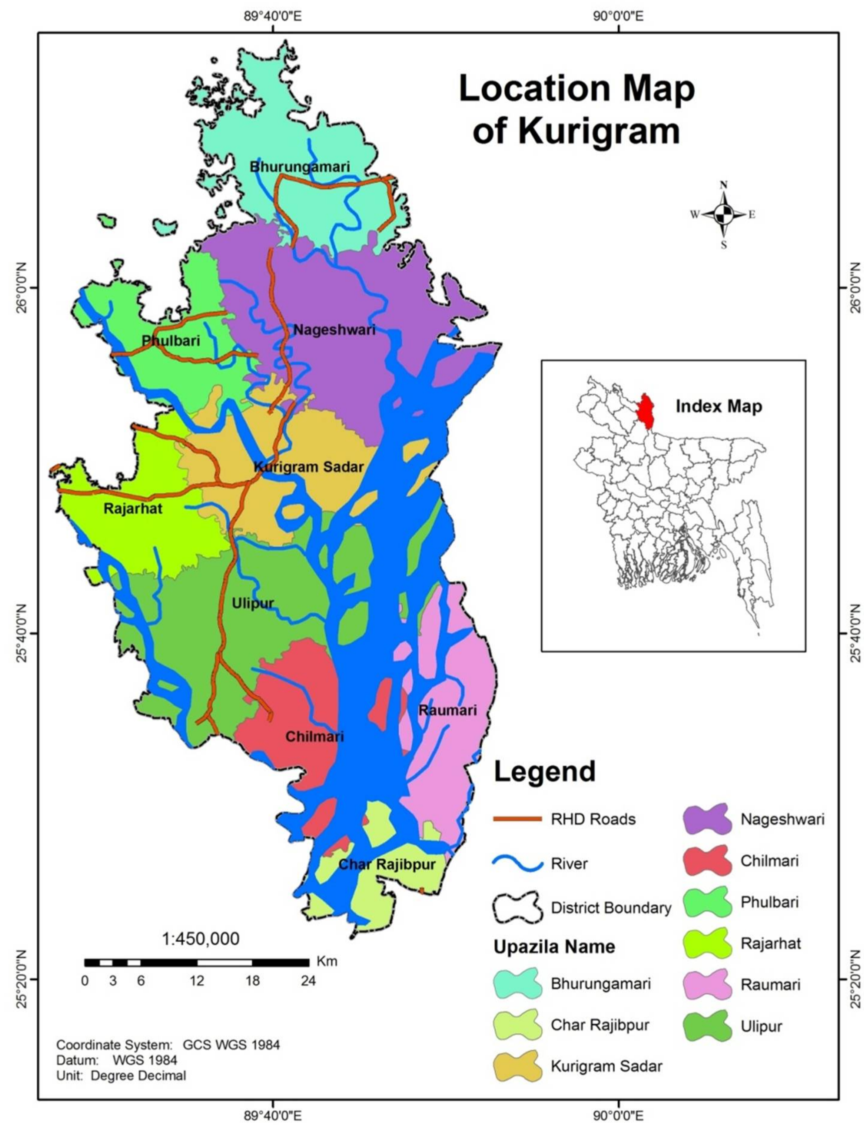


Figure 6-16 Location Map of Kurigram

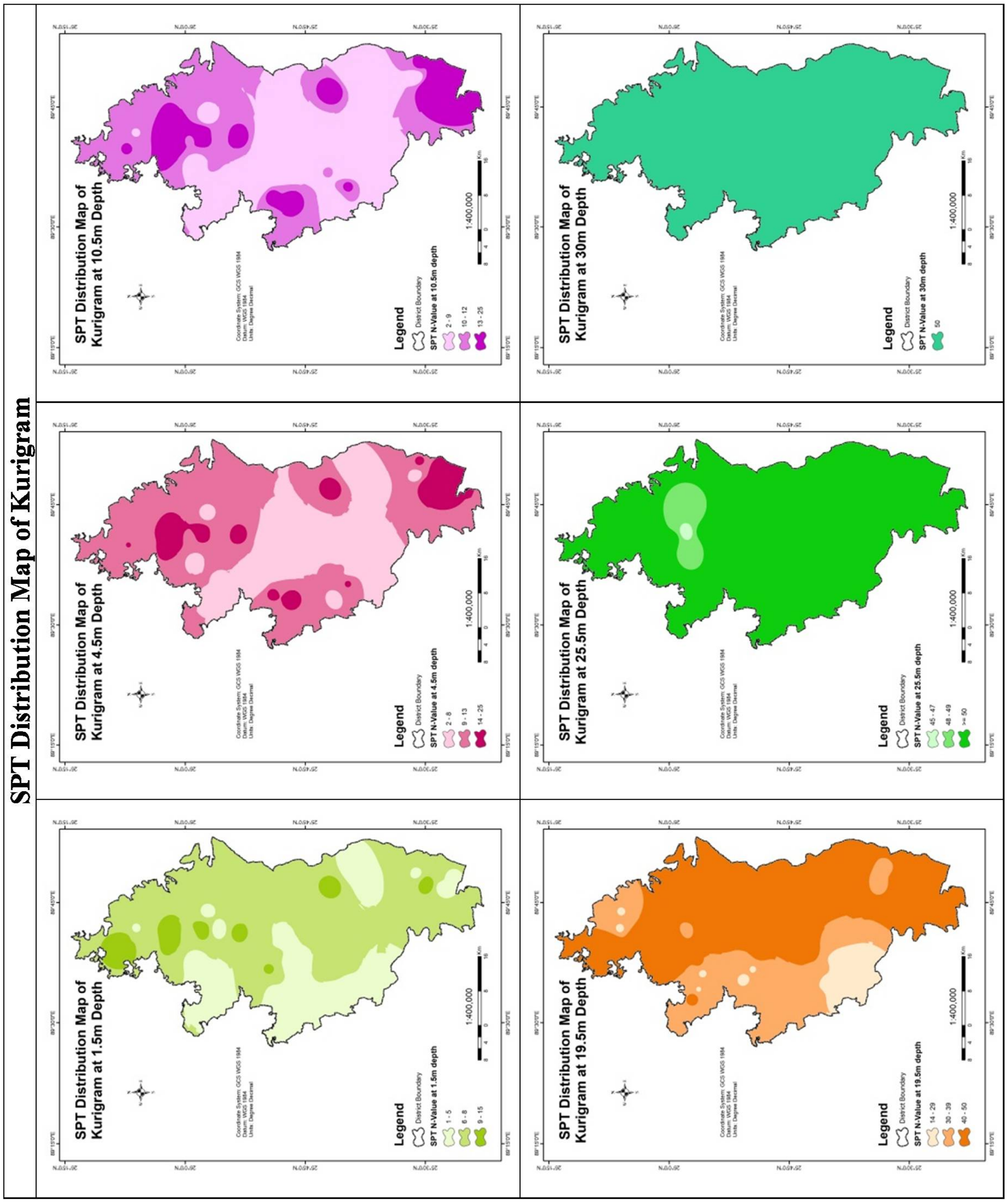


Figure 6-17 Distribution Map of Kurigram

The above figure 6-17represents SPT N value distribution map at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, and 30 m of Kurigram.

At 1.5 m depth of Kurigram SPT values from 1 to 5 have found in central-west and north to central west. Rest of the areas have values of that predominantly from 6 to 8, except 9 to 15 in some small areas in the north, at a small area in the middle part of the district, and at a very small area in south.

At 4.5 m depth there SPT values from 7 to 8 have been found throughout most of the middle part to northwest. Values from 9 to 13 were observed at some areas at the southernmost corner, at westernmost part in the central-west, at a small area in central-east, and in most of the northern portion. Values of that from 14 o 25 were found at a small area in south, at very small areas in central- and central-west, and at two small areas in the north.

At 4.5 m depth there SPT values from 2 to 9 have been found throughout most of the middle part to northwest. Values from 10 to 12 were observed at some areas at the southernmost corner, at westernmost part in the central-west, at a small area in central-east, and in most of the northern portion. Values of that from 13 o 25 were found at a small area in south, at very small areas in central- and central-west, and at two small areas in the north.

At 19.5 m depth of Kurigram, SPT N values from 14 to 29 were found in a smalla rea in southwest, and otherwise discretely in very small zones in northwest and northeast. Values from 30 to 39 have been observed in western portion to some areas in the middle part of south, and at a small area in northeast. Values from 40 to 50 were found from northwest to southeast, continually throughout the middle part of the district.

At 25.5 m depth most of the area exhibited SPT N values greater than 50, but a very small area approximately at the middle part of the northern portion constrained values of that from 45 to 47, and in between a very little zone had values from 48 to 49.

At 30 m depth of the district SPT values are greater than 50 throughout.

Manikganj District

Manikganj District is bordered by Tangail district to north. West, West-South and Southern borders respectively Jamuna and Padma Rivers disconnected the district from Pabna and Faridpur. Dhaka is to the Eastern, north-eastern and south-eastern of Manikganj district. The area of Manikganj District is 1,383.66 Sq Km. It's Geo position is 23˚52' to 45˚0' North latitudes and 90˚4' to 15˚0' east longitude (Figure 6-18).

