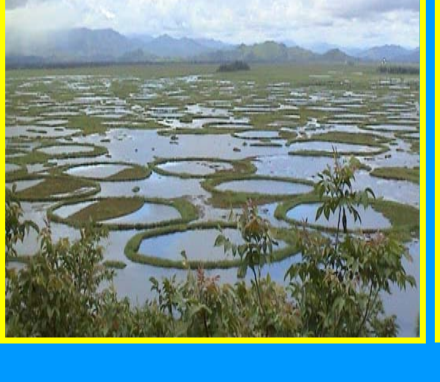
NATIONAL WETLAND ATLAS:

SIKKIM

Sponsored by

Ministry of Environment and Forests
Government of India

Space Applications centre
Indian Space Research Organisation
Ahmedabad – 380 015



This publication deals with the updated database and status of wetlands, compiled in Atlas format. Increasing concern about how our wetlands are being influenced has led to formulation of a project entitled "National Wetland Inventory and Assessment (NWIA)" to create an updated database of the wetlands of India. The wetlands are categorised under 19 classes and mapped using satellite remote sensing data from Indian Remote Sensing Satellite: IRS P6- LISS III sensor. The results are organised at 1: 50, 000 scales at district, state and topographic map sheet (Survey of India reference) level using Geographic Information System (GIS). This publication is a part of this national work and deals with the wetland status of a particular State/Union Territory of India, through text, statistical tables, satellite images, maps and ground photographs.

The atlas comprises wetland information arranged into nine sections. How the NWIA project work has been executed highlighted in the first six sections viz: Introduction, NWIA project, Study area, Data used, Methodology, and Accuracy. This is the first time that high resolution digital remote sensing data has been used to map and decipher the status of the wetlands at national scale. The methodology highlights how the four spectral bands of LISS III data (green, red, near infra red and short wave infra red) have been used to derive various indices and decipher information regarding water spread, turbidity and aquatic vegetation. Since, the aim was to generate a GIS compatible database, details of the standards of database are also highlighted in the methodology.

The results and finding are organised in three sections; viz: Maps and Statistics, Major wetland types, and Important Wetlands of the area. The Maps and Statistics are shown for state and district level. It gives details of what type of wetlands exists in the area, how many numbers in each type, their area estimates in hectare. Since, the hydrology of wetlands are influenced by monsoon performance, extent of water spread and their turbidity (qualitative) in wet and dry season (post-monsoon and pre-monsoon period) are also given. Similarly the status of aquatic vegetation (mainly floating and emergent types) in two seasons is also accounted for. Status of small wetlands are also accounted as numbers and depicted in maps as points. Wetland map also show important ancillary information like roads/rail, relevant habitations. False Colour Composite (FCC) of the satellite image used (any one season) is shown along with the derived wetland map to give a feeling of manifestation of wetlands in remote sensing data and synoptic view of the area. The status of some of the important wetlands like Ramsar sites, National Parks are shown with recent field photographs.

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As a part of the project on National Wetland Inventory and Assessment (NWIA)

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MESSAGE

It gives me great pleasure to introduce this Atlas, the latest in a series, prepared by Space Applications Centre, Ahmedabad in connection with the National Wetland Inventory and Assessment Project.

This Atlas maps and catalogues information on Wetlands across India using the latest in satellite imaging, one of the first of its kind. Wetlands are areas of land critical ecological significance that support a large variety of plant and animal species adapted to fluctuating water levels. Their identification and protection becomes very important.

Utility-wise, wetlands directly and indirectly support millions of people in providing services such as food, fiber and raw materials. They play important roles in storm and flood control, in supply of clean water, along with other educational and recreational benefits. Despite these benefits, wetlands are the first target of human interference and are among the most threatened of all natural resources. Around 50% of the earth's wetlands are estimated to already have disappeared worldwide over the last hundred years through conversion to industrial, agricultural and residential purposes. Even in current scenario, when the ecosystem services provided by wetlands are better understood - degradation and conversion of wetlands continues.

Aware of their importance, the Government of India has formulated several policies and plans for the conservation and preservation of these crucial ecosystems. Realising the need of an updated geospatial data base of these natural resources as the pre-requisite for management and conservation planning, National Wetland Inventory and Assessment (NWIA) project was formulated as a joint vision of Ministry of Environment & Forestry, Govt. India, and Space Applications Centre (ISRO). I am told that the latest remote sensing data from Indian Remote Sensing satellite (IRS P6) have been used to map the wetlands. The present atlas is part of this project and highlights the results of the study state in terms of statistics of various types of wetlands, extent of water, aquatic vegetation and turbidity in pre and post monsoon period. I also note that special efforts are made to provide detailed information of important wetlands like Ramsar sites, National Parks etc.

I am certain that this Atlas will raise the bar in developing such database and will be of great use for researchers, planners, policy makers, and also members of the general public.

(Jairam Ramesh)

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FOREWORD

Wetlands defined as areas of land that are either temporarily or permanently covered by water exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry. Wetlands are one of the most productive ecosystems and play crucial role in hydrological cycle. Utility wise, wetlands directly and indirectly support millions of people in providing services such as storm and flood control, clean water supply, food, fiber and raw materials, scenic beauty, educational and recreational benefits. The Millennium Ecosystem Assessment estimates conservatively that wetlands cover seven percent of the earth's surface and deliver 45% of the world's natural productivity and ecosystem services. However, the very existence of these unique resources is under threat due to developmental activities, and population pressure. This calls for a long term planning for preservation and conservation of these resources. An updated and accurate database that will support research and decision is the first step towards this. Use of advanced techniques like Satellite remote sensing, Geographic Information System (GIS) is now essential for accurate and timely spatial database of large areas. Space Applications Centre (ISRO) took up this challenging task under the project "NWIA" (National Wetland Inventory and Assessment) sponsored by Ministry of Environment & Forests. To account for numerous small yet important wetlands found in the country, mapping at 1:50,000 scales has been taken up. Two date IRS LISS III data acquired during pre and post monsoon season are used for inventory to account for wet and dry season hydrology of wetlands. The map outputs include the status of water spread, aquatic vegetation and turbidity. Ancillary layers like road/rail, habitations are also created. Very small wetlands below the mappable unit are also identified and shown points. The results are complied as Atlases of wetlands for states/Union Territories of India. This Atlas highlights results for a particular state/UT and hopes to improve our understanding of the dynamics and distribution of wetlands and their status in the area.

I congratulate the team for bringing out this informative atlas and sincerely hope that this will serve as a useful source of information to researchers, planners and general public.

January 25, 2010

(Ranganath R. Navalgund)

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This project has benefited from the wisdom of many people**.** It is a pleasure to acknowledge the contributions made by the wetland experts especially to Prof. C.K. Varshney, Former Dean, School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, Prof. A.R. Yousuf, The University of Kashmir, Srinagar, Prof. Pradeeep Shrivastava, Head, Wetland Research Centre, Barakatullah University, Bhopal, Dr. Prikshit Gautam, Director, WWF-India, Dr. S. Narendra Prasad, Salim Ali Centre for Ornithology and Nature, Coimbtore and Dr. R.K. Suri, Additional Director, Ministry of Environment and Forests, Govt. of India, New Delhi, and the database experts from ISRO who participated in the peer Review meeting to finalise the "Wetland Classification System" followed in this project

We acknowledge the positive role played by 16^{th} SC-B (Standing Committee on Bioresources and Environment) of NNRMS (National Natural Resources Management System) meeting in formulating this project. We are extremely thankful to the members of the"Steering Committee" of the project, under the chairmanship of Dr E J James, Director – Water Institute, Karunya University, for their periodical review, critical comments and appreciation of the efforts by the project team. We are thankful to SC-B under the chairmanship of Secretary, MoEF, for periodic review of the progress of the project and guidance towards timely completion of the work. We acknowledge the valuable contributions made by Dr J K Garg, the then scientist of SAC for his active role in formulation of this project, co-authoring the procedure manual document.

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(Sushma Panigrahy)

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1.0 INTRODUCTION

It is increasingly realised that the planet earth is facing grave environmental problems with fast depleting natural resources and threatening the very existence of most of the ecosystems. Serious concerns are voiced among scientists, planners, sociologists, politicians, and economists to conserve and preserve the natural resources of the world. One of the constraints most frequently faced for decision making is lack of scientific data of our natural resources. Often the data are sparse or unauthentic, rarely in the form of geospatial database (map), thus open to challenges. Hence, the current emphasis of every country is to have an appropriate geospatial database of natural resources based on unambiguous scientific methods. The wetland atlas of Sikkim, which is part of the National Wetland Atlas of India, is an attempt in this direction.

1.1 Wetlands

Wetlands are one of the crucial natural resources. Wetlands are areas of land that are either temporarily or permanently covered by water. This means that a wetland is neither truly aquatic nor terrestrial; it is possible that wetlands can be both at the same time depending on seasonal variability. Thus, wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, dominant plants and soil or sediment characteristics. Because of their transitional nature, the boundaries of wetlands are often difficult to define. Wetlands do, however, share a few attributes common to all forms. Of these, hydrological structure (the dynamics of water supply, throughput, storage and loss) is most fundamental to the nature of a wetland system. It is the presence of water for a significant period of time which is principally responsible for the development of a wetland. One of the first widely used classifications systems, devised by Cowardin *et al,* 1979, was associated to its hydrological, ecological and geological aspects, such as: marine (coastal wetlands including rock shores and coral reefs, estuarine (including deltas, tidal marshes, and mangrove swamps), lacustarine (lakes), riverine (along rivers and streams), palustarine ('marshy'- marshes, swamps and bogs). Given these characteristics, wetlands support a large variety of plant and animal species adapted to fluctuating water levels, making the wetlands of critical ecological significance. Utility wise, wetlands directly and indirectly support millions of people in providing services such as food, fiber and raw materials, storm and flood control, clean water supply, scenic beauty and educational and recreational benefits. The Millennium Ecosystem Assessment estimates conservatively that wetlands cover seven percent of the earth's surface and deliver 45% of the world's natural productivity and ecosystem services of which the benefits are estimated at $20 trillion a year (Source: www.MAweb.org). The Millennium Assessment (MA) uses the following typology to categorise ecosystem services:

Provisioning services:	The resources or products provided by ecosystems, such as food, raw materials (wood), genetic resources, medicinal resources, ornamental resources (skin, shells, flowers).
Regulating services:	Ecosystems maintain the essential ecological processes and life support systems, like gas and climate regulation, water supply and regulation, waste treatment, pollination, etc.
Cultural and Amenity services:	Ecosystems are a source of inspiration to human culture and education throughout recreation, cultural, artistic, spiritual and historic information, Science and education.
Supporting services:	Ecosystems provide habitat for flora and fauna in order to maintain biological and genetic diversity.

Despite these benefits, wetlands are the first target of human interference and are among the most threatened of all natural resources. Around 50% of the earth's wetland area is estimated to already have disappeared over the last hundred years through conversion to industrial, agricultural and residential developments. Even in current scenario, when the ecosystem services provided by wetlands are better understood - degradation and conversion of wetlands continues. This is largely due to the fact that the 'full value' of ecosystem functions is often ignored in policy-making, plans and corporate evaluations of development projects.

1.2 Mapping and Geospatial Technique

To conserve and manage wetland resources, it is important to have inventory of wetlands and their catchments. The ability to store and analyse the data is essential. Digital maps are very powerful tools to achieve this. Maps relate the feature to any given geographical location has a strong visual impact. Maps are thus essential for monitoring and quantifying change over time scale, assist in decision making. The technique used in the preparation of map started with ground survey. The Survey of India (SOI) topographical maps are the earliest true maps of India showing various land use/cover classes including wetlands. Recent years have seen advances in mapping technique to prepare maps with much more information. Of particular importance is the remote sensing and geographic information system (GIS) techniques. Remote sensing is now recognised as an essential tool for viewing, analyzing, characterising, and making decisions about land, water and atmospheric components.

From a general perspective, remote sensing is the science of acquiring and analyzing information about objects or phenomena from a distance (Jensen, 1986; Lillesand and Keifer, 1987). Today, satellite remote sensing can be defined as the use of satellite borne sensors to observe, measure, and record the electromagnetic radiation (EMR) reflected or emitted by the earth and its environment for subsequent analysis and extraction of information. EMR sensors includes visible light, near-, mid- and far-infrared (thermal), microwave, and long-wave radio energy. The capability of multiple sources of information is unique to remote sensing. Of specific advantage is the spectral, temporal, and spatial resolution. Spectral resolution refers to the width or range of each spectral band being recorded. Since each target affects different wavelengths of incident energy differently, they are absorbed, reflected or transmitted in different proportions. Currently, there are many land resource remote sensing satellites that have sensors operating in the green, red, near infrared and short wave Infra red regions of the electromagnetic spectrum giving a definite spectral signature of various targets due to difference in radiation absorption and reflectance of targets. These sensors are of common use for land cover studies, including wetlands**.** Figure 1 shows typical spectral signature of few targets from green to SWIR region. Converted to image, in a typical false colour composite (FCC) created using NIR, red and green bands assigned as red, green and blue colour, the features become very distinct as shown in Figure 2. In FCC, the vegetation thus appears invariably red (due to high reflection in NIR from green leaves).

Since the early 1960s, several satellites with suitable sensors have been launched into orbit to observe and monitor the earth and its environment. Most early satellite sensors acquired data for meteorological purposes. The advent of earth resources satellite sensors (those with a primary objective of mapping and monitoring land cover) occurred, when the first Landsat satellite was launched in July 1972. Currently, more than a dozen orbiting satellites of various types provide data crucial to improving our knowledge of the earth's atmosphere, oceans, ice and snow, and land. Of particular interest to India is the indigenous series of satellites called Indian Remote Sensing satellites (IRS-Series). Since the launch of the first satellite IRS 1A in 1988, India has now a number of satellites providing data in multi-spectral bands with different spatial resolution. IRS P6/RESOURCESAT 1 is the current generation satellite that provides multi-spectral images in spatial resolution of 5.8 m (LISS IV), 23.5 m (LISS III) and 56m (AWiFS). Over the past few decades, Indian remote sensing data has been successfully used in various fields of natural resources (Navalgund *et al*, 2002).

Development of technologies like Geographic Information System (GIS) has enhanced the use of RS data to obtain accurate geospatial database. GIS specialises in handling related, spatially referenced data, combining mapped information with other data and acts as analytical tool for research and decision making. During the past few decades, technological advances in the field of satellite remote sensing (RS) sensors, computerized mapping techniques, global positioning system (GPS) and geographic information system (GIS) has enhanced the ability to capture more detailed and timely information about the natural resources at various scales catering to local, regional, national and global level study.

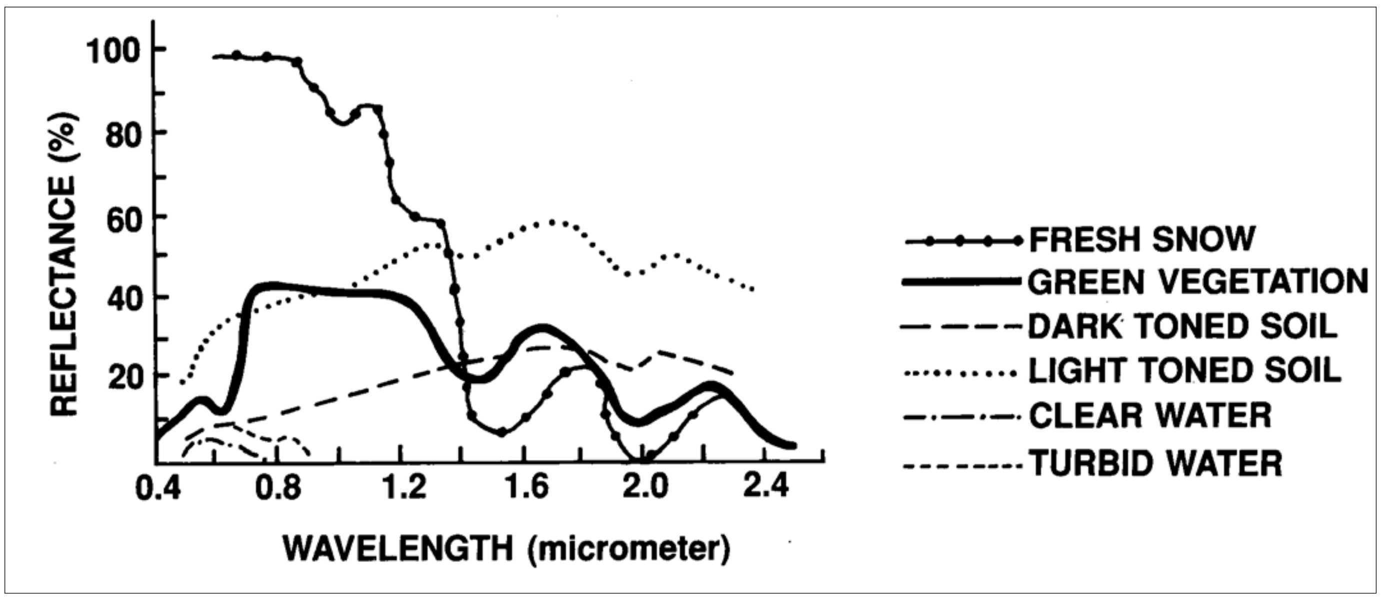
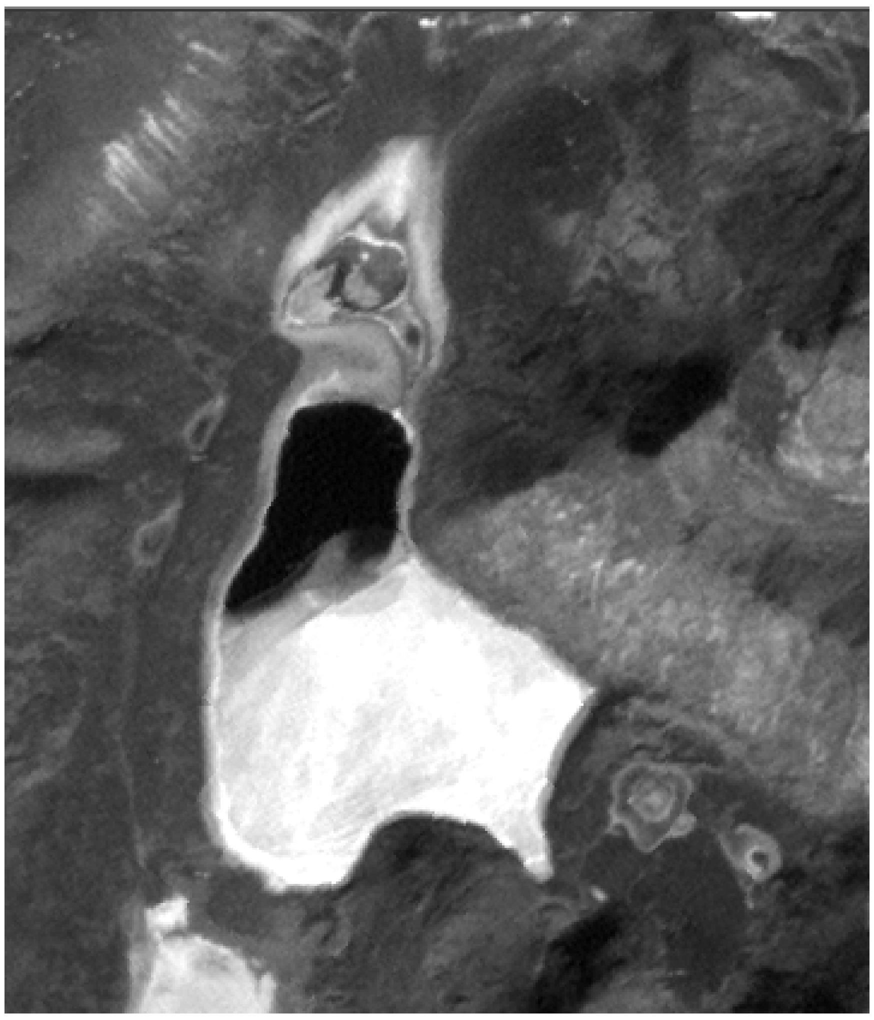


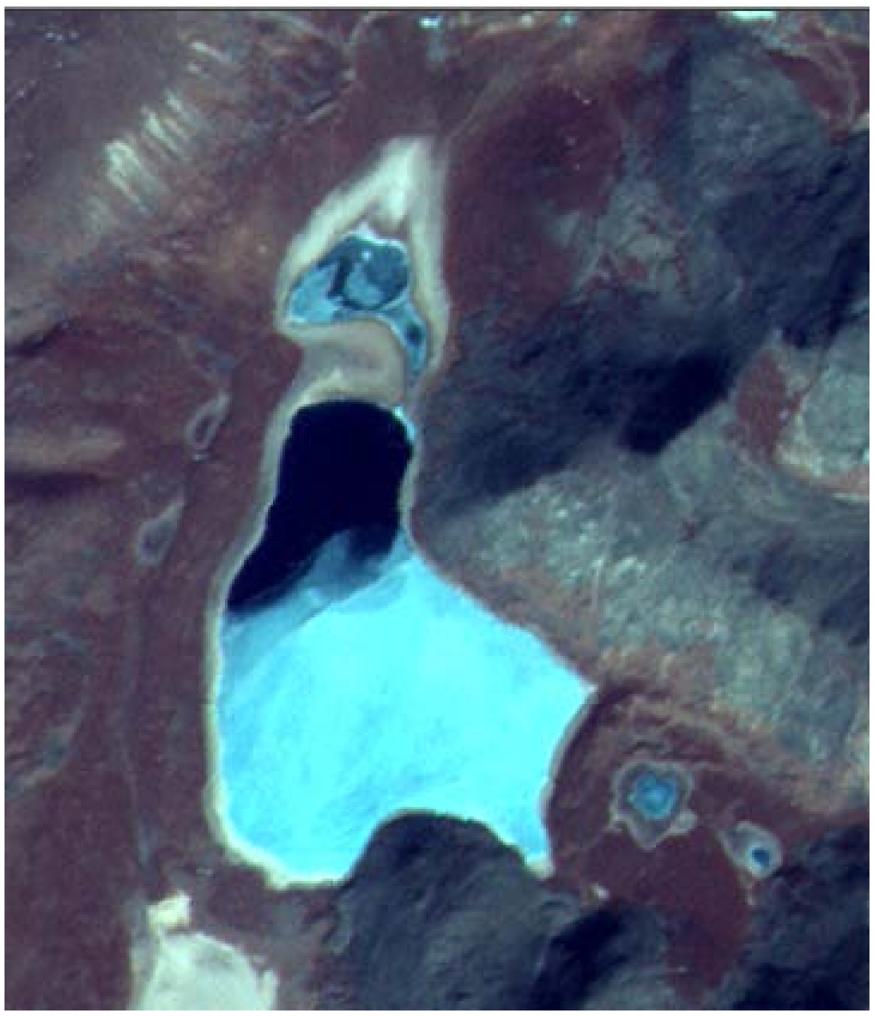
Figure 1: Spectral Signature of various targets

BAND-1: GREEN



BNAD2: RED

BAND-3: NIR



LISS-IV FCC: Green Red NIR

Figure 2: Various land features as they appear in three spectral bands and in a typical three band FCC

1.3 Wetland Inventory of India

India with its large geographical spread supports large and diverse wetland classes, some of which are unique. Wetlands, variously estimated to be occupying 1-5 per cent of geographical area of the country, support about a fifth of the known biodiversity. Like any other place in the world, there is a looming threat to the aquatic biodiversity of the Indian wetlands as they are often under a regime of unsustainable human pressures. Sustainable management of these assets therefore is highly relevant. Realising this, Govt. of India has initiated many appropriate steps in terms of policies, programmes and plans for the preservation and conservation of these ecosystems. India is a signatory to the Ramsar Convention for management of wetland, for conserving their biodiversity and wise use extending its scope to a wide variety of habitats, including rivers and lakes, coastal lagoons, mangroves, peat-lands, coral reefs, and numerous human-made wetland, such as fish and shrimp ponds, farm ponds, irrigated agricultural land, salt pans reservoirs, gravel pits, sewage farms, and canals. The Ministry of Environment and Forests has identified a number of wetlands for conservation and management under the National Wetland Conservation Programme and some financial assistance is being provided to State Governments for various conservation activities through approval of the Management Action Plans. The need to have an updated map database of wetlands that will support such actions has long been realized.

Mapping requires a standard classification system. Though there are many classification systems for wetlands in the world, the Ramsar classification system is the most preferred one. The 1971 Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat is the oldest conservation convention. It owes its name to its place of adoption in Iran. It came into being due to serious decline in populations of waterfowl (mainly ducks) and conservation of habitats of migratory waterfowl. Convention provides framework for the conservation and 'wise use' of wetland biomes. Ramsar convention is the first modern global intergovernmental treaty on conservation and wise use of natural resources (www.ramsar.org). Ramsar convention entered into force in 1975. Under the text of the Convention (Article 1.1) wetlands are defined as:

"areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters".

In addition, the Convention (Article 2.1) provides that wetlands:

"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands".

The first scientific mapping of wetlands of India was carried out during1992-93 by Space Applications Centre (ISRO), Ahmedabad, at the behest of the Ministry of Environment and Forests (MoEF), Govt. of India using remote sensing data from Indian Remote Sensing satellites (IRS-Series). The mapping was done at 1:250,000 scale using IRS 1A LISS-I/II data of 1992-93 timeframe under the Nation-wide Wetland Mapping Project. Since, no suitable wetland classification existed for comprehensive inventory of wetlands in the country at that time; the project used a classification system based on Ramsar Convention definition of wetlands. The classification considers all parts of a water mass including its ecotonal area as wetland. In addition, fish and shrimp ponds, saltpans, reservoirs, gravel pits were also included as wetlands. This inventory put the wetland extent (inland as well as coastal) at about 8.26 million ha (Garg *et al*, 1998). These estimates (24 categories) do not include rice/paddy fields, rivers, canals and irrigation channels.

Further updating of wetland maps of India was carried out by SAC using IRS P6/Resourcesat AWiFS data of 2004-05 at 1:250000 scale. In recent years, a conservation atlas has been brought out by Salim Ali Centre for Ornithology and Natural History (SACON, 2004), which provide basic information required by stakeholders in both wetland habitat and species conservation. Space Applications Centre has carried out many pilot projects for development of GIS based wetland information system (Patel *et al*, 2003) and Lake Information system (Singh *et al*, 2003).