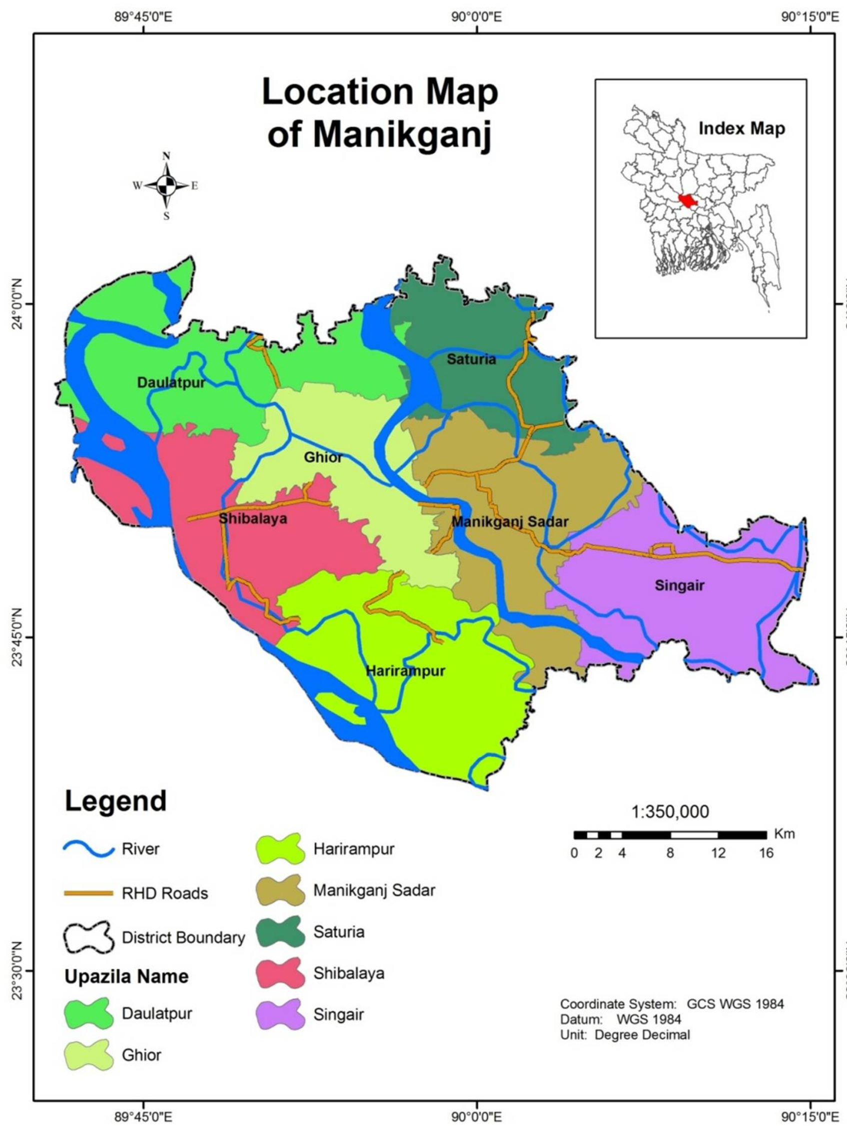


Figure 6-18 Location Map of Manikganj

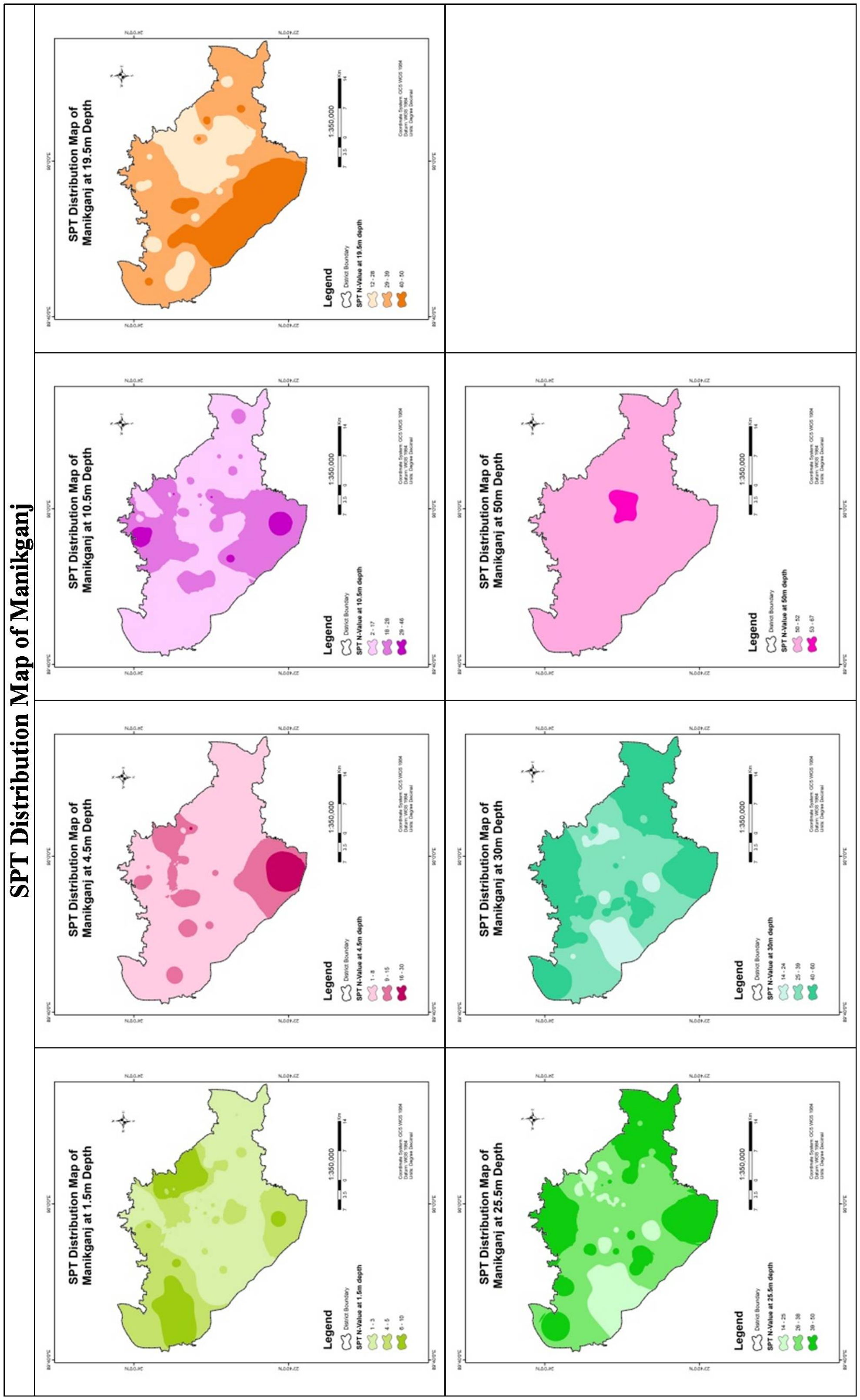


Figure 6-19 Distribution Map of Manikganj

Soils at 1.5 m depth of Manikganj district possess SPT N values from 1 to 3 in most of the areas, except 4 to 5 in northwest, northeast and southernmost corner, and values from 6 to 10 at a small area just north to central-west and at a small area just north to central east (Figure 6-19).

At 4.5 m depth SPT values from 1 to 8 prevail in most of the area, except 9 to 15 at some discrete small area as in the north and at southern corner, and 16 to 30 at a small area at the southernmost corner.

Soils at 10.5 m depth possess SPT values from 2 to 17 from east to west, i.e., continually in the central-east, middle part and central-west of Manikganj. Moreover, 18 to 28 SPT values were found at southernmost and northernmost corners. On top of that, values of that ranging from 29 to 46 were observed at two very small areas, one in the southernmost portion and other in the northernmost portion.

At 19.5 m SPT N values from 12 to 28 has been in the eastern half of the middle part to central east. Values from 29 to 39 have been found in most of the rest areas, except 40 to 50 from central west to western margin of south.

At 25.5 m depth values of that from 14 to 25 were found at a small area just north of central-east. Otherwise, 26 to 38 SPT values prevail in most of the area, 39 to 50 in northernmost part, southernmost part, southeast corner, and northwest corner at small areas.

At 25.5 m depth values of that from 14 to 24 were found at a small area just north of central-east. Otherwise, 26 to 39 SPT values prevail in most of the area, 40 to 60 in northernmost part, southernmost part, southeast corner, and northwest corner at small areas.

At 50 m depth of Manikganj SPT values from 50 to 52 prevail throughout the area, except 53 to 67 at a very small in approximately the middle part.

Nilphamari District

Nilphamari District is bordered by Shiliguri (Indian district) to the north, Rangpur and Dinajpur districts to the south, Rangpur and Lalmonirhat districts to the east, Panchagarh and Dinajpur districts to the west. the Geo position of the district is between 25˚44' to 26˚19' North latitudes and between 88˚46' to 89˚12' east longitude. The area of Nilphamari is 1546.59 Sq Km (Figure 6-20).

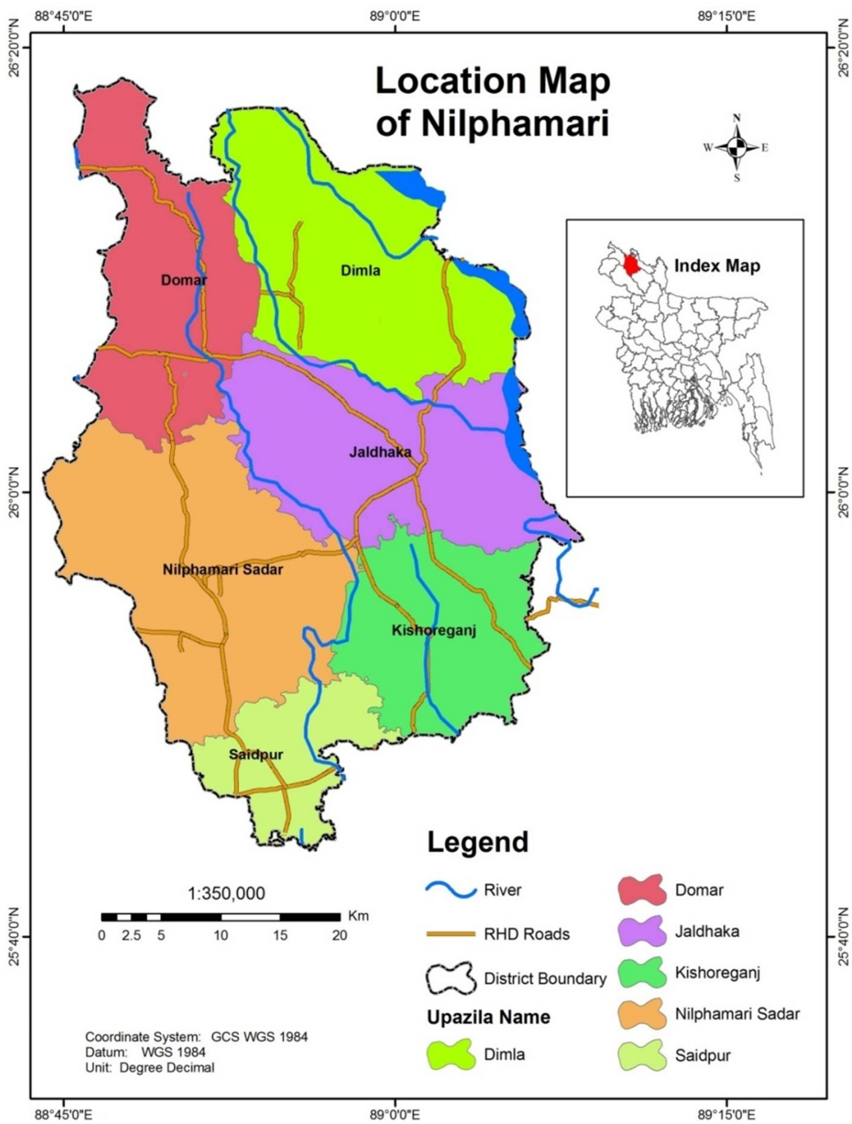


Figure 6-20 Location Map of Nilphamari

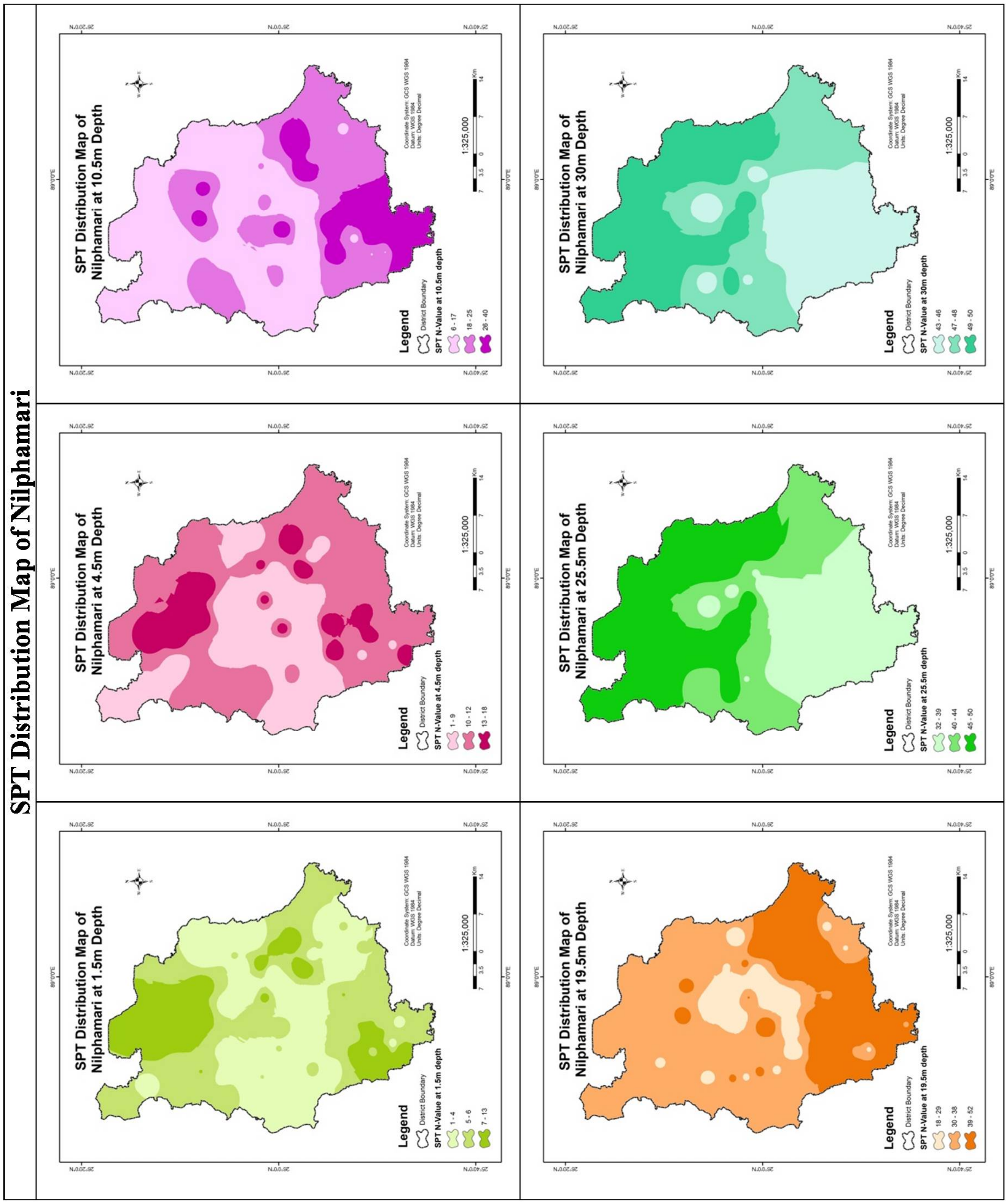


Figure 6-21 Distribution Map of Nilphamari

The above maps represents SPT N value distribution at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, and 30 m depth of Nilphamari district (Figure 6-21).

SPT N value from 1 to 4 at 1.5 m depth is seen throughout the middle part of NIlphamari district to southeast and also at a small zone in the north. SPT N value from 5 to 6 is seen clustered in three large zones—one covers the northern part of the district, extending as narrow zone up to the middle part; another zone is concentrated at the southwest corner; another one is concentrated at the southeast part of the project area.

At 4.5 m depth SPT N value range from 1 to 9 is seen at the northernmost part, in an area extending easterly from central-west to the middle part of the district, and another one is at a small area in the east of the central-eastern locality of Nilphamari. Values of that from 10 to 12 have been found throughout maximum area in the south, extemdings continually to northwest from northeast through the central-eastern part of the project location.

Soils at 10.5 m depth of Nilphamari district have SPT N values from 6 to 17 throughout the maximum area of the middle and northern part. Values of that from 18 to 25 is seen in most of the southern portion of the district, except at the southwest corner. These values have further been found at three discrete zones in the middle part of the project area. SPT values from 26 to 40 was observed in the southwestern portion and at a small zone in the southeastern portion, south of the middle-eastern part of Nilphamari.

Soils at 19.5 m depth SPT N value from 18 to 29 at the middle part of the district occur as a comparatively large zone and otherwise discretely at very small areas. Soils with value range of that of 30 to 38 occur throughout the northern part of the area and in the middle. A small zone of such soil is also seen at the southernmost part of the district. SPT value 39 to 52 has been found largely in the southern portion of the district.

At 25.5 m depth of the district there are soils with SPT value from 32 to 39 largely in the southern portion of the district. SPT range from 40 to 44 has been found in the middle part of the district to the southeast portion. Northern part of the district, and continually some areas in the central-west and central-east has soils with SPT values from 45 to 50.

SPT value range from 43 to 46 at 30 m depth has been found largely in the southern portion of Nilphamari. Values of that ranging from 47 to 48 was found in the middle part to the south-eastern part of the district. Soils with SPT N value from 49 to 50 mainly occurs throughout the northern area and central-east area.

Pabna District

Pabna District is bordered by Sirajganj and Natore districts to the north, Rajbari and Kushtia districts to the south, Manikganj and Sirajganj districts to the east, Kushtia district and the Ganga River to the west. The area of Pabna District is 2376.13 Sq Km. The Geo position of the district is between 24˚03’ to 24˚12’ North latitudes and between 89˚10’ to 89˚25’ east longitude (Figure 6-22).