2.0 NATIONAL WETLAND INVENTORY AND ASSESSMENT (NWIA) PROJECT

Realising the importance of many small wetlands that dot the Indian landscape, it has been unanimously felt that inventory of the wetlands at 1:50,000 scale is essential. The task seemed challenging in view of the vast geographic area of our country enriched with diverse wetland classes. Space Applications Centre with its experience in use of RS and GIS in the field of wetland studies, took up this challenging task. This is further strengthened by the fact that guidelines to create geospatial framework, codification scheme, data base structure etc. for natural resources survey has already been well established by the initiative of ISRO under various national level mapping projects. With this strength, the National Wetland Inventory and Assessment (NWIA) project was formulated by SAC, which was approved and funded by MoEF.
The main objectives of the project are:

- To map the wetlands on 1:50000 scale using two date (pre and post monsoon) IRS LISS III digital data following a standard wetland classification system. (Sikkim state was mapped on 1:25,000 scale using IRS LISS-IV and LISS-III data)
- Integration of ancillary theme layers (road, rail, settlements, drainage, administrative boundaries)
- Creation of a seamless database of the states and country in GIS environment.
- Preparation of State-wise wetland atlases.

The project was initiated during 2007. The first task was to have a classification system that can be used by different types of users while amenable to database. An expert/peer group was formed and the peer review was held at SAC on June 2007 where wetland experts and database experts participated and finalized the classification system. It was agreed to follow the classification system that has been used for the earlier project of 1:250,000 scale, with slight modification. Modified National Wetland Classification system for wetland delineation and mapping comprise 19 wetland classes which are organized under a Level III hierarchical system. The definition of each wetland class and its interpretation method was finalized. The technical/procedure manual was prepared as the standard guideline for the project execution across the country (Garg and Patel, 2007). The present atlas is part of the national level data base and deals with the state of Sikkim.

2.1 Wetland Classification System

In the present project, Modified National Wetland Classification system is used for wetland delineation and mapping comprising 19 wetland classes which are organized under a Level III hierarchical system (Table 1). Level one has two classes: inland and coastal, these are further bifurcated into two categories as: natural and man-made under which the 19 wetland classes are suitably placed. Two-date data pertaining to pre-monsoon and post-monsoon was used to confirm the classes. Wetlands put to agriculture use in any of the two dates are not included as wetland class. Definitions of wetland categories used in the project is given in Annexure-I.

2.2 Spatial Framework and GIS Database

The National Spatial Framework (NSF) has been used as the spatial framework to create the database (Anon. 2005a). The database design and creation standard suggested by NRDB/NNRMS guidelines is followed. Feature codification scheme for every input element has been worked out keeping in view the nationwide administrative as well as natural hierarchy (State-district- within the feature class for each of the theme. All data elements are given a unique name, which are self explanatory with short forms.

Following wetland layers are generated for each inland wetland:

- Wetland extent: As wetlands encompass open water, aquatic vegetation (submerged, floating and emergent), the wetland boundary should ideally include all these. Satellite image gives a clear signature of the wetland extent from the imprint of water spread over the years.

- Water spread: There are two layers representing post-monsoon and pre-monsoon water spread during the year of data acquisition.

- Aquatic vegetation spread: The presence of vegetation in wetlands provides information about its trophic condition. As is known, aquatic vegetation is of four types, viz. benthic, submerged, floating and emergent. It is possible to delineate last two types of vegetation using optical remote sensing data. A qualitative layer pertaining to presence of vegetation is generated for each season (as manifested on pre-monsoon and post-monsoon imagery).

- Turbidity of open water: A layer pertaining to a qualitative turbidity rating is generated. Three qualitative turbidity ratings (low, medium and high) is followed for pre- and post-monsoon turbidity of lakes, reservoirs, barrages and other large wetlands.

- Small wetlands (smaller than minimum mappable unit: < 0.50 ha) are mapped as point features.

- Base layers like major road network, railway, settlements, and surface drainage are created (either from the current image or taken from other project data base).

Table 1: Wetland Classification System and coding

Wettcode*	Level I	Level II	Level III
1000	Inland Wetlands		
1100		Natural	
1101			Lakes
1102			Ox-Bow Lakes/ Cut-Off Meanders
1103			High altitude Wetlands
1104			Riverine Wetlands
1105			Waterlogged
1106			River/stream
1200		Man-made	
1201			Reservoirs/ Barrages
1202			Tanks/Ponds
1203			Waterlogged
1204			Salt pans
2000	Coastal Wetlands		
2100		Natural	
2101			Lagoons
2102			Creeks
2103			Sand/Beach
2104			Intertidal mud flats
2105			Salt Marsh
2106			Mangroves
2107			Coral Reefs
2200		Man-made	
2201			Salt pans
2202			Aquaculture ponds

* Wetland type code

3.0 STUDY AREA

The Himalayan state of Sikkim is surely one of the mystic places on earth. The rugged terrain, pristine rivers, eye-soothing lakes, majestic mountains and rich cultural heritage makes it a paradise, yet to be explored. Physiographically it has a dynamic variety in its altitude ranging from one of the highest places on earth to as low as 240 m above MSL (mean sea level). On May 16th , 1975 Sikkim officially became the 22nd state of the Indian Union. Sikkim is situated in the North Eastern region of India. The state borders Nepal in the west, China to the north and the east and Bhutan in the southeast. The Indian state of West Bengal borders Sikkim to its south. It lies between 27°04'46'' N to 28°07'48''N latitude and 88°00'58'' to 88°55'25''E longitude (Figure 3). The total geographical area of the state is 7,096 km^2 occupying an area of 0.67% of the total geographical area of the country. It is the second smallest state after Goa.

3.1 Physiography and Surface Drainage

On the basis of geographical features, the state is divided into four physiographical units; i) Lower hills, ii) Upper hills, iii) Alpine zones, and iv) Snow land

Among the four districts, North district is covered mainly by snow covered mountains, having the least population. World's 3rd highest mountain, Mount Khangchendzonga, (8598 m) gives a standing guard to this tiny though majestic state of Sikkim which has only 7096 sq. km area. Sikkim is a place of both religious beliefs and practices on the one hand, and environmental restoration and conservation on the other.

Sikkim has a very rugged and formidable topography and flat lands. The towering mountains that define this paradise of nature also create a barrier to efficient agriculture. These mountains fall directly in the path of the monsoon clouds making the state one of the wettest in the country. Most of the peaks above 6100 m lie towards the western border of Sikkim. The main mountains other than Khangchendzonga are Kabru, Siniolchu, Pandim, Rathong, Kokthang, Talung, Kanglakhang, Simvo and Jonsang. The central Sikkim traversed by another mountain ridge in the north to south direction. This mountain ridge separates the Tista and Rangit valley, and ends at the confluence of these two rivers. The gnarled topography tends, to smoothen out in the upper reaches of the Tista River in the Lachen valley where the Tibetian Plateau juts into Sikkim. The state of Sikkim also shelters many Glaciers (slow moving river of ice), mainly Zemu Glacier, Rathong Glacier and Lhonak Glacier. The status of these Glaciers has become a measuring stick of climate change. The mountain ranges are interspersed with passes which can be used to cross from one side to another. The important passes in east district are Nathula, Jelepla, Bhutan la and Chola. The western part of the state has Chiwabhanjang and Kangla. In the North district of Sikkim, Chorten Nyimala, Kongra-la, Lungnala and Donkiala are important pass.

Along with the mountains, Glaciers and passes, the state of Sikkim also have many lakes though not of very large size. These lakes are both spring fed as well as river fed. The premier lakes of the state are Changu (Tsomgo), Khechodpalri, Gurudongmar, Cholamu, Memencho, Lampokhari, Samiti etc. These lakes also form the source of many rivers. The main river of Sikkim is Tista which originates from Lake Cholamu. Its main tributary is Rangit which originates from Rathong Glacier and meets Tista at the border between Sikkim and West Bengal. The river Ramam a tributary of Rangit, a part of Rangit itself and Rangpoo chu, a tributary of Tista define the southern border between Sikkim and West Bengal. The other smaller tributaries of the Tista River are Zemu chu, Lonak chu, Lachung chu, Talung chu and Bakcha chu. The state of Sikkim has many hot-springs known for their medicinal and therapeutic value. The most important are the ones located at Phurchachu (Reshi), Yumthang, Borang, Ralang, Taram-chu and Yumey Samdung. All these hot-springs have high sulphur content and are located near the river banks.

3.2 Geology

Geologically, Sikkim state belongs to the young folded mountains of the Himalayan system. Half-schistose, gneissose and Precambrian are the three major rock constituents of the geology of Sikkim. Precambrian rock is found in a big part of the state of Sikkim and hence is a significant part of Sikkim geology. The region taken up by this rock has a relatively smaller age than the hilly regions of the state. The Precambrian rock is made up of schists and phyllites. The presence of schists and phyllites makes the slopes of the region prone to erosion and weathering. The possibility of erosion of soil and the reduction of mineral content is increased by excessive rainfall. Such geology is susceptible to natural disasters like landslides. The hilly regions of Sikkim mainly constitutes of two kinds of rocks - half-schistose and gneissose. These two kinds of rocks form crucial constituents of the geology in Sikkim. The kind of soil prevalent in the north-eastern state of Sikkim is suitable for deciduous and evergreen forests.

The soil does not have a high content of organic matter and is not rich in minerals. The texture of this soil is coarse. The presence of these two kinds of rocks has turned the soil of these regions brown and clayey.

Numerous snow-fed streams in Sikkim have carved out river valleys in the west and south of the state. These streams combine into the Teesta and its tributary, the Rangeet. These are the two main drainage basins. The Teista, described as the "lifeline of Sikkim", flows through the state from north to south.

Sikkim is covered by nineteen 1:50,000 scale SOI topographical maps and sixty 1:25,000 scale maps that form the spatial frame work for mapping (Figure 4).

A detail of district information followed in the atlas is given in Annexure-II.