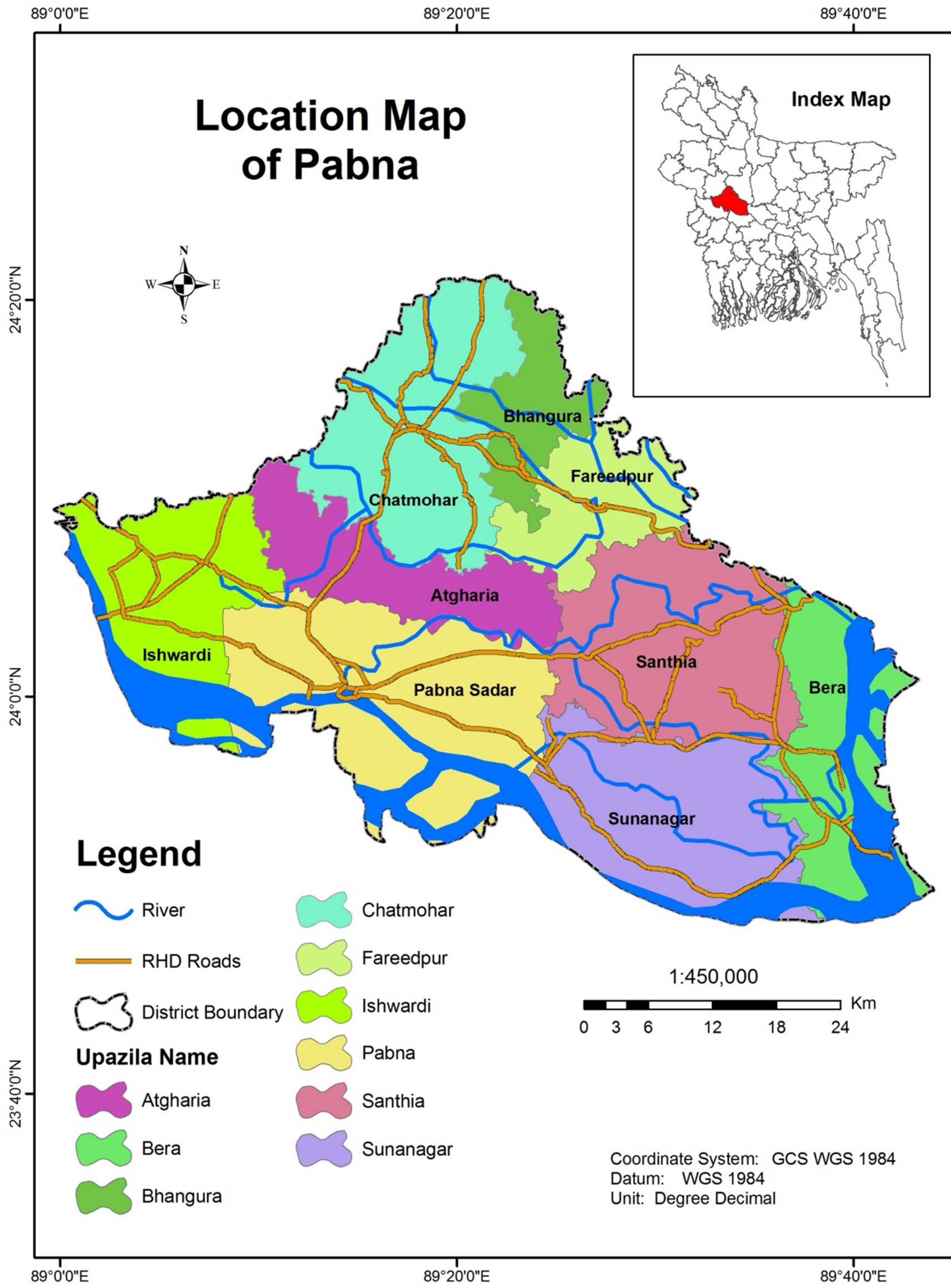


Figure 6-22 Location Map of Pabna

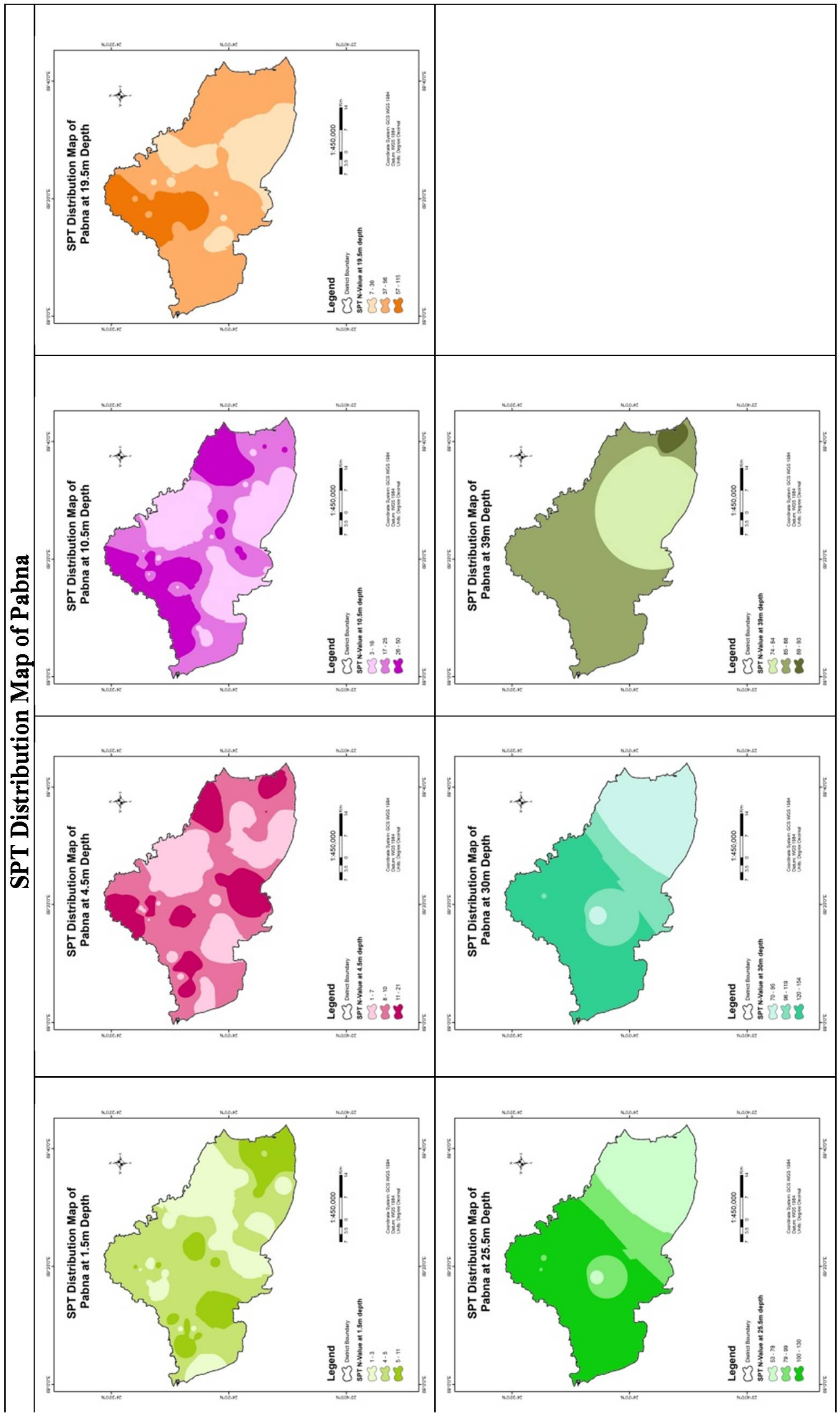


Figure 6-23 Distribution Map of Pabna

At 1.5 m depth of Pabna, at a small area in westernmost central-west, and a large area from south central to central-east possess soils with SPT N value from 1 to 3. It can be seen SPT value distribution map at 1.5 m depth that rest of the area mostly has values of that from 4 to 5, except 6 to 11 at some very small areas in west, middle part, and southern portion (Figure 6-23).

At 4.5 m depth of Pabna, at a small area in westernmost central-west, central-east, and a large area from south central to central-east possess soils with SPT N value from 1 to 7. It can be seen SPT value distribution map at 4.5 m depth that rest of the area mostly has values of that from 8 to 10, except 11 to 21 at some small areas in north, south, east, and west corners.

SPT N value distribution at 10.5 m depth is as such that vaues of that ranging from 3 to 10 were observed in some areas in south, southwest and central-east during borehole oinvestigation. Moreover, 17 to 25 SPT values were found in rest of the areas, but 26 to 50 at two areas—one is in northwest, and the other is near central-east.

SPT N value distribution map at 19.5 m depth exhibits that soils at this depth have much higher values compared to the previous depths. During borehole investigation, values of that ranging from 7 to 36 were found at a very small zone just south of centralwest and in a narrowly extended area from central-south to central east. Otherwise, 37 to 56 SPT values were found mostly in rest of the areas, but 57 to 117 only in an area from middle part of Pabna to it's westerly northernmost boundary, and halfway through the western half of the northern zone.

At 25.5 m depth, soils with SPT N values from 53 to 78 were found throughout the southern part of Pabna, soils with values of that from 79 to 99 were found in the middle part, amd soils with 100 to 130 SPT values were found in the northern portion.

At 25.5 m depth, soils with SPT N values from 70 to 95 were found throughout the southern part of Pabna, soils with values of that from 96 to 119 were found in the middle part, amd soils with 120 to 154 SPT values were found in the northern portion.

At 39 m depth, soils with SPt values from 74 to 84 were found in southern and some of the middle part of Pabna. Rest of the areas have values of that from 85 to 88, except a very small area having values from 89 to 90 in southeast.

Rajbari District

Rajbari District is bordered by Pabna district to the north, Magura and Faridpur districts to the south, Manikganj district to the east, Kushtia and Jhenaidah districts to the west. The area of Rajbari district is 1092.28 Sq Km. The Geo position of the district is between 23˚35' to 23˚55' North Latitudes and between 89˚09' to 89˚55' east Longitude (Figure 6-24).