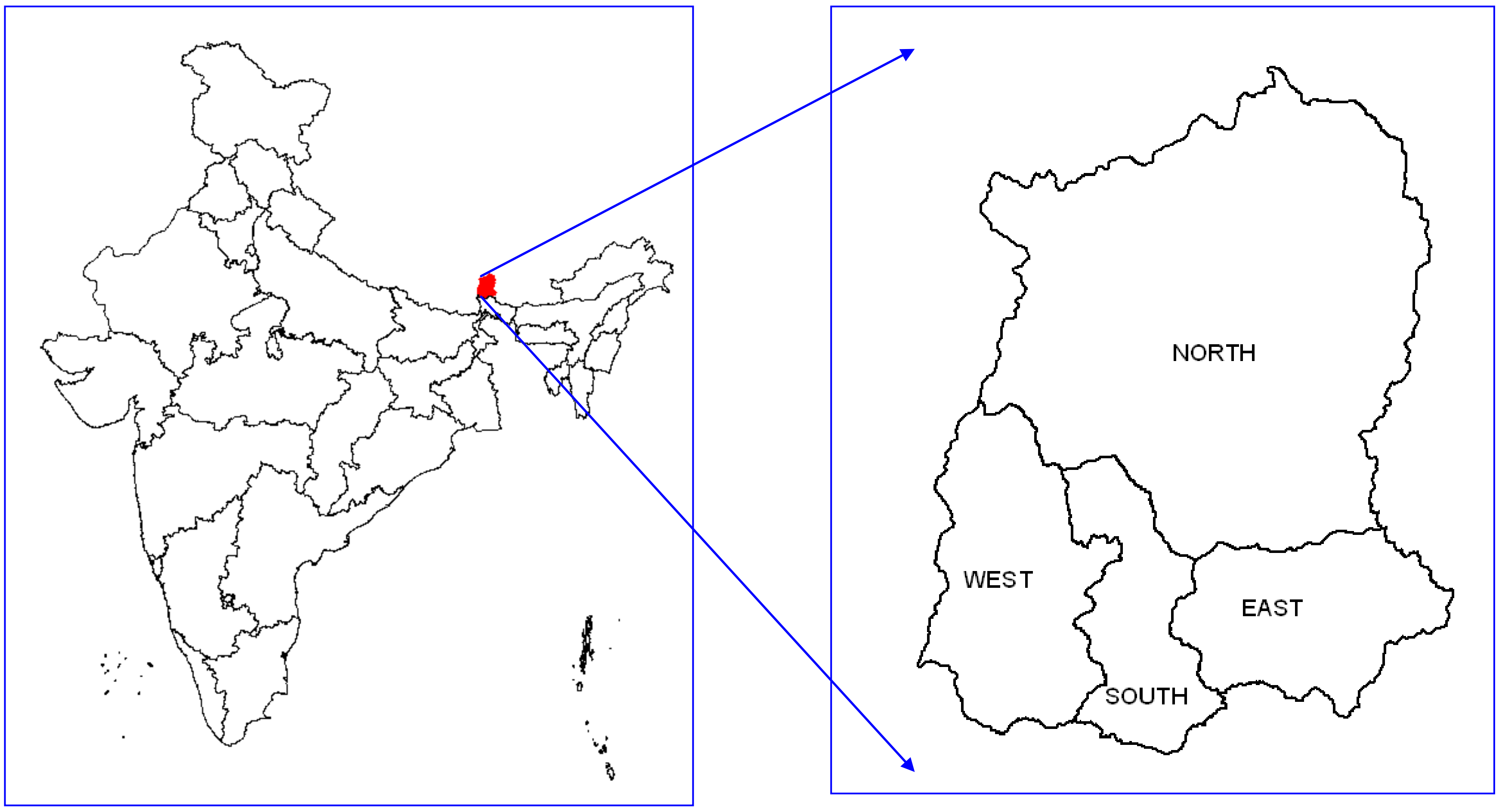


Figure 3: Location map

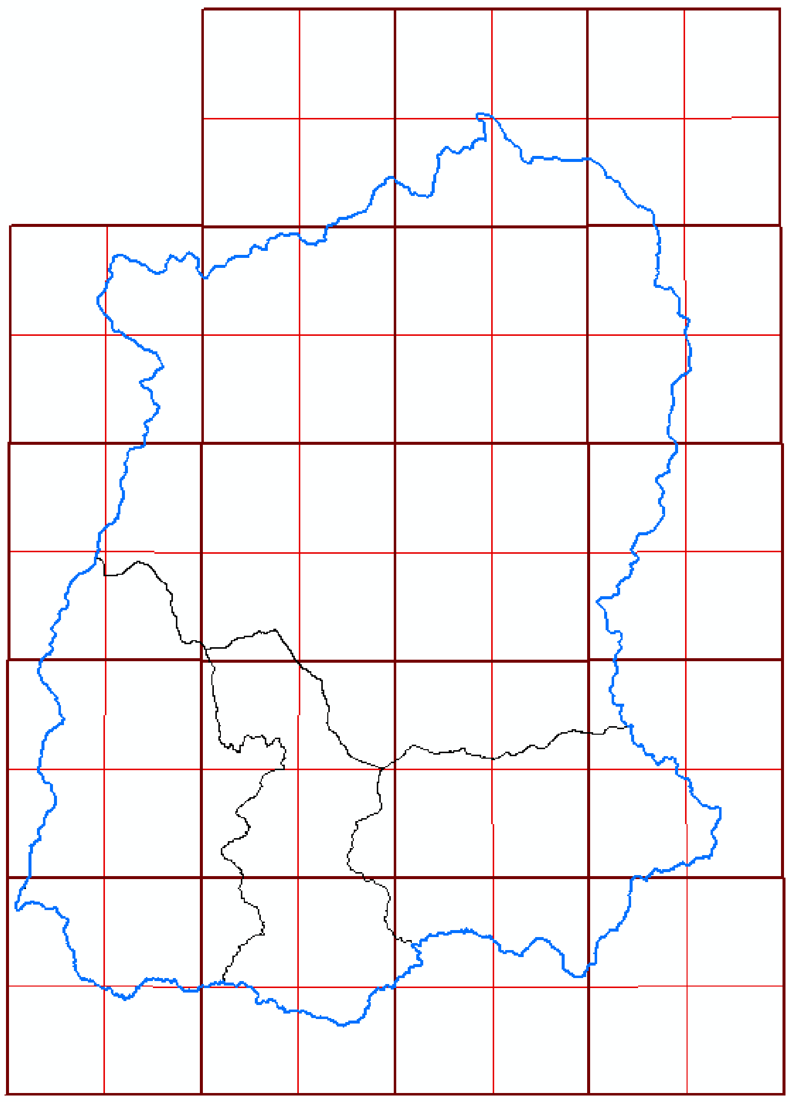


Figure 4: Spatial framework of Sikkim

3.3 Climate

The climate ranges from sub-tropical in the south to tundra in the northern parts. The tundra-type region in the north is clad by snow for four months a year though the temperature drops below 0 °C (32 °F) almost every night. Most of the inhabited regions of Sikkim, however, witness a temperate climate, with the temperatures seldom exceeding 28 °C (82.4 °F) in summer or dropping below 0 °C (32 °F) in winter. The mean monthly temperature in summer is 15 °C. The average annual temperature for most of Sikkim is around18 °C (64.4 °F). The record for the longest period of continuous rain is 11 days. In the northern region, because of high altitude, temperatures drop below −40 °C (−40 °F) in winter. The maximum rainfall of the state is recorded in the month of July and August. During the monsoon, heavy rains that increase the possibility of landslides.

3.4 Important wetlands

Along with the mountains, Glaciers and passes, the state of Sikkim also have many lakes though not in very large size. The lakes are both spring fed as well as river fed. The premier lakes of the state are Changu (Tsomgo), Khechodpalri, Gurudongmar, Cholamu, Memencho, Lampokhari, Samiti etc. The Tsomgo lake covering and area of 24.47 ha is one of the important tourist sites in the state .The lake is about 15 m deep and is a home for brahiminy ducks. These ecosystems are ideal habitat for Red Panda, Rhododendrons and various species of birds. To, preserve such biosphere the Kanchenjunga National Park and reserve has been established in 1977.

4.0 DATA USED

4.1 Remote sensing data

IRS P6 LISS IV and LISS III data have been used to map the wetlands. The spatial resolution of LISS-IV data is suitable for 1:25,000 scale mapping. The state of Sikkim is covered in 2 IRS LISS III scene (Figure 5). Two date data, were used to capture the pre-monsoon and post-monsoon hydrological variability of the wetlands respectively (Table-2). Figure 6 shows the overview of the part of Sikkim as seen in the LISS IV FCC of post-monsoon pre-monsoon data respectively.

Table-2: Satellite data used

Sr. No.	Path-Raw	orbit	Date of Acquisition
LISS-IV			
1	101-052	021924	07-January-2008
2	101-053	021924	07-January-2008
3	101-054	021924	07-January-2008
4	101-055	021924	07-January-2008
5	101-057	022393	09-February-2008
6	101-060	022393	09-February-2008
7	102-006	022663	28-February-2008
8	102-022	026073	25-October-2008
9	102-023	026073	25-October-2008
10	102-033	028801	05-May-2009
11	102-038	031529	13-November-2009
12	102-038	031188	20-October-2009
13	102-039	031529	13-November-2009
14	102-039	031600	18-November-2009
15	102-040	026826	17-December-2008
16	102-040	031600	18-November-2009
17	102-041	026826	17-December-2008
18	102-042	026826	17-December-2008
19	102-043	030918	01-October-2009
20	102-043	026826	17-December-2008
21	102-045	031941	12-December-2009
22	102-046	031941	12-December-2009
23	102-049	031870	07-December-2009
24	102-050	031870	07-December-2009
25	102-051	031259	25-October-2009
26	102-052	031259	25-October-2009
27	102-053	031259	25-October-2009
28	102-055	027167	10-January-2009
LISS-III			
	107-51		Nov 15, 2005, Jan 26, 2006, and Apr 13, 2005
	107-52		Nov 15, 2005, Jan 26, 2006, and Apr 13, 2005

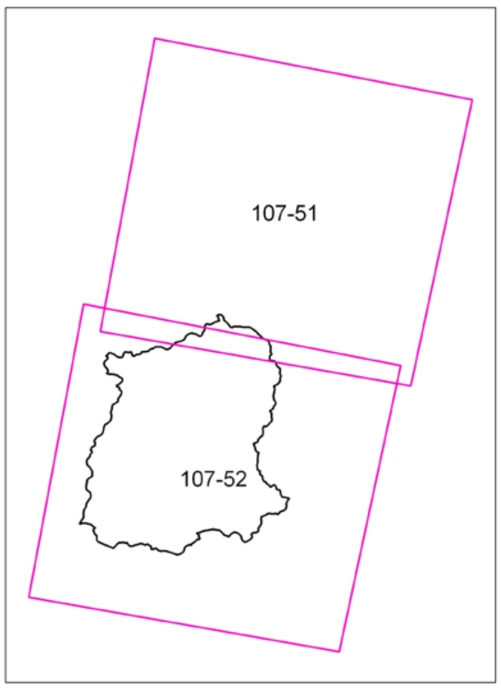


Figure 5: IRS P6 LISS-III coverage of Sikkim

4.2 Ground truth data

Remote sensing techniques require certain amount of field observation called "ground truth" in order to convert into meaningful information. Such work involves visiting a number of test sites, usually taking the satellite images. The location of the features is recorded using the GPS. The standard proforma as per the NWIA manual was used to record the field data. Field photographs are also taken to record the water quality (subjective), status of aquatic vegetation and water spread. All field verification work has been done during October and November 2008.

4.3 Other data

Survey of India topographical maps (SOI) were used for reference purpose. Lineage data of National Wetland Maps at 1:250,000 scale was used for reference.

5.0 METHODOLOGY

The methodology to create the state level atlas of wetlands is adhered to NWIA technical guidelines and procedure manual (Garg and Patel, 2007). The overview of the steps used is shown in Figure 7. Salient features of methodology adopted are

- Generation of spatial framework in GIS environment for database creation and organisation.
- Geo-referencing of satellite data
- Identification of wetland classes as per the classification system given in NWIA Manual and mapping of the classes using a knowledge based digital classification and onscreen interpretation
- Generation of base layers (rail, road network, settlements, drainage, administrative boundaries) from satellite image and ancillary data.
- Mosaicing/edge matching to create district and state level database.
- Coding of the wetlands following the standard classification system and codification as per NWIA manual.
- Preparation of map compositions and generation of statistics
- Outputs on A3 size prints and charts for atlas.

Work was carried out using ERDAS Imagine, Arc/Info and Arcgis softwares.

5.1 Creation of Spatial Framework

This is the most important task as the state forms a part of the national frame work and covered in multiple map sheets. To create NWIA database, NNRMS/NRDB standards is followed and four corners of the 1:50,000 (15' x 15') grid is taken as the tics or registration points to create each map taking master grid as the reference. Spatial framework details are given in NWIA manual (Patel and Garg, 2007). The spatial framework for Sikkim state is shown in Figure 4.

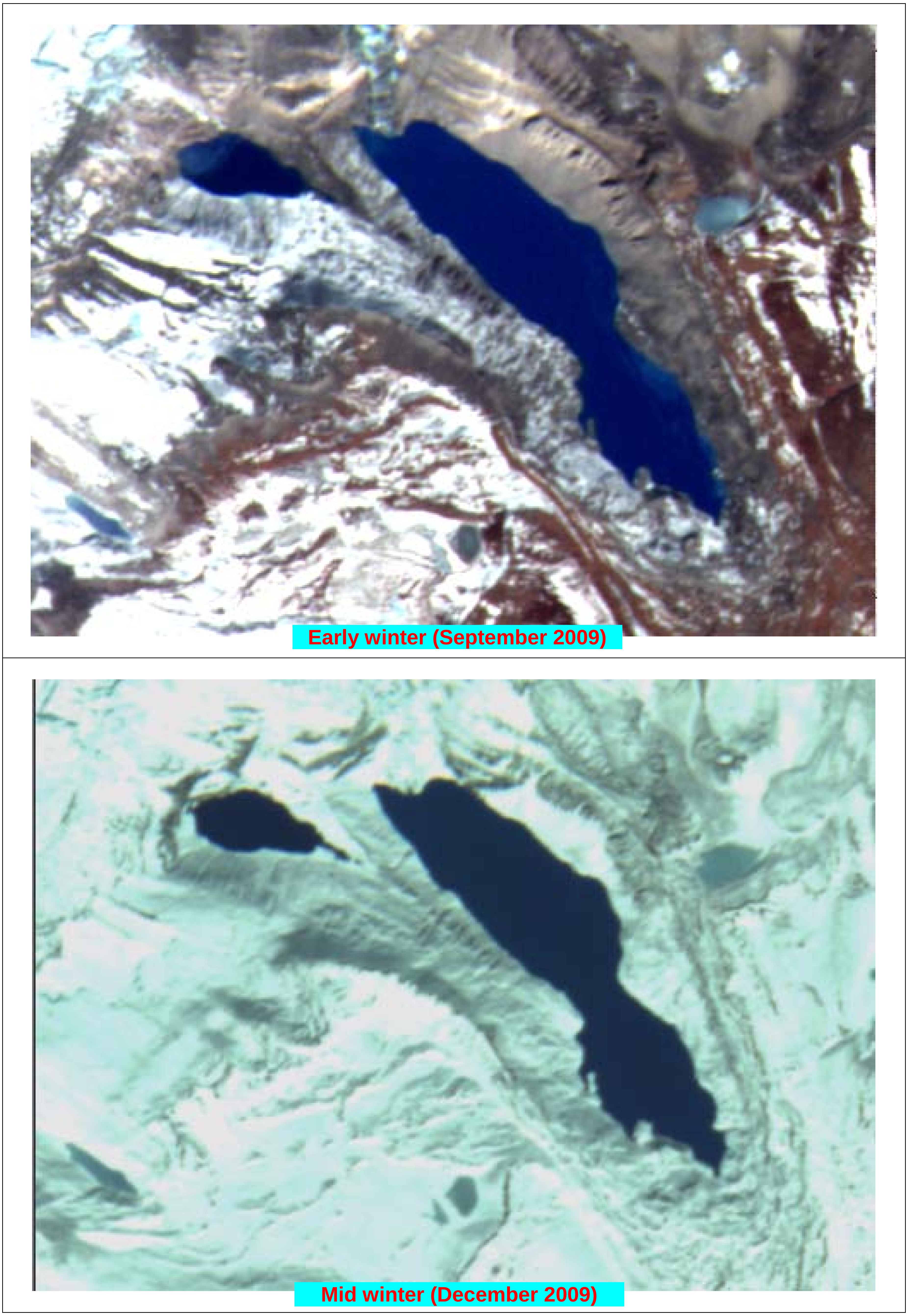


Figure 6: IRS LISS-IV FCC (Early winter and midwinter), Part of Sikkim state

5.2 Geo-referencing of Satellite Data

In this step the raw satellite images were converted to specific map projection using geometric correction. This is done using archive geometrically corrected LISS III data (ISRO-NRC-land use / land cover project). Standard image processing software was used for geo-referencing. First one date data was registered with the archive image. The second date data was then registered with the first date data.

5.3 Mapping of Wetlands

The delineation of wetlands through image analysis forms the foundation for deriving all wetland classes and results. Consequently, a great deal of emphasis has been placed on the quality of the image Interpretation. In the present study, the mapping of wetlands was done following digital classification and onscreen visual interpretation. Wetlands were identified based on vegetation, visible hydrology and geography. There are various methods for extraction of water information from remote sensing imagery, which according to the number of bands used, are generally divided into two categories, i.e. Single-band and multi-band methods. Single-band method usually involves choosing a band from multi-spectral image to distinguish water from land by subjective threshold values. It may lead to over- or under-estimation of open water area. Multi-band method takes advantage of reflective differences of each band.

In this project, five indices known in literature that enhances various wetland characteristics were used except NDPI and MNDWI due to lack of SWIR/MIR band in LISS-IV (McFeetres, 1986; Xu Hanqiu, 2006; Lacaux *et al*, 2007; Townshend and Justice, 1986; Tucker and Sellers, 1986) as given below:

i) Normalised Difference Water Index (NDWI) = (Green-NIR) / (Green + NIR)

ii) Modified Normalised Difference Water Index (MNDWI) = (Green-MIR) / (Green + MIR)

iii) Normalised Difference Vegetation Index (NDVI) = (NIR - Red) / (NIR + Red)

iv) Normalised Difference Pond Index (NDPI) = (MIR – Green / MIR + Green)

v) Normalised Difference Turbidity Index (NDTI) = (Red – Green) / (Red + Green)

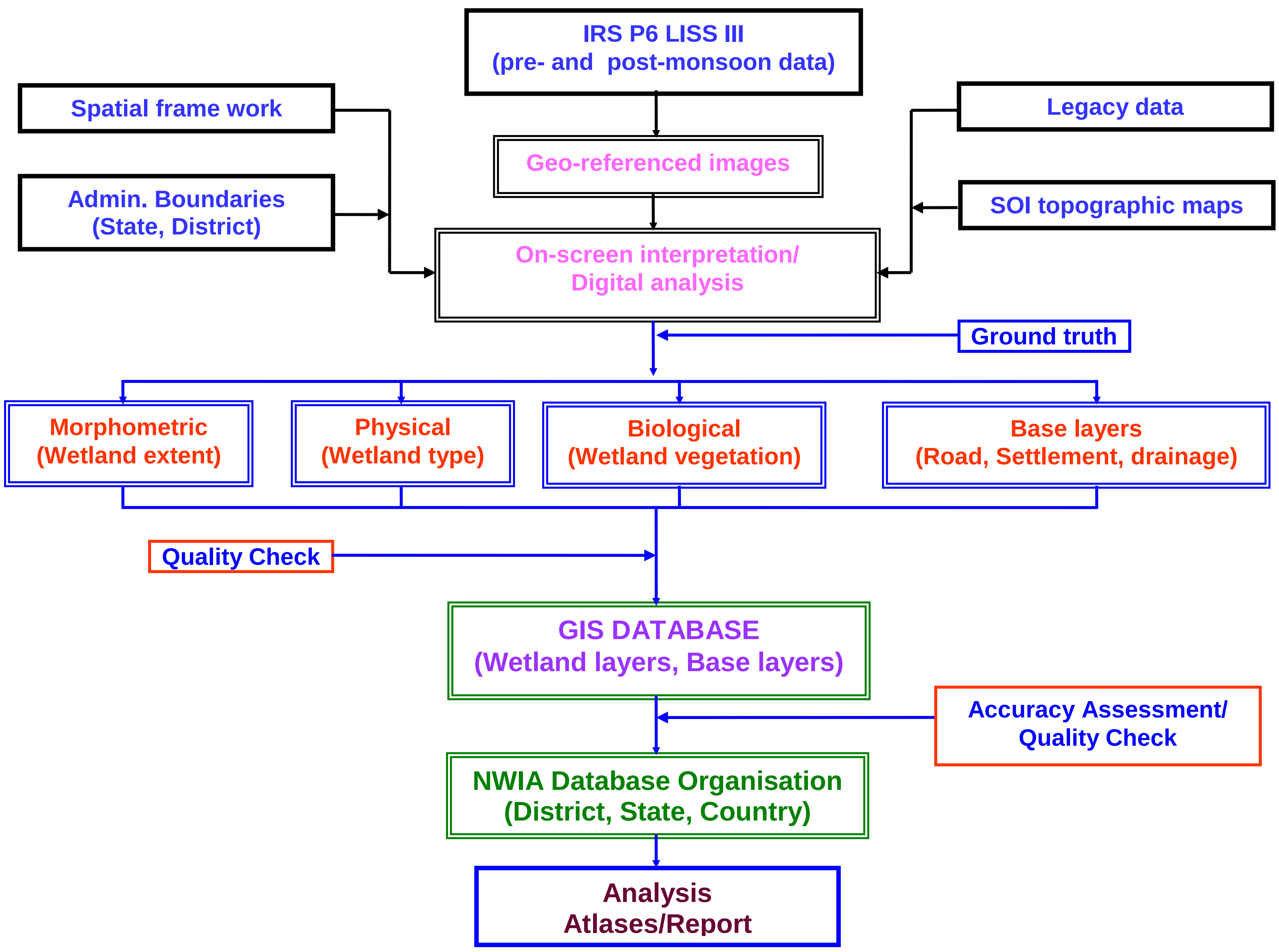


Figure 7: Flow chart of the methodology used

The indices were generated using standard image processing software, stacked as layers (Figure 8). Various combinations of the indices/spectral bands were used to identify the wetland features as shown in Figure 9. The following indices were used for various layer extractions:

- Extraction of wetland extent :
  NDWI, NDVI and NDTI image was used to extract the wetland boundary through suitable hierarchical thresholds.

- Extraction of open water :
  NDWI was used with in the wetland mask to delineate the water and no-water areas.

- Extraction of wetland vegetation :
  NDVI image was used to generate the vegetation and no-vegetation areas within a wetland using a suitable threshold.

- Turbidity information extraction :
  NDWI image was used to generate qualitative turbidity level (high, moderate and low) based on following steps:

  a) Conversion of post and pre-monsoon water spread polygons into Area of Interest (AoI).
  b) Grouping of all AoIs excluding all non-wetland areas into a single entity.
  c) Generate a signature statistics like minimum, maximum, mean and standard deviations.
  d) Generate a raster turbidity image through a model for AoI only with conditional categorisation.
  e) Convert the raster into vector and update the attributes or edit the water spread layer (copied as turbidity layer) in polygon mode so as to retain all the attributes.
  f) Assign turbidity classes as per the Table 3.

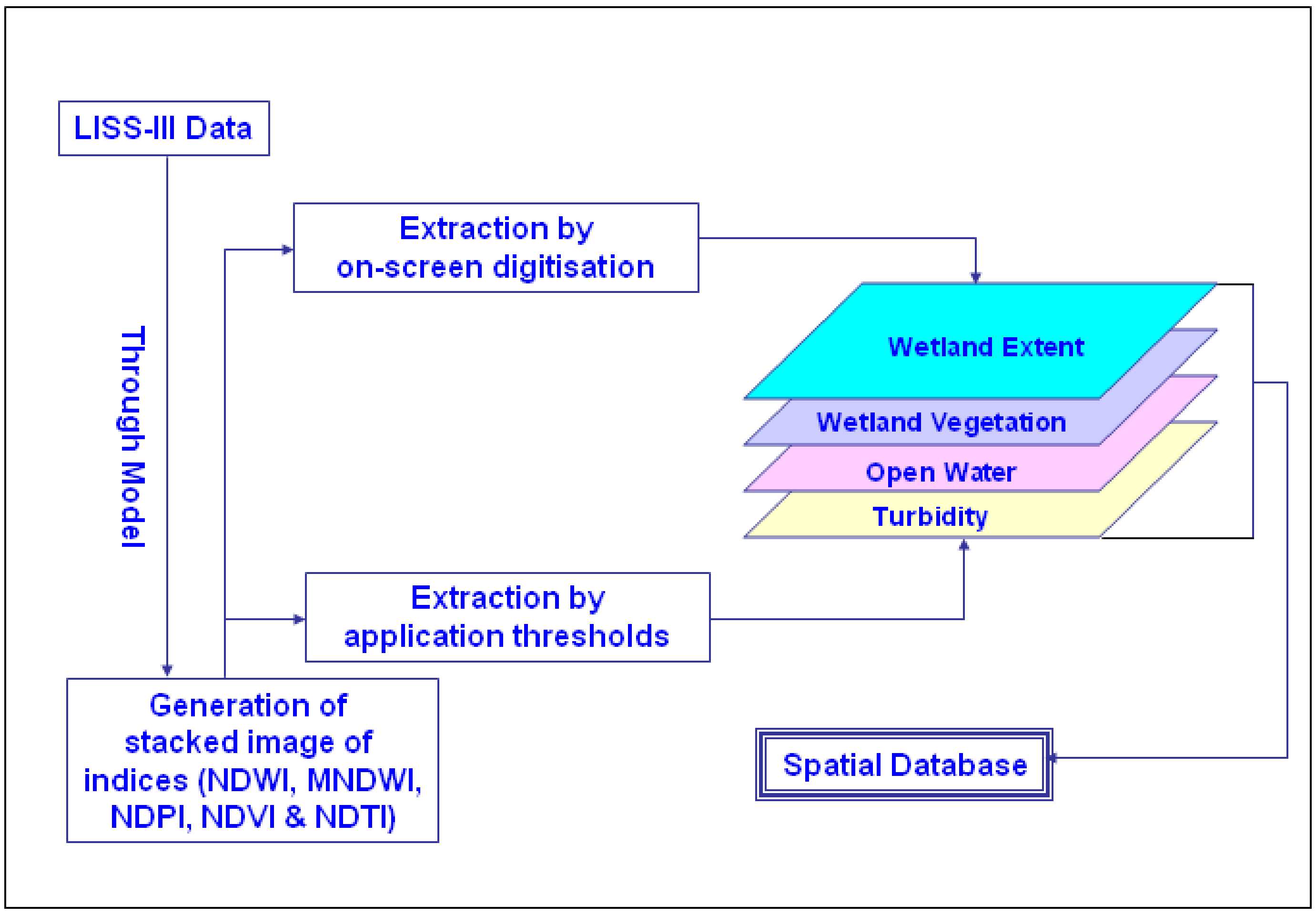
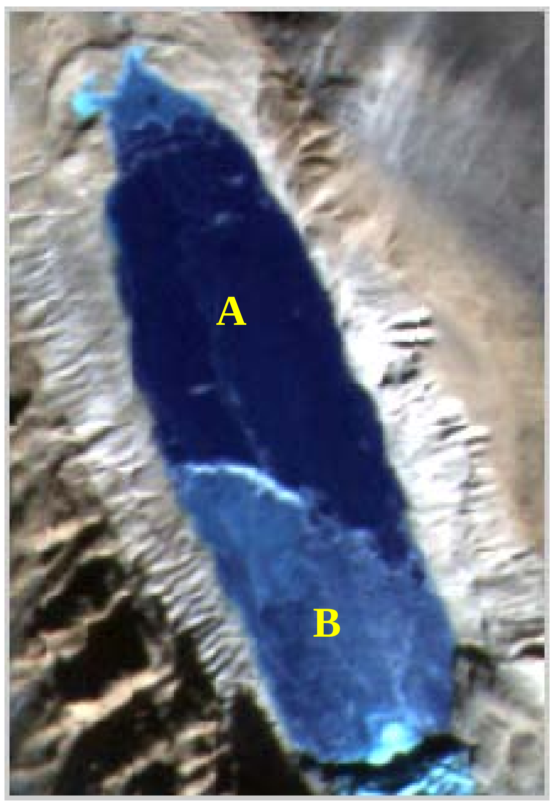


Figure 8: Steps in the extraction of wetland components

Table 3: Qualitative turbidity based on Mean and Standard deviation observed in the NDWI image

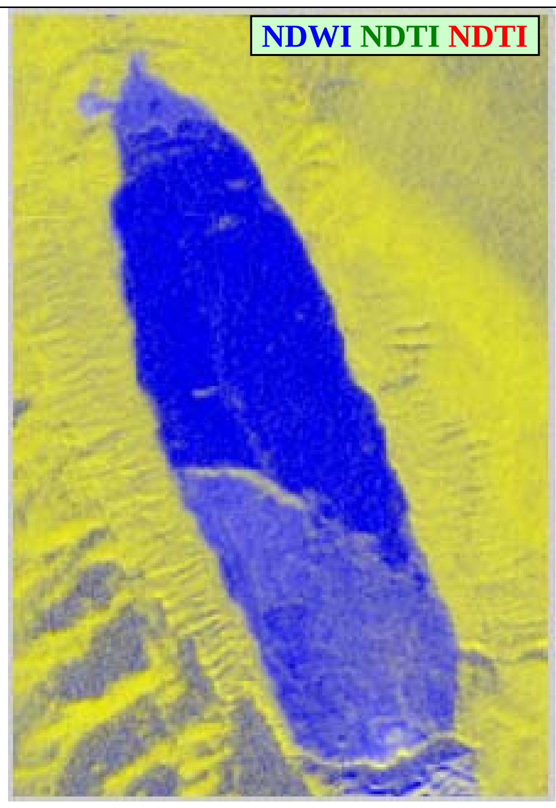
Sr. No.	Conditional criteria	Qualitative Turbidity
1.	$\le \mu - 1\sigma$	High/Bottom reflectance
2.	$> -1\sigma$ to $\le +1\sigma$	Moderate/Bottom reflectance
3.	$> +1\sigma$	Low