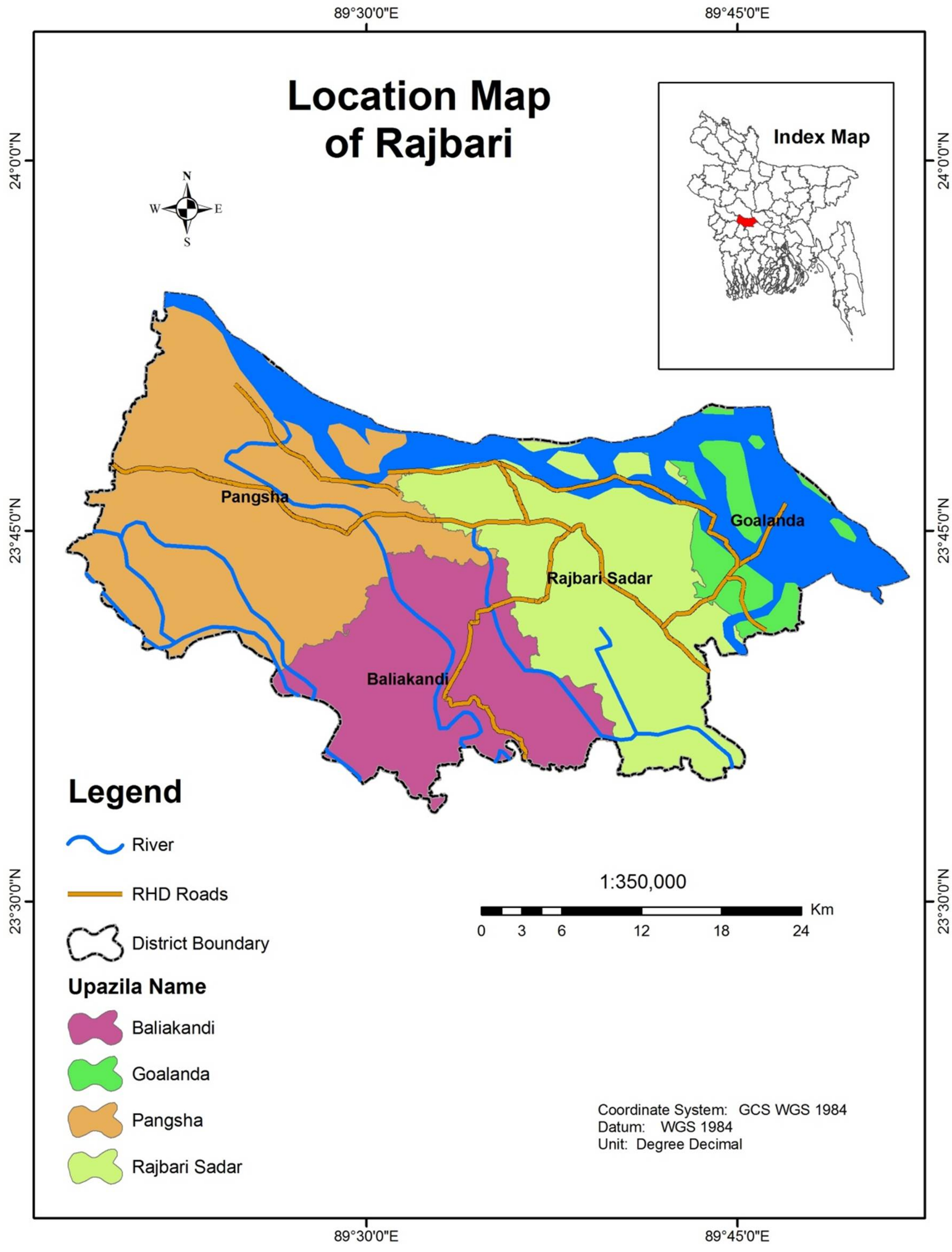


Figure 6-24 Location Map of Rajbari

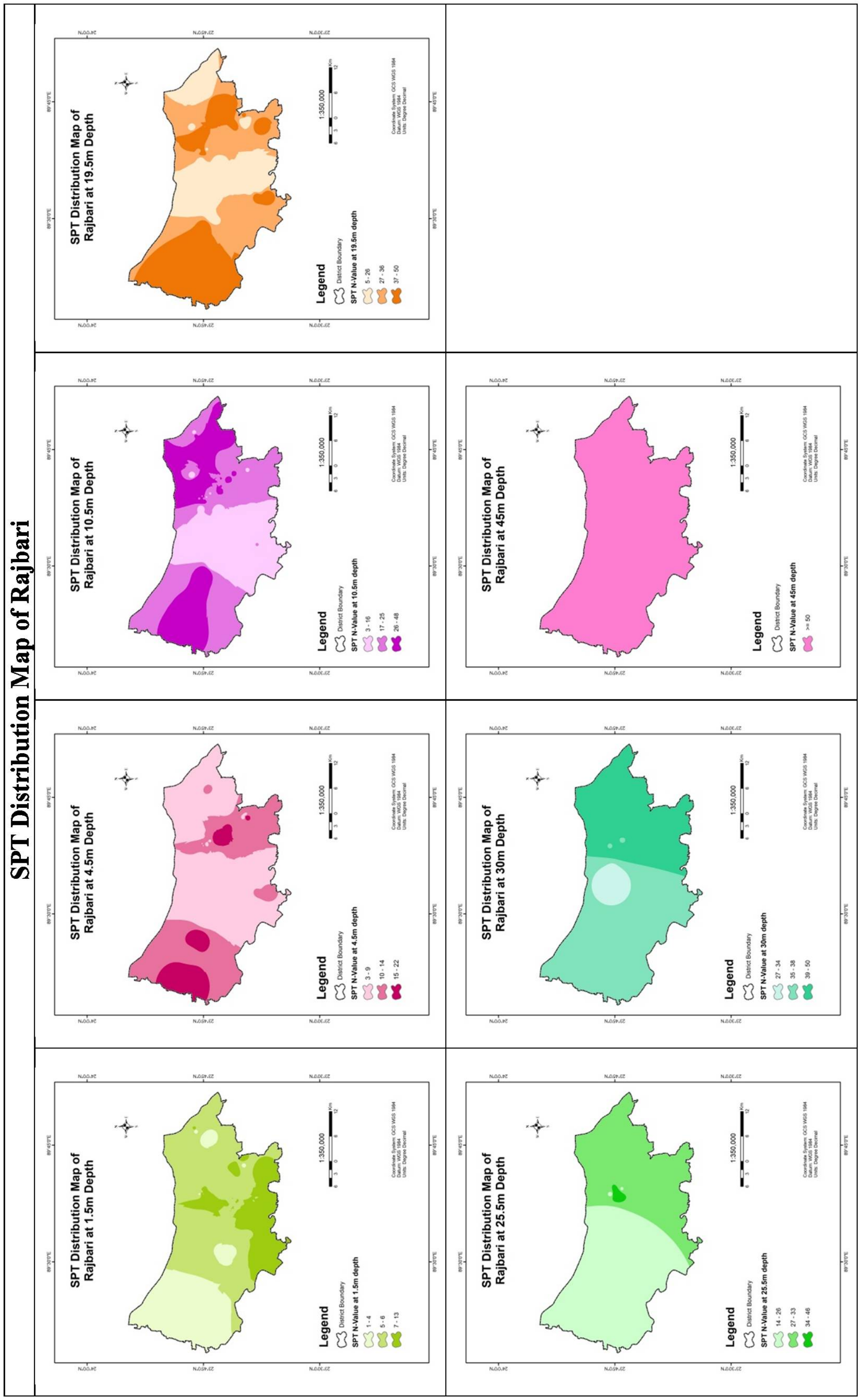


Figure 6-25 Distribution Map of Rajbari

The above figure 6-25shows SPT N value distribution at 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, 30 m, and 45 m depth of Rajbari district.

Soils with SPT N value range from 1 to 6 at 1.5 m depth are distributed throughout the eastern part of the area and extends from north to south. In most of the area, i.e., in most of the area of the middle and norther portion and continually in the western portion, of Rajbari SPT value from 5 to 6 was found. Values of that ranging from 7 to 13 was found as elongated from east to west at the southernmost part of the district. These values have further been found as a small zone at the middle part of the project area.

At 4.5 m depth, SPT N value range from 3 to 9 was found in the middle part, this zone extends from north to south, and in the easternmost area. Soils with SPT N value range from 10 to 14 are distributed in the westernmost locality and in an area just to the east of the middle part of the district, which zone occurs as a narrow strip and elongated from north to south. Another value range from 15 to 22 has been found as a small zone at the westernmost area, as a small zone just to the east of the previous one, and as a much smaller zone at the central-eastern portion of the project location.

SPT N value range from 3 to 16 was found at the middle part of the area, this zone extends from north to south within the study area. Values of that ranging from 17 to 25 has been found at a small area in the westernmost portion, just east of the middle part of the area as elongated from north to south, and at two discrete areas in the west, one occurs north of central-west portion and another occurs to the south of that. The highest value range there is 26 to 48. These values are seen in the central-west and in the central-east, where extension is from north to south.

At 19.5 m depth of the project area, soils with SPT N value range from 5 to 26 is distributed largely in two areas. One occurs at the middle part of the district, which is elongated from north to south as a narrow strip. Another area is relatively small and lies on the central-eastern portion of the easternmost part of the project location. SPT value range from 27 to 36 is observed as two discrete zones in the northernmost and the southernmost part to the west of the middle portion of the location. These values have been further seen just east of the middle portion of the location as elongated from north to south in a narrow pattern like a irregular strip and also at two areas, one is in the north and other is in the south, in the central-east portion of Rajbari.

At 25.5 m depth of Rajbari, SPT N value range from 14 to 26 was found throughout the eastern part to the half of the middle part of the study area. The other half of the study area mainly has SPT Values from 27 to 33. At a very small area, SPT Na value range from 34 to 46 has been found. This small zone is located just north from the middle part of the project location.

SPT value range from 27 to 34 at 30 m depth occurs in the soils of small area just from the middle part of the study location. SPT range from 35 to 38 was found throughout the western part and in most of the middle part of the study area. The rest of the area, i.e., the eastern portion, is occupied with soils of SPT values from 30 to 50.

Soils at 45 m depth of the study location have SPT N value greater than 50 throughout.

Rangamati District

Rangamati District is bordered by Tripura and Mizoram (Indian State) to the north, Bandarban district to the south, Mizoram (Indian State) and Chin State (Mayanmar) to the east, Khagrachari and Chittagong district to the west. The Geo position of the district is between 22˚27’ to 23˚44’ north latitudes and between 91˚56’ to 92˚33’ east longitude. It is the largest district of Bangladesh in area and the area of the district is 6,116.11 Sq Km (Figure 6-26).