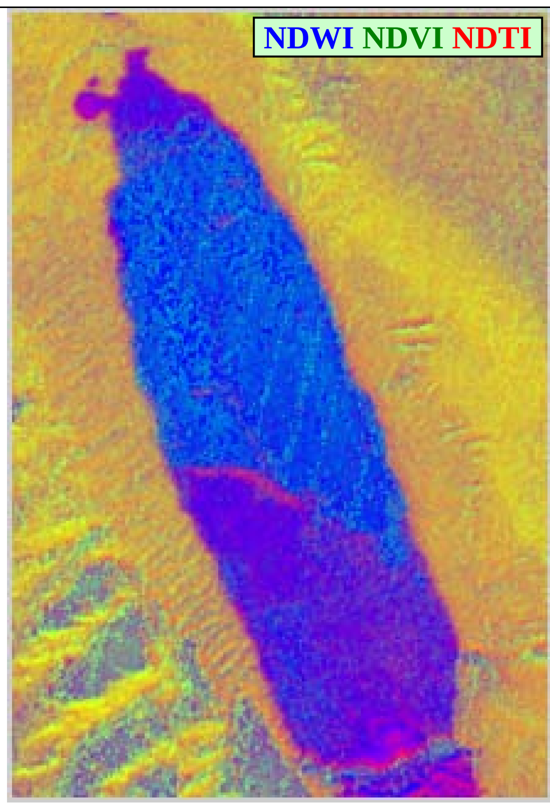
IRS P6 LISS-IV FCC G R NIR

A: Open-water

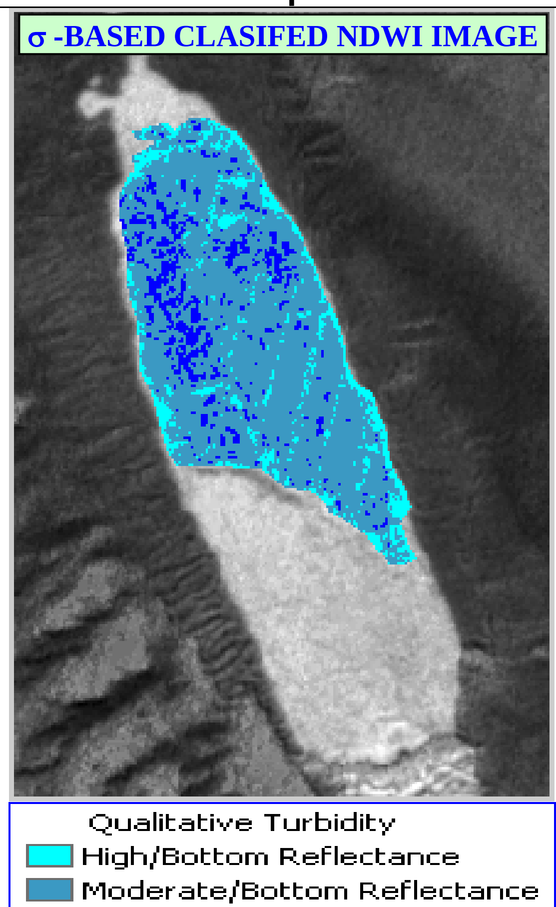
B: Semi-frozen water



Useful for delineation of wetland boundary



Useful for delineation of open-water and vegetation



Useful for qualitative turbidity rating

Figure 9: Various combinations of the spectral bands/ indices used to identify wetland components

5.4 Conversion of the Raster (indices) into a Vector Layer

The information on wetland extent, open water extent, vegetation extent and turbidity information was converted into vector layers using regional growing properties or on-screen digitization.

5.5 Generation of Reference Layers

Base layers like major road network, settlements, drainage are interpreted from the current image or taken from other project data base. The administrative boundaries (district, state) are taken from the known reference data.

5.6 Coding and Attribute Scheme

Feature codification scheme for every input element has been worked out keeping in view the nationwide administrative as well as natural hierarchy (State-district-taluka) within the feature class for each of the theme. All data elements are given a unique name/code, which are self explanatory with short forms.

5.7 Map composition and output

Map composition for atlas has been done at district and state level. A standard color scheme has been used for the wetland classes and other layers. The digital files are made at 1:50,000 scale. The hard copy outputs are taken in A3 size.

6.0 ACCURACY ASSESSMENT

A comprehensive accuracy assessment protocol has been followed for determining the quality of information derived from remotely sensed data. Accuracy assessment involves determination of thematic (classification) as well as location accuracy. In addition, GIS database(s) contents have been also evaluated for accuracy. To ensure the reliability of wetland status data, the project adhered to established quality assurance and quality control measures for data collection, analysis, verification and reporting.

This study used well established, time-tested, fully documented data collection conventions. It employed skilled and trained personnel for image interpretation, processing and digital database creation. All interpreted imagery was reviewed by technical expert team for accuracy and code. The reviewing analyst adhered to all standards, quality requirements and technical specifications and reviewed 100 percent of the work. The various stages of quality check include:

1. Image-Image Geo-referencing/Data generation
2. Reference layer preparation using NWIA post monsoon and pre-monsoon LISS-IV and LISS-III data.
3. Wetland mapping using visual/digital interpretation techniques.
4. Geo-data base creation and organization
5. Output products.

6.1 Data verification and quality assurance of output digital data files

All digital data files were subjected to rigorous quality control inspections. Digital data verification included quality control checks that addressed the geospatial correctness, digital integrity and some cartographic aspects of the data. Implementation of quality checks ensured that the data conformed to the specified criteria, thus achieving the project objectives. There were tremendous advantages in using newer technologies to store and analyze the geographic data. The geospatial analysis capability built into this study provided a complete digital database to better assist analysis of wetland change information. All digital data files were subjected to rigorous quality control inspections. Automated checking modules incorporated in the geographic information system (Arc/GIS) were used to correct digital artifacts including polygon topology. Additional customized data inspections were made to ensure that the changes indicated at the image interpretation stage were properly executed.

MAPS AND STATISTICS

7.0 WETLANDS OF SIKKIM: MAPS AND STATISTICS

Area estimates of various wetland categories for Sikkim have been carried out using GIS layers of wetland boundary, water-spread, aquatic vegetation and turbidity. Total 451 wetlands have been mapped at 1:25,000 scale in the state. In addition, 245 wetlands (smaller than 0.50 ha) have also been identified. Total wetland area estimated is 8463 ha accounting for about 1.19 per cent of the geographic area of state The major wetland types are High altitude lakes accounting for 35.48 per cent of the wetlands (3003 ha), river/stream (5097 ha) and Lake/ponds (118 ha). Graphical distribution of wetland type is shown in Figure 10.

For assessment of qualitative turbidity based on signature statistics of NDWI image for open water features has been considered as explained in the methodology. Accordingly, wetlands where open water features have not been manifested on satellite data were excluded in spite of the fact that these wetlands are associated with water. Overall three wetland types are assessed for turbidity namely Lake/Pond, High altitude lake and River/Stream. Aquatic vegetation seen in lake/pond category having 7 ha in post- and pre-monsoon seasons

The extent of open water in post-monsoon of the year 2006 is 7092 ha which comprised 2380 ha of low and 4712 ha of moderate turbidity. The extent under turbidity classes changed considerably in the pre-monsoon of 2005 which is estimated as 885 ha of low and 4136 ha of moderate turbidity out of 5021 ha of open water features based on LISS-III data. Details of the wetland statistics of the district is given in Table 4.

Table 4: Area estimates of wetlands in Sikkim

Area in ha

Sr. No.	Wettcode	Wetland Category	Number of wetlands	Total wetland area	% of wetland area	Open Water	
						Post-monsoon area	Pre-monsoon area
	1100	**Inland Wetlands - Natural**					
1	1101	Lakes/Ponds	45	118	1.40	8	8
2	1103	High altitude wetlands	405	3003	35.48	2953	882
3	1106	River/Stream	1	5097	60.22	4131	4131
		Sub-Total	**451**	**8218**	**97.11**	**7092**	**5021**
		Wetlands (<0.50 ha)	245	245	2.89	-	-
		Total	**696**	**8463**	**100.00**	**7092**	**5021**

Area under Aquatic Vegetation	7	7

Area under turbidity levels		
Low	2380	885
Moderate	4712	4136
High	-	-

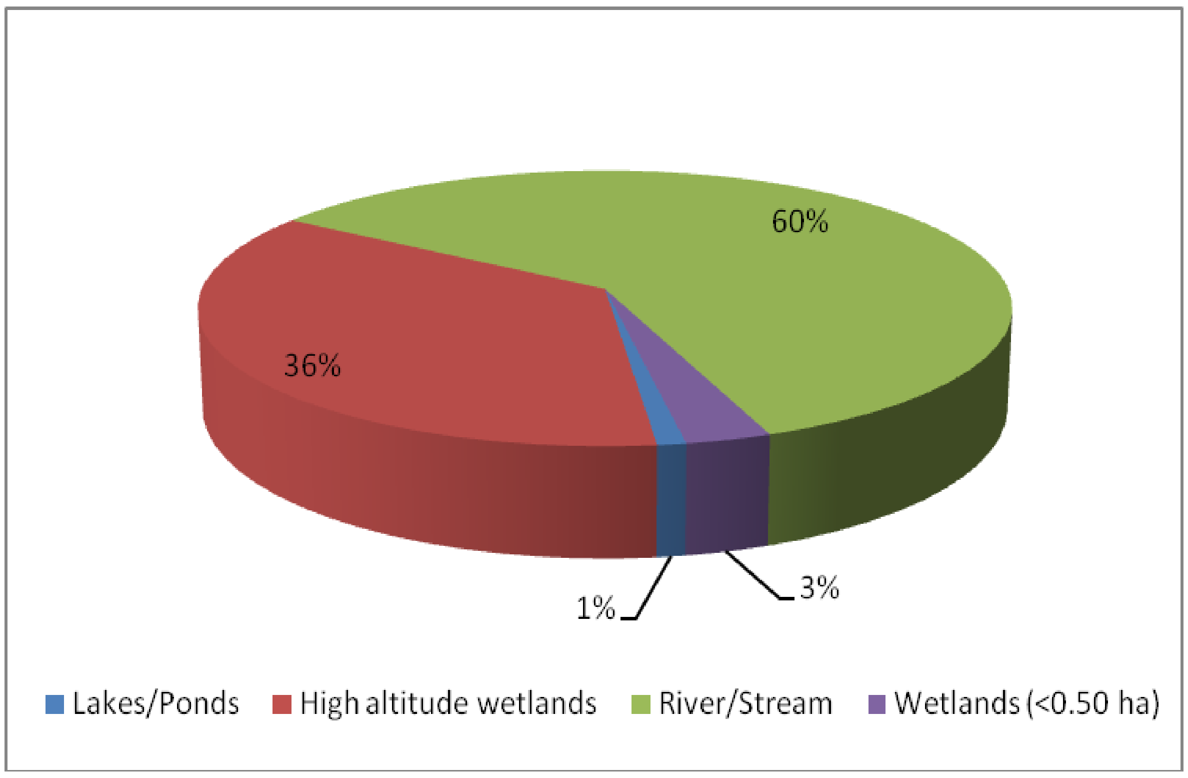


Figure 10: Type-wise wetland distribution in Sikkim

High Altitude Wetlands occupy an important place in terms of their ecological character and conservation value. Analysis of these wetlands falling three altitudinal zones has been carried out with the aid of a Digital Elevation Model (SRTM-DEM). Accordingly, three altitudinal zones were identified and distribution along with extent has been estimated. There are 10 wetlands of this category with an extent of 108 ha in 3000-4000 m altitude zone. While the zone between 4000-5000 m, there are 130 wetlands with an extent of 920 ha and in the zone > 5000 m, there are 119 wetlands with an extent of 2022 ha.

7.1 DISTRICT-WISE WETLAND MAPS AND STATISTICS

The state has four districts. District-wise distribution of wetlands showed that three districts can be called as wetland rich. North has highest concentration with around 60.40 percent of total wetland area in state and it share 1.21% of geographic area of district. This is mainly due to the location of the famous Gurudongmar Lake. The other two districts are: East and West comprise 14.43 and 14.23 per cent of area under wetland respectively. South district has the lowest area under wetland (10.94 %) out of the total wetland extract. Wetland category of High altitude was observed only in three districts. District-wise wetland area estimates is given in Table-5. District-wise graphical distribution of wetlands is depicted in Figure 11. The districts with very high concentration of small wetlands (< 0.50 ha) is North with 171 followed by West and East District with 41 and 30 respectively, while south district has lowest with 3 such wetlands.

Wetland statistics followed by wetland map and corresponding satellite data for each district is given to have a fairly good idea about the distribution pattern and density of wetlands in the district.

Table-5: District-wise wetland area

Sr. No.	District	Geographic Area (sq. km)	Wetland Area (ha)	% of total wetland area	% of geographic area
1	North	4226	5112	60.40	1.21
2	West	1166	1204	14.23	1.03
3	South	750	926	10.94	1.23
4	East	954	1221	14.43	1.28
	Total	**7096**	**8463**	**100.00**	**1.19**

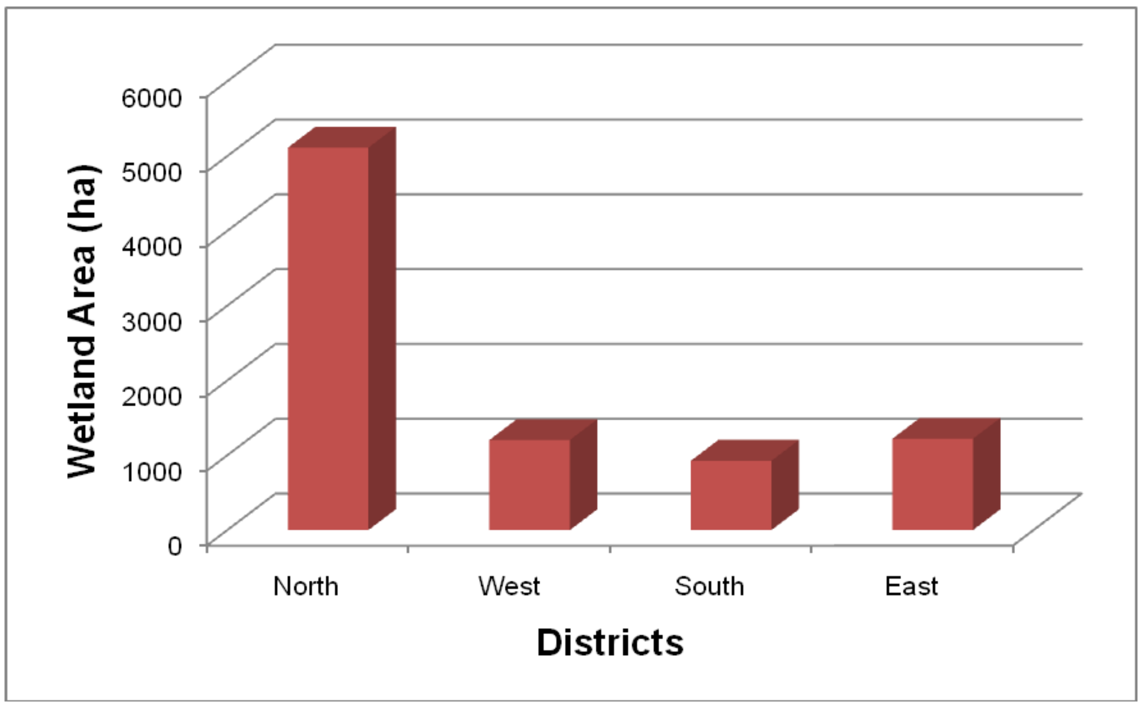
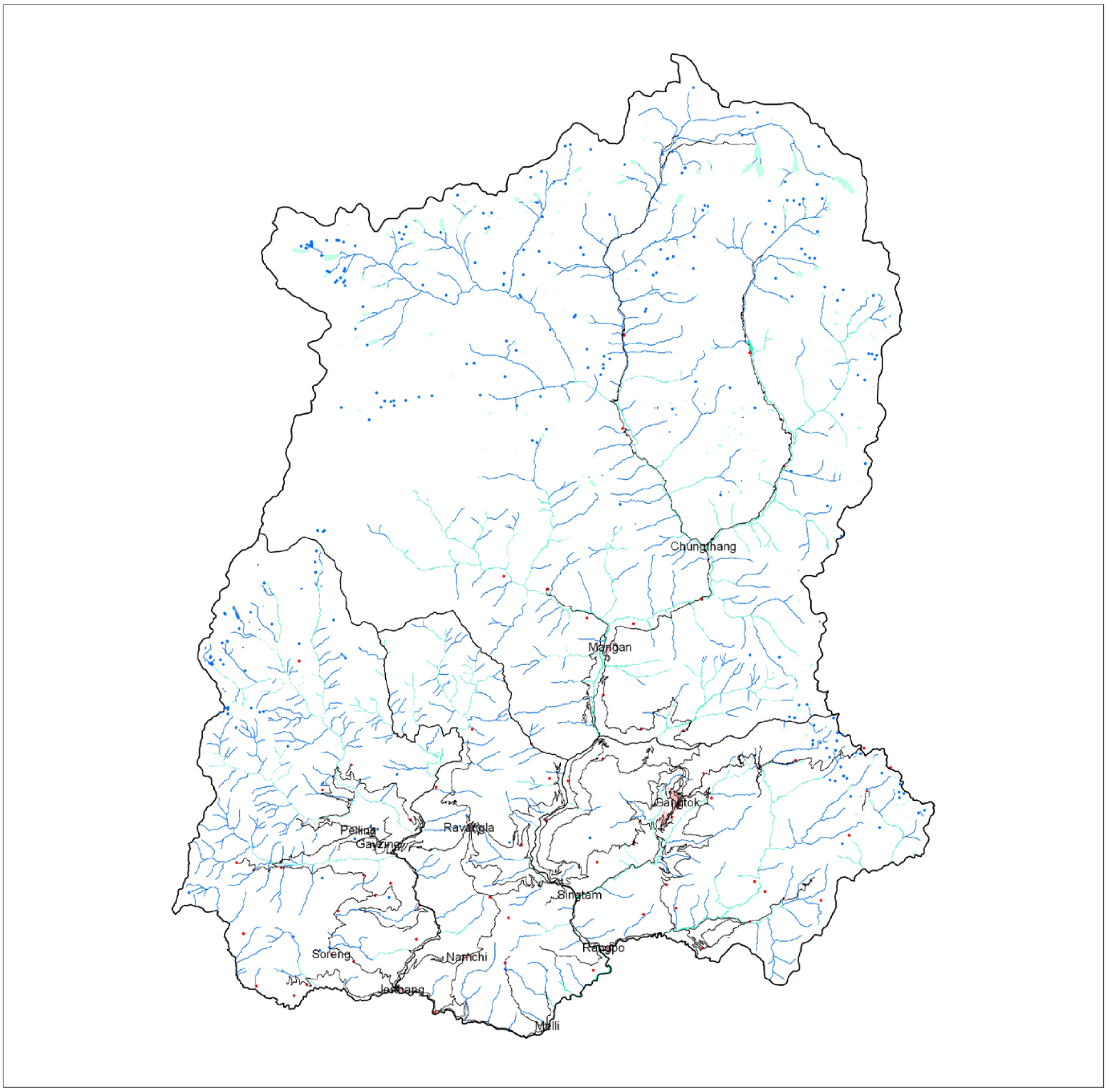


Figure 11: District-wise graphical distribution of wetlands

State : Sikkim

WETLAND MAP

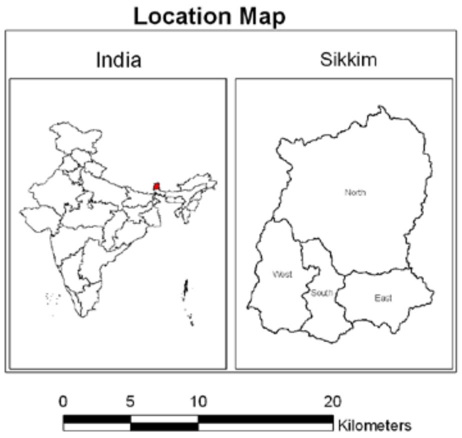


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Major Roads
- Railway
- Town/Settlements
- District Boundary
- State Boundary
- International Boundary

Location Map



Data Source : IRS P6 LISS IV data (2008-09)

Prepared By : Space Applications Centre (ISRO), Ahmedabad

Sponsored By: Ministry of Environment and Forests, Government of India

IRS-P6 LISS-III post-monsoon data(2005)

7.1.1 North

The North district with its headquarter at Mangan (72 Km from Gangtok) lies between 88°07’00” E to 88°31’48” E Longitudes and 27°04’12” N and 27°33’00” N Latitudes and the total geographical area of the District is 4226 Sq. Km. It is bounded on the North by China, on the South by South West and East District, on the East by China. The total population of the district is 41030 (census 2001). The District is divided into two Sub-Divisions, viz (1) Mangan Sub-Division with its HQ at Mangan, and (2) Chungthang Sub-Division with its HQ at Chungthang. This district can be termed as the wetland district of the state as the wetland area estimated is 5112 ha, accounting for 1.21 per cent of geographic area. The wetland types found are High altitude lakes (wetland) and River/Stream. Small wetlands, which are less than minimum mapable units (MMU), are 171 in the district. The dominant type of wetland found in the North district is high altitude lakes (wetland) which account for around 52.70 per cent of the total wetland area of the district. Major part of the famous Gurudogmar Lake lies in this district. All the wetlands of this district come under open water and there is no aquatic vegetation found in this district. The turbidity rating of the open water is observed to be mainly moderate following low. Details of the wetland statistics of the district is given in Table 6.

For assessment of qualitative turbidity based on signature statistics of NDWI image for open water features has been considered as explained in the methodology. Accordingly, wetlands where open water features have not been manifested on satellite data were excluded in spite of the fact that these wetlands are associated with water. Overall two wetland types are assessed for turbidity namely High altitude wetlands and River/Stream. The extent of open water in post-monsoon of 2006 is 4543 ha which comprised 2171 ha of low and 2372 ha of moderate. The extent under turbidity classes changed considerably in the pre-monsoon of 2005 which is estimated as 598 ha of low and 1987 ha of moderate turbidity out of 2585 ha of open water features.

Table 6: Area estimates of wetlands in North

Area in ha

Sr. No.	Wettcode	Wetland Category	Number of wetlands	Total wetland area	% of wetland area	Open Water	
						Post-monsoon area	Pre-monsoon area
	1100	**Inland Wetlands - Natural**					
1	1101	Lakes/Ponds	15	19	0.37	-	-
2	1103	High altitude wetlands	321	2694	52.70	2674	716
3	1106	River/Stream	1	2228	43.59	1869	1869
		Sub-Total	**337**	**4941**	**96.65**	**4543**	**2585**
		Wetlands (<0.50 ha)	171	171	3.35	-	-
		Total	**508**	**5112**	**100.00**	**4543**	**2585**

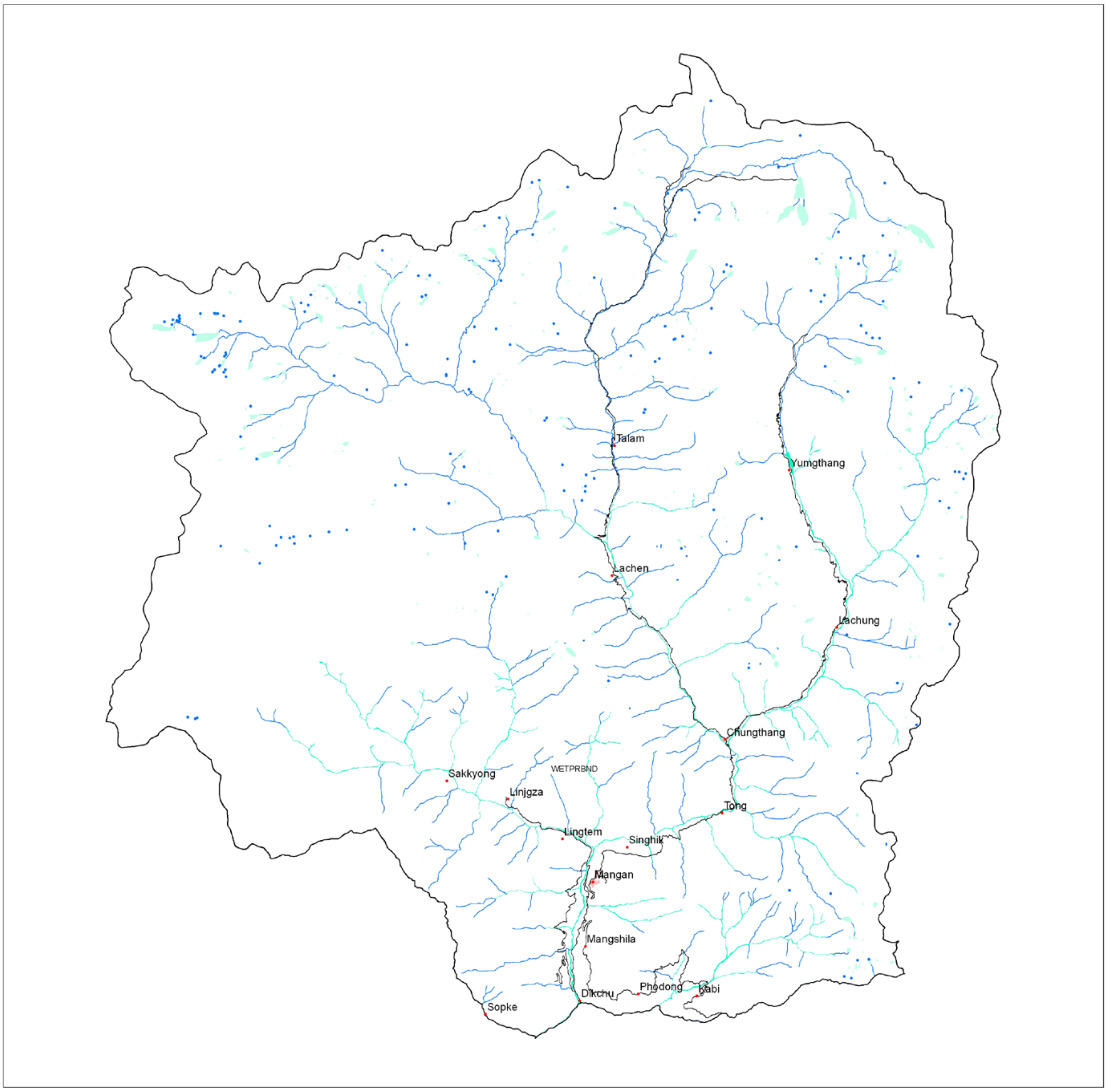
Area under Aquatic Vegetation	-	-

Area under turbidity levels		
Low	2171	598
Moderate	2372	1987
High	-	-

State : Sikkim

WETLAND MAP

District : North

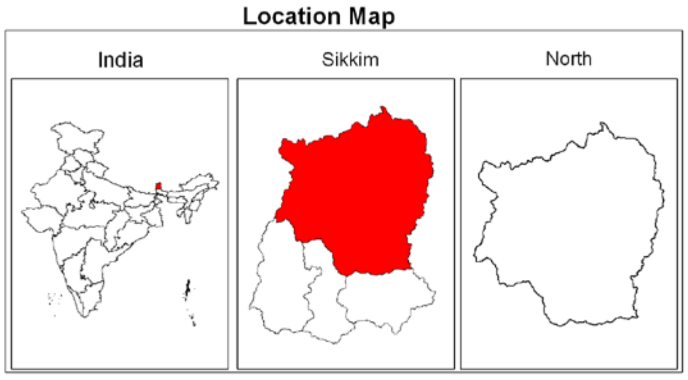


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Major Roads
- Railway
- Town/Settlements
- District Boundary
- State Boundary
- International Boundary