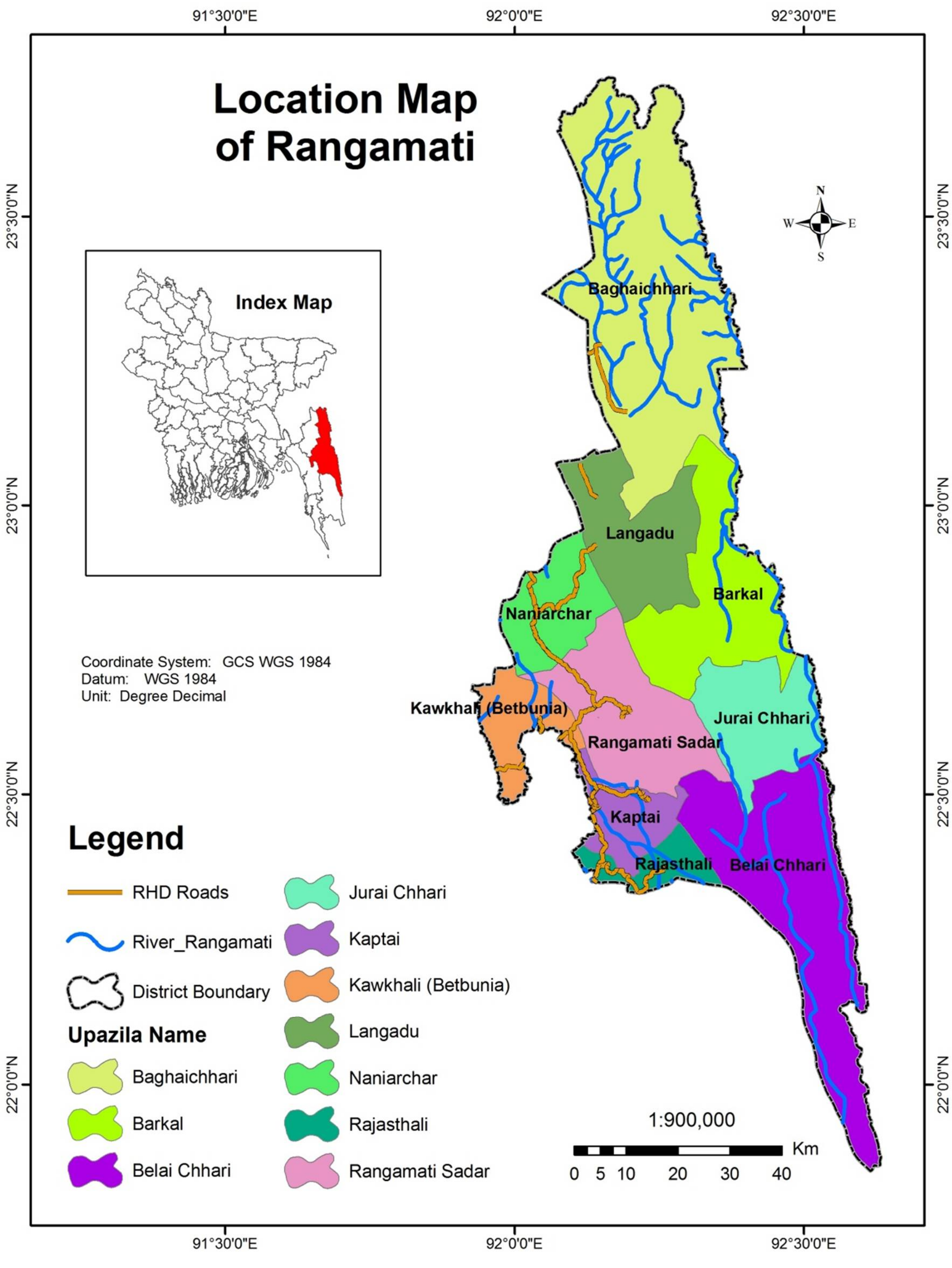


Figure 6-26 Location Map of Rangamati

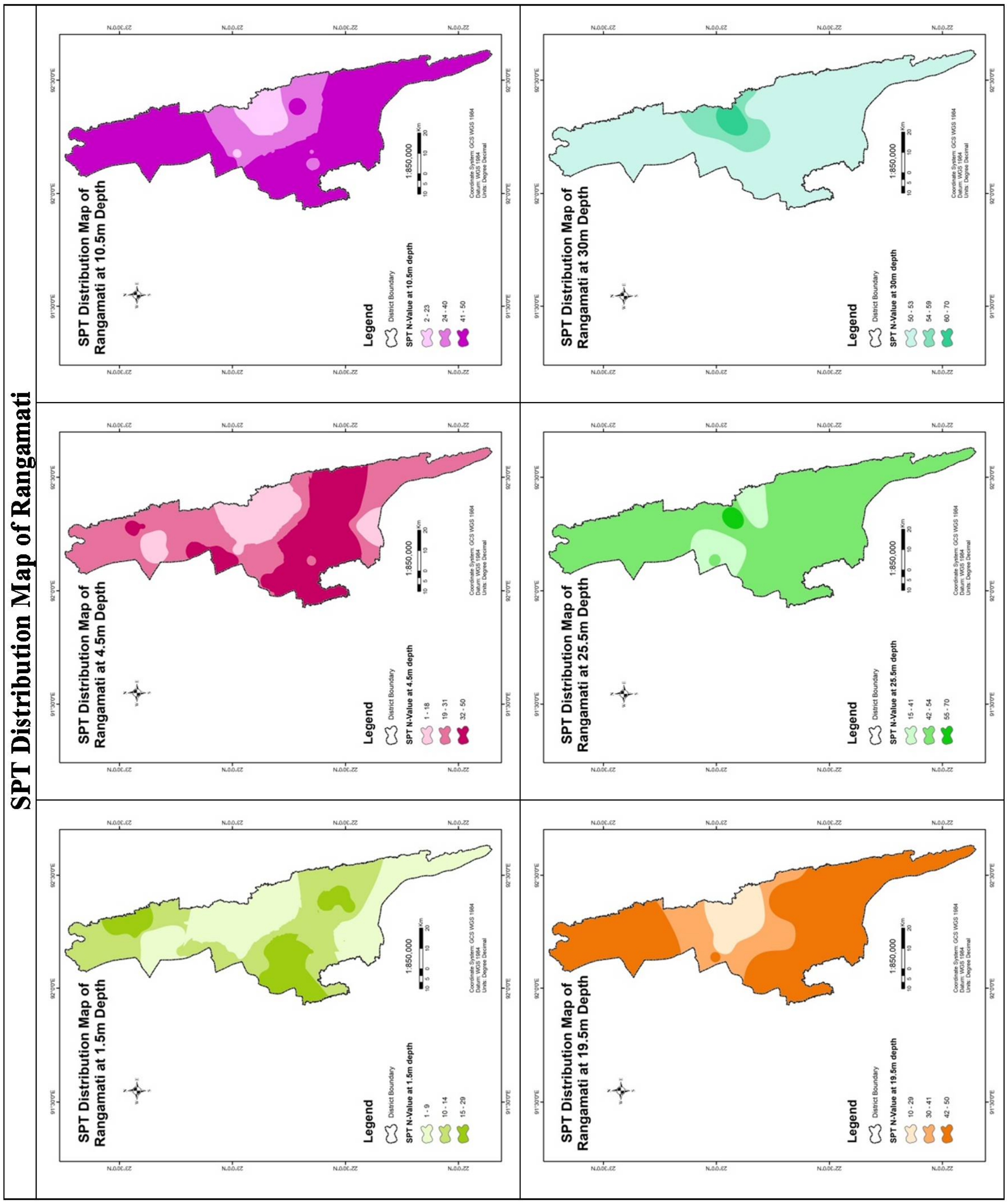


Figure 6-27 Distribution Map of Rangamati

SPT N value distribution pattern 1.5 m, 4.5 m, 10.5 m, 19.5 m, 25.5 m, and 30 m depth of Rangamati district has been manifested on the above maps (Figure 6-27).

It can be observed that at 1.5 m depth of the district, there are two zones clustering SPT value range from 1 to 9. One is at the southernmost portion, upto the middle part, and another occupies most of the middle part of the area, upto some areas in the north. SPT Values 10 to 14 has been in the northernmost part, and in some areas of the middle part of Rangamati district. Moreover, values of that ranging from 15 to 29 are seen occupying three discrete zones in the proeject area. One is at the easternmost area in the northernmost location, one is at central-west, and the other one is at a small zone, just south of central-east.

At 4.5 m of the district SPT value range from 1 to 18 has been found clustering in central-east, at a small azone at the middle part of the northern portion, and at south of the central portion of Rangamati district. SPT N values from 19 to 31 is seen clustering in most of the southern portion to the middle part, in most of the norther part, and in an area from east to west at the middle part of Rangamati. Soils with values of that ranging from 32 to 50 was found in the central part as elongated from east to west, at an area just north of central-west, and asterly at a very small zone at the middle part of the northern zone.

SPT value range from 2 to 23 at 10.5 m depth has been found at an small area in the central-east. SPT values from 24 to 40 was found mainly in the eastern half of the study area,but this zone narrowly extends upto central-west. The rest of the area, i.e., the northern part, and the southern part of Rangmati is occupied by soils with values of that ranging from 41 to 50 at 10.5 m depth.

At 19.5 m depth of Rangmati district, SPT values from 10 to 29 is seen in the central-east portion. Rest of the middle part of the district is occupied by soils of SPT values from 30 to 41. 42 to 50 is the SPT value range in the rest of the northern part and southern part of Rangamati.

25.5 m depth of Rangmati district is occupied by soils with SPT value ranging from 15 to 41 at a small zone in central-east and at a small zone just north of central-west. Most of the area is occupied by soils of SPT value range from 42 to 54, except one very small zone just north of central-east with soils of values of that ranging from 55 to 70.

At 30 m depth of Rangmati district, most of the soils have SPT values from 50 to 53. But there is a small zone in central-east with SPT values from 54 to 59, and within this zone there is another small zone with SPT values from 60 to 70.

Shariatpur District

Shariatpur District is bordered by Munshiganj district to the north, Barisal district to the south, Chandpur district to the east and Madaripur district to the west.The area of Shariatpur district is 1174.05 Sq Km. The Geo position of the district is between 23˚01’ to 23˚27’ North latitudes and between 90˚13’ to 90˚36’ east longitude (Figure 6-28).

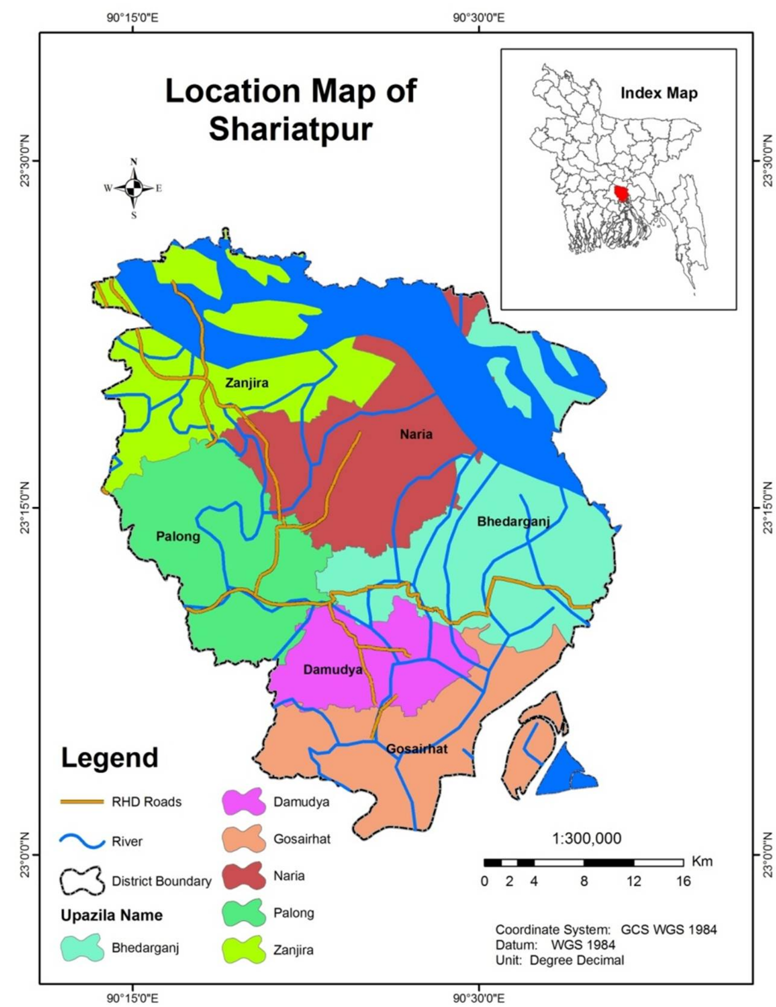


Figure 6-28 Location Map of Shariatpur

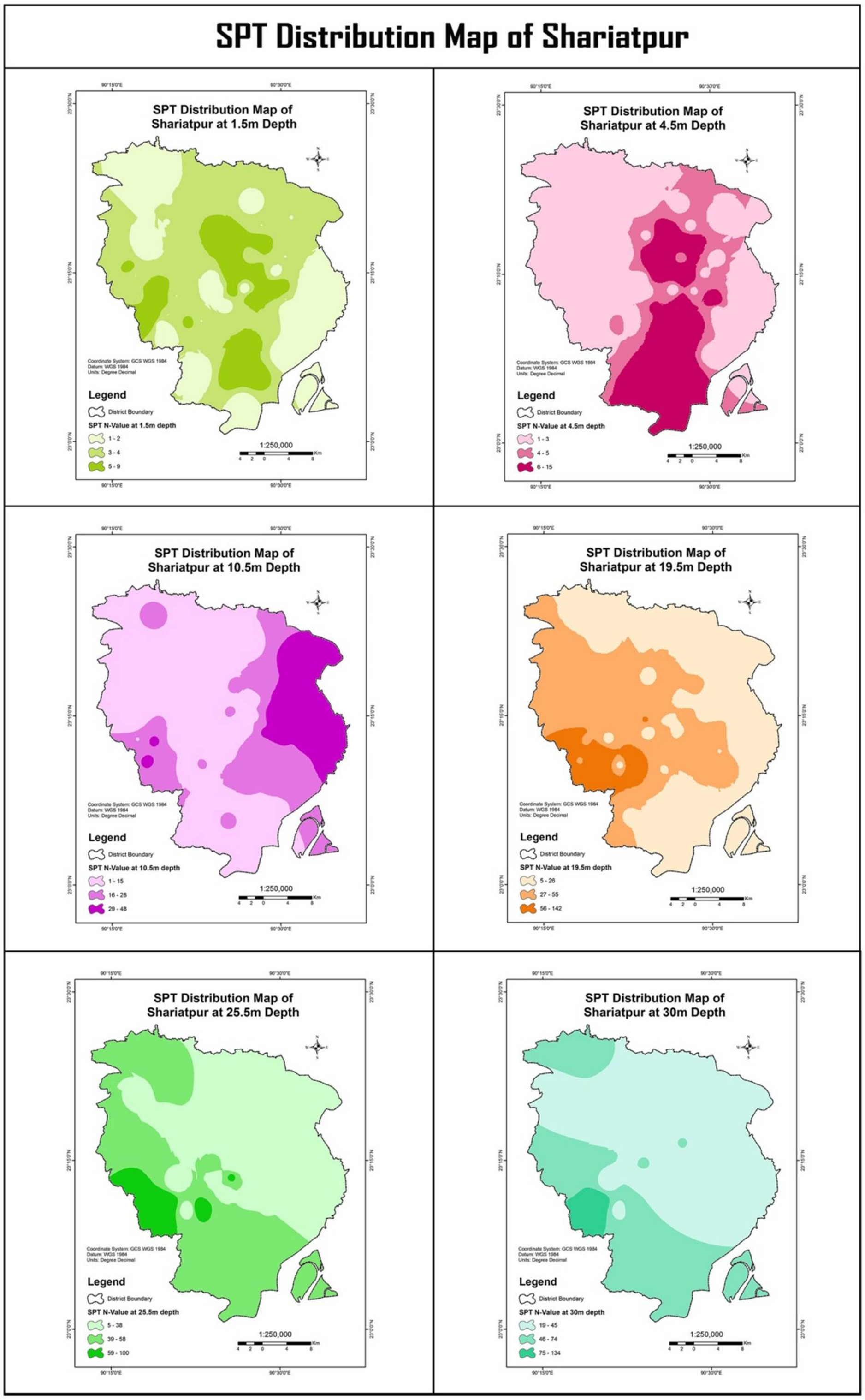


Figure 6-29 Distribution Map Shariatpur

At 1.5 m depth SPT N values from 1 to 2 has been found in northernmost portion, southern and southwestern part, and together in central-east and northeastern part. Values of that from 3 to 4 were found in most of the rest of the area, 5 to 9 in middle part, southwestern part, and southern part (Figure 6-29).

At 4.5 m depth of Shariatpur, SPT N values from 1 to 3 were found in west and central-east. Va;ues of that from 4 to 5 have been observed in middle and easterly northern part. Values from 6 to 15 were found during investigation in a small area in the middle and easterly southern part.

At 10.5 m depth, SPT N value from 1 to 15 is seen from the north to the south on the distribution map for the depth, and covers most of the area of Shariatpur. But, values from 16 to 28 has been found at a very small area in the north, in central-west, and some areas in the east. SPT N values from 29 to 48 were found only in easternmost portion of central-east.

SPT values increase 19.5 m depth. Values of that from 5 to 26 were observed throughout northern, central-eastern, and southern portion. Values from 27 to 54 is seen in most of the remaining areas, except 55 to 172 at a comparatively small area just south of central-east.

Values of that from 5 to 38 were observed throughout northern, central-eastern, and southern portion at 25.5 m depth. Values from 39 to 58 is seen in most of the remaining areas, except 59 to 100 at a comparatively small area just south of central-east.

SPT Values from 19 to 45 were observed throughout northern, central-eastern, and southern portion at 30 m depth. Values from 46 to 73 is seen in most of the remaining areas, except 74 to 134 at a comparatively small area just south of central-east.

Sherpur District

Sherpur District is bordered by Meghalaya district (India) to the north, Jamalpur and a part of Mymenshigh district to the south, Mymensingh District to the east and Jamalpur district to the west. The area of Sherpur district is 1364.67 Sq Km. The Geo position of the district is between 25˚18’24’’ to 24˚52’09’’ North latitudes and between 90˚18’26’’ to 89˚52’56’’ east longitude (Figure 6-30).

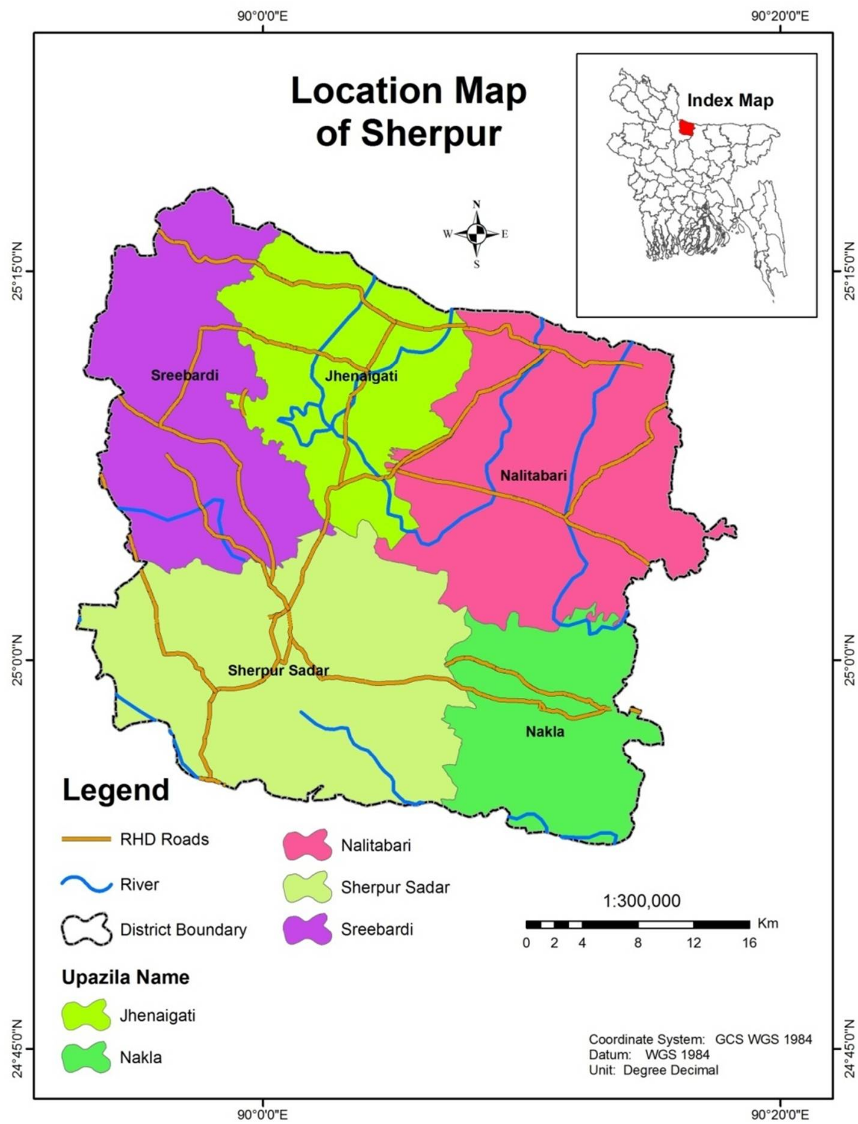


Figure 6-30 Location Map of Sherpur

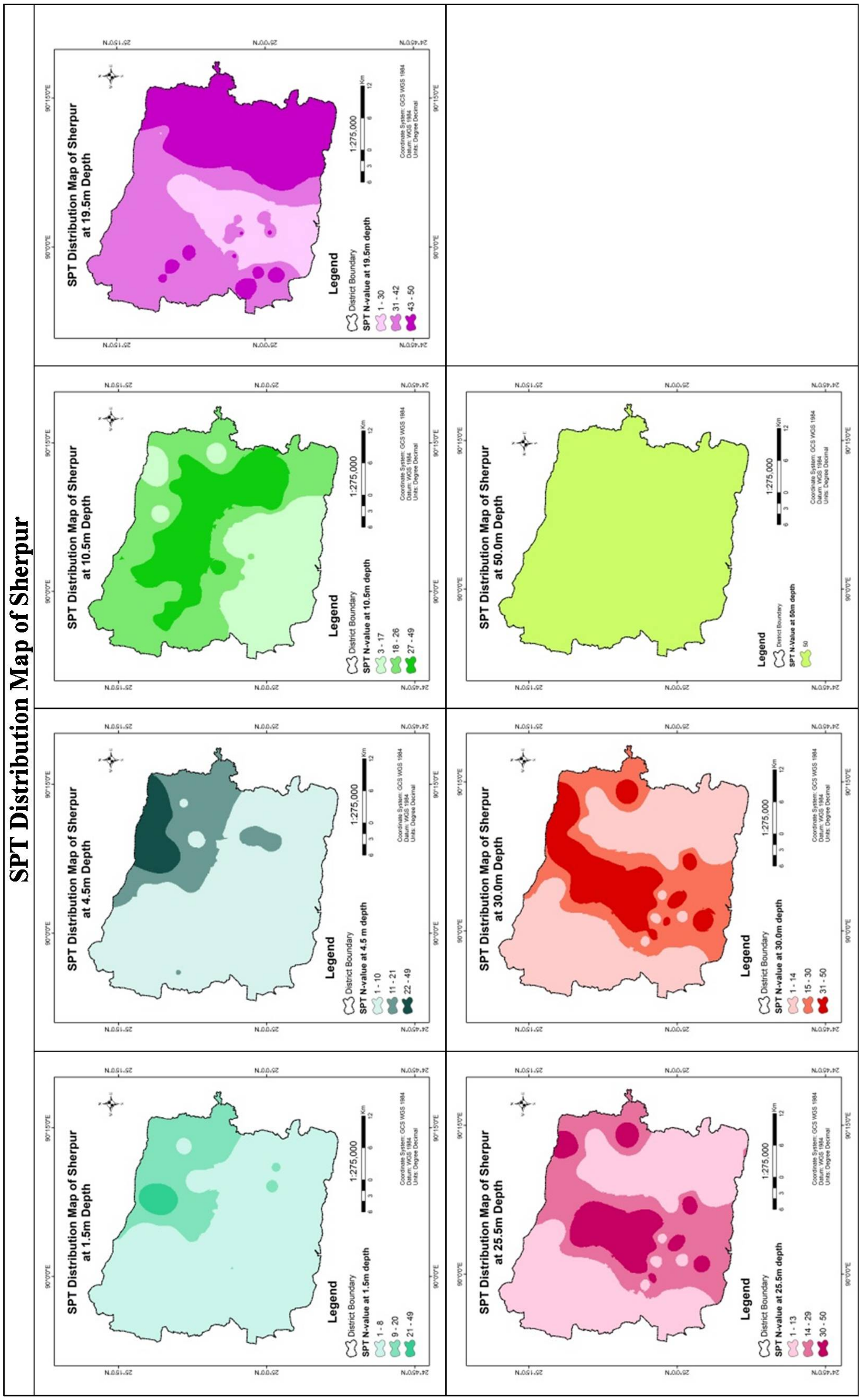


Figure 6-31 Distribution Map of Sherpur

SPT N value distribution map of Sherpur at 1.5 m depth shows that values of that from 1 to 8 prevail throughout north, west, middle and north. Values of that from 9 to 20 were obtained in most of northeast, except 21 to 49 at a small area in between towards west (Figure 6-31).

1 to 10 11 21 22 to 49 SPT N value distribution map of Sherpur at 4.5 m depth shows that values of that from 1 to 10 prevail throughout north, west, middle and north. Values of that from 11 to 21 were obtained in most of northeast, except 22 to 49 at a small area in between in northeast corner.

At 10.5 m depth SPT N values from 3 to 17 were obtained in southwest and central-south from the middle part of Sherpur. Values from 18 to 26 were found at most part of the rest of the area, except an area just north from the middle having SPT values from 27 to 49.

At 19.5 m depth SPT N values from 1 to 30 were found throughout the middle part to central-south of Sherpur. Values from 31 to 42 were obtained continually from southeast throughout centralwest, northeast and north, which further extended as a N-S trending strip from the north to the south, just east from the central part. 43 to 50 SPT N avlues were obtained theoughout the eastern portion.

At 25.5 m depth SPT values from 1 to 13 were found in east and west. 14 to 29 SPT values were observed from northeast to central-north and central-south, along the middle portion, but within this area values of that from 30 to 50 were also found at the middle of Sherpur. The later values wee also observed as discrete small localized zones.

At 30 m depth SPt values from 1 to 14 were found in east and west. Values from 15 to 30 were found in central-south, central-north, and northeast. SPT values from 31 to 50 were found from the middle to central and eastern portion of the northern part.

At 50 m depth of Sherpur, SPT N value 50 was found throughout the area.

7. GEOTECHNICAL DATA REPRESENTATION AT GOOGLE EARTH MAP

KML (Keyhole Markup Language) is an XML based file format used to display geographic data in an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile. With KML, we can display pretty much everything on a map. We can upload it to Google Maps (Google My Maps feature) and share it with everyone. But best of all, anyone can upload the file to an online host, and use the KMLs to be displayed on custom maps (i.e. on blogs, websites, etc.). This way, one can customize the maps' look & feel and its behavior to suit ones needs.

In this task, all compiled primary data have been uploaded into ArcGIS. After that, all those data saved as a shapefile and then convert to a KML file. This KML file demonstrates all information which belongs to each borehole (Figure 7-1 and 7-2). In this file, each primary borehole demonstrate every layer of the borehole as well as every borehole contain all laboratory data, Electrical Resistivity, PLAXIS data, SPT-N value, etc.

Following information are present in KML file:

Depth: Depth or Thickness of the layer

Sample Description: Description of the layer

SPT-N value: The borehole is drilled deeper and the test is repeated. Often soil recovery is poor and counting errors per interval may occur. The number of hammer strikes it takes for the tube to penetrate the second and third 6 inch depth is called the 'standard penetration resistance', or otherwise called the 'N-value'. Range of SPT-N value of each layer.

Unit weight: The specific weight (also known as the unit weight) is the weight per unit volume of a material. The symbol of specific weight is γ (the Greek letter Gamma). A commonly used value is the specific weight of water on Earth at 5°C which is 9.807 kN/m3 or 62.43 lbf/ft3. Range of the unit weight value of every layer.

Void Ratio: Void ratio is usually used in parallel with soil porosity (n) , which is defined as the ratio of the volume of voids to the total volume of the soil. KML file contains ranges of the void ratio of the layer.

Moisture Content: Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, crops, or wood.

Angle of Friction: It is the angle (φ), measured between the normal force and resultant force, that is attained when failure just occurs in response to a shearing stress. Its tangent is the coefficient of sliding friction. Its value is determined experimentally.

Specific Gravity: Specific gravity is the ratio of the density of a substance to the density of a reference substance; equivalently, it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume.

Grain size analysis: This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. Sand, Silt and Clay percentage range would be demonstrated in the KML file.

Atterberg Limit: The Atterberg limits are a basic measure of the critical water contents of a fine-grained soil: its shrinkage limit, plastic limit, and liquid limit. As a dry, clayey soil takes on increasing amounts of water, it undergoes distinct changes in behavior and consistency. Plasticity index, plastic limit, and liquid limit range show in the KML file.

Cohesion: The cohesion is a term used in describing the shear strength soils. Its definition is mainly derived from the Mohr-Coulomb failure criterion and it is used to describe the non-fractional part of the shear resistance which is independent of the normal stress. In the stress plane of Shear stress-effective normal stress, the soil cohesion is the intercept on the shear axis of the Mohr-Coulomb shear resistance line.

PLAXIS: Total Dispalsement, Effective Stress, Bending moment and Shear force range are shown.

Electrical Resistivity: Electrical resistivity (also known as resistivity, specific electrical resistance, or volume resistivity) is an intrinsic property that quantifies how strongly a given material opposes the flow of electric current. Resistivity is commonly represented by the Greek letter ρ (rho). The range of the resistance of the soil layer would be presented in the KML file.

Converting ArcGIS layers (shapefiles) to Google Earth allows others to easily see layers without specialized software. Both ArcGIS and Google Earth Pro contain tools that allow conversion to and saving in KML format.

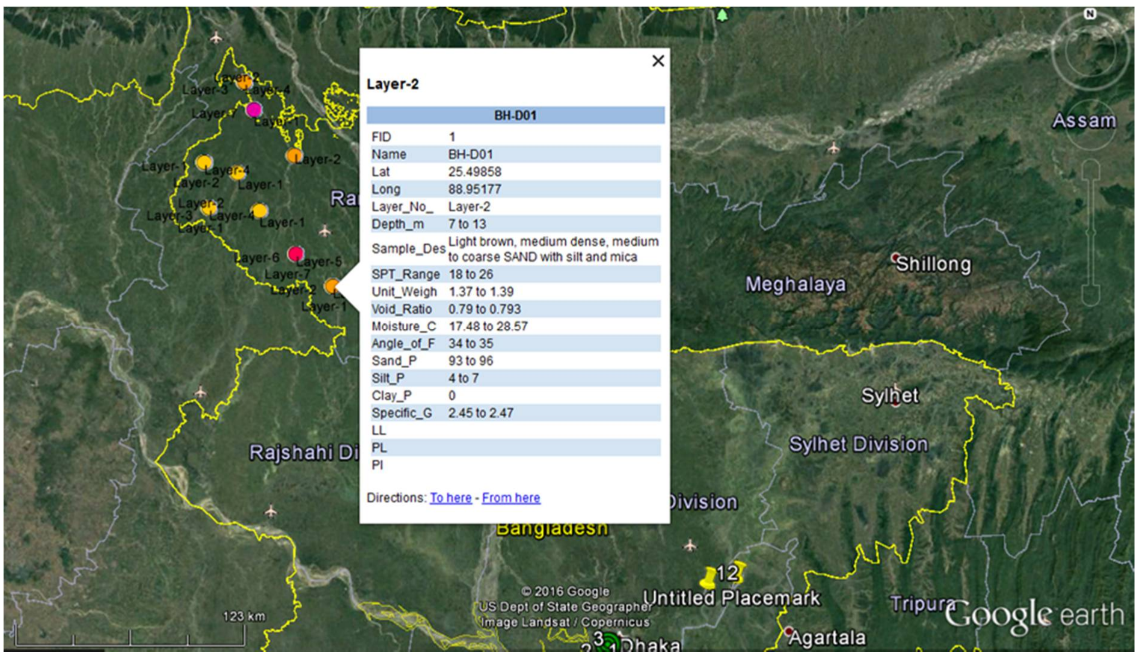


Figure 7-1 The KML file presentation 2015-2016 works (package 4)

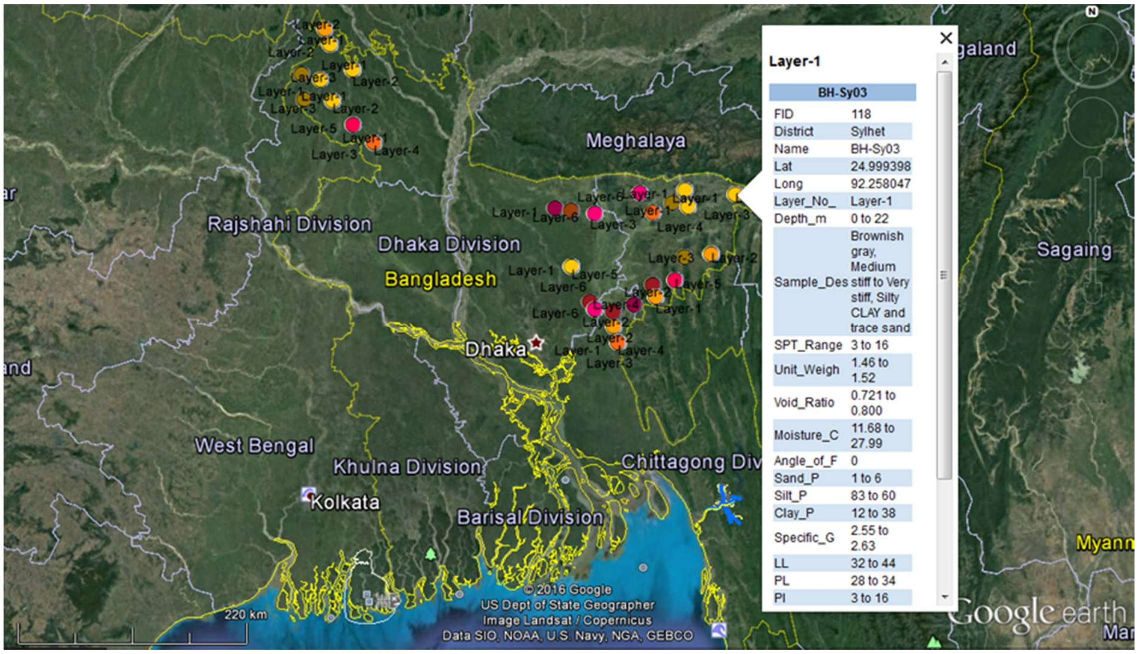


Figure 7-2 The KML file presentation 2015-2016 works (package 1)

8. CONCLUSION

Bangladesh Road Research Laboratory (BRRL) is a circle of Roads and Highway Department, and is responsible for the preparation of soil investigation reports and conducts research programs related to construction material to establish sustainable road networks in Bangladesh. Currently, BRRL is deciding to hand over a portion of its task to the eligible Individual Consultant to prepare engineering soil map of the remaining districts and compiling all the previous maps under the supervision of BRRL. Individual Consultant, Geologist cum GIS specialist, has accomplished the project work through engineering geological mapping. The collected data have been analyzed by experts, and interpreted by specialists. The project output has been delivered in technical reports. Although Individual Consultant has proven capability to conduct such project works, this particular task was quite challenging due to time constraint.

Soil mapping, the ultimate goal of this research, was aided by largely secondary data and along with few primary borehole data of most district. Primary borehole were attempted to determination of physical properties and engineering properties of the soil (2013-16). Later on, these information were compiled as KML/KMZ file for Google earth presentation for making them user friendly. This project, more specifically, attemped to complile all primary borehole's information (2013-2016), surface and sub-surface soil profiling, preparation of engineering soil map on the basis of soil resistance (N-value), identification of lowland roads in the flood prone area, delineation of roads lying on soft soil, and earthquake hazard determination.

Use of primary data is highly recommended for increasing accuracy and reliability of the outcomes. As per engineering soil mapping a number aspects should also be incorporated for delineating the complete scenario of engineering aspects of soils on which lying are existing roads, and where there will be constructed road in future. So, detailed engineering soil mapping including seismic hazard risk assessment, flood hazard vulnerability prediction, water logged area mapping, soil consolidation testing, impact of organic content evaluating, soil liquefaction potential assessment, etc.

should be done and presented as a microzonation map to enhance longevity of roads and reduce maintenance cost.

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