Location Map



0 5 10 20 Kilometers

Data Source :
IRS P6 LISS IV data (2008-09)

Prepared By :
Space Applications Centre (ISRO), Ahmedabad

Sponsored By:
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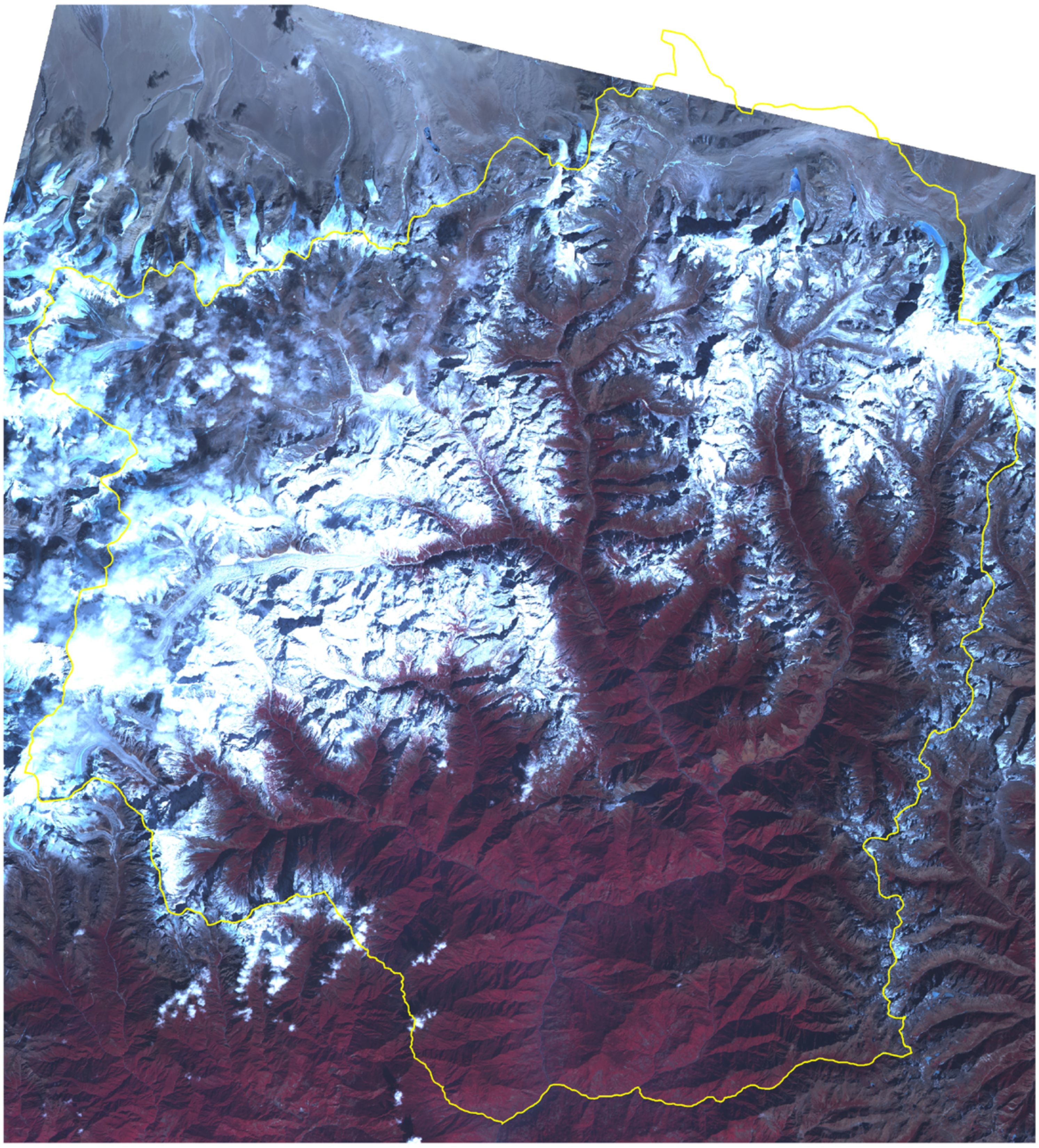
Government of India



IRS P6 LISS-III postmonsoon data (2005)

7.1.2 West

The West district and its district headquarter Gayzing lies in the western part of Sikkim at and 88°01’00” E to 88°21’00” E Longitude and 27°06’00” N to 27°36'00” N Latitude. It is the border district of the state. Its neighbors are Nepal in west, south district in the east, West Bengal on the south and North district of Sikkim on the north. The district headquarter is about 95 km away from Gangtok. The famous lake Khechodpalri lies in this district and Yaksum the first capital of the state and Rabdesi the second capital of state also lies in this district. The total geographical area of the district is 1166 sq. km. The district is divided into two subdivision viz. Gayzing and Soreng. As per Census 2001, the population of the district is 1, 23,256 with the density of population per sq. km. being 84. The wetland area estimated is 1204 ha. Small wetlands, which are less than minimum mapable units (MMU), are 41 in the district. The major wetland type is river/stream and Lakes/Ponds, which account for 81.83 % and 8.08 % (Table 7). There is only one lake/pond with 97 ha of extent. Till the date of data acquisition (November 15, 2005) freezing has taken place and on the other hand in pre-monsoon (April 13, 2005) melting has not occurred which resulted in lower pre-monsoon open water extent compared to post-monsoon open water extent. Details of the wetland statistics of the district is given in Table 7.

For assessment of qualitative turbidity based on signature statistics of NDWI image for open water features has been considered as explained in the methodology. Accordingly, wetlands where open water features have not been manifested on satellite data were excluded in spite of the fact that these wetlands are associated with water. Overall three wetland types are assessed for turbidity namely lakes, High altitude wetlands and River/Stream. The extent of open water in post-monsoon of 2005 is 949 ha which comprised 158 ha of low and 791 ha of moderate. The extent under turbidity classes has shown a change in the pre-monsoon of 2005 which is estimated as 235 ha of low and 714 ha of moderate turbidity out of 949 ha of open water features.

Table 7: Area estimates of wetlands in West

Area in ha

Sr. No.	Wettcode	Wetland Category	Number of Wetlands	Total Wetland Area	% of wetland area	Open Water	
						Post-monsoon Area	Pre-monsoon Area
	1100	**Inland Wetlands - Natural**					
1	1101	Lakes/Ponds	1	97	8.08	8	8
2	1103	High altitude wetlands	17	81	6.69	81	81
3	1106	River/Stream	1	985	81.83	860	860
		Sub-Total	**19**	**1163**	**96.59**	**949**	**949**
		Wetlands (<0.50 ha)	41	41	3.41	-	-
		Total	**60**	**1204**	**100.00**	**949**	**949**

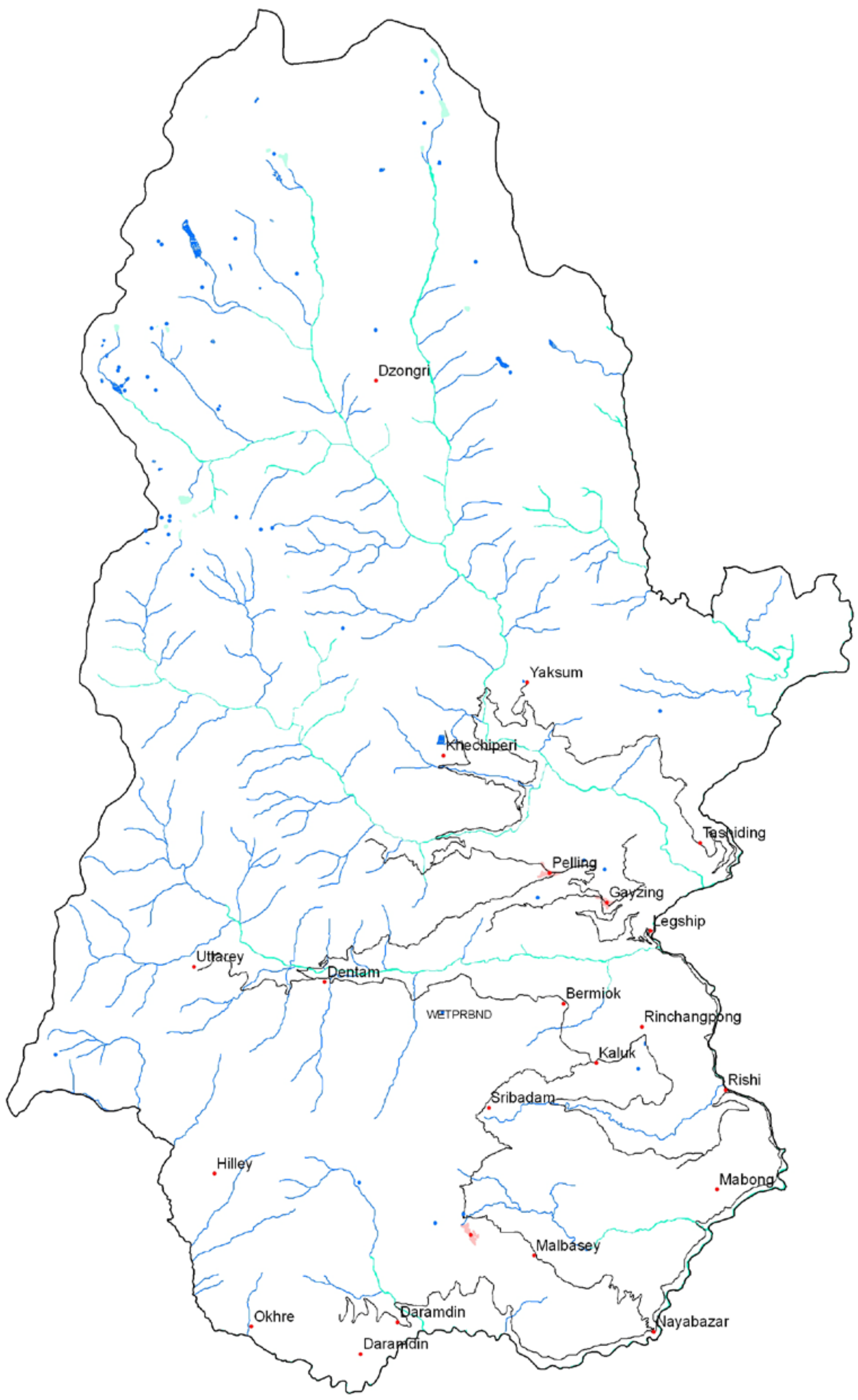
Area under Aquatic Vegetation	7	7

Area under turbidity levels		
Low	158	235
Moderate	791	714
High	-	-

State : Sikkim

WETLAND MAP

District : West

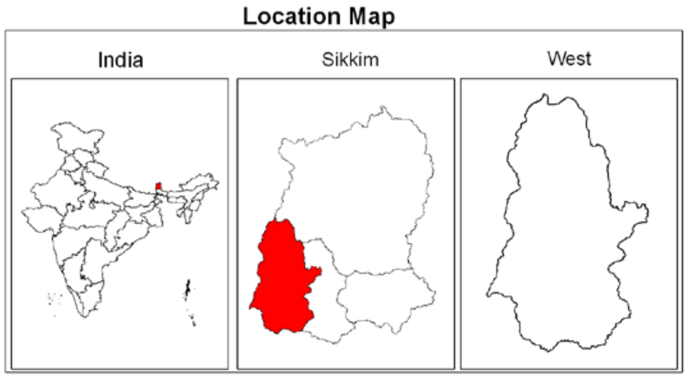


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Major Roads
- Railway
- Town/Settlements
- District Boundary
- State Boundary
- International Boundary

Location Map



0 4 8 16 Kilometers

Data Source :
IRS P6 LISS IV data (2008-09)

Prepared By :
Space Applications Centre (ISRO), Ahmedabad

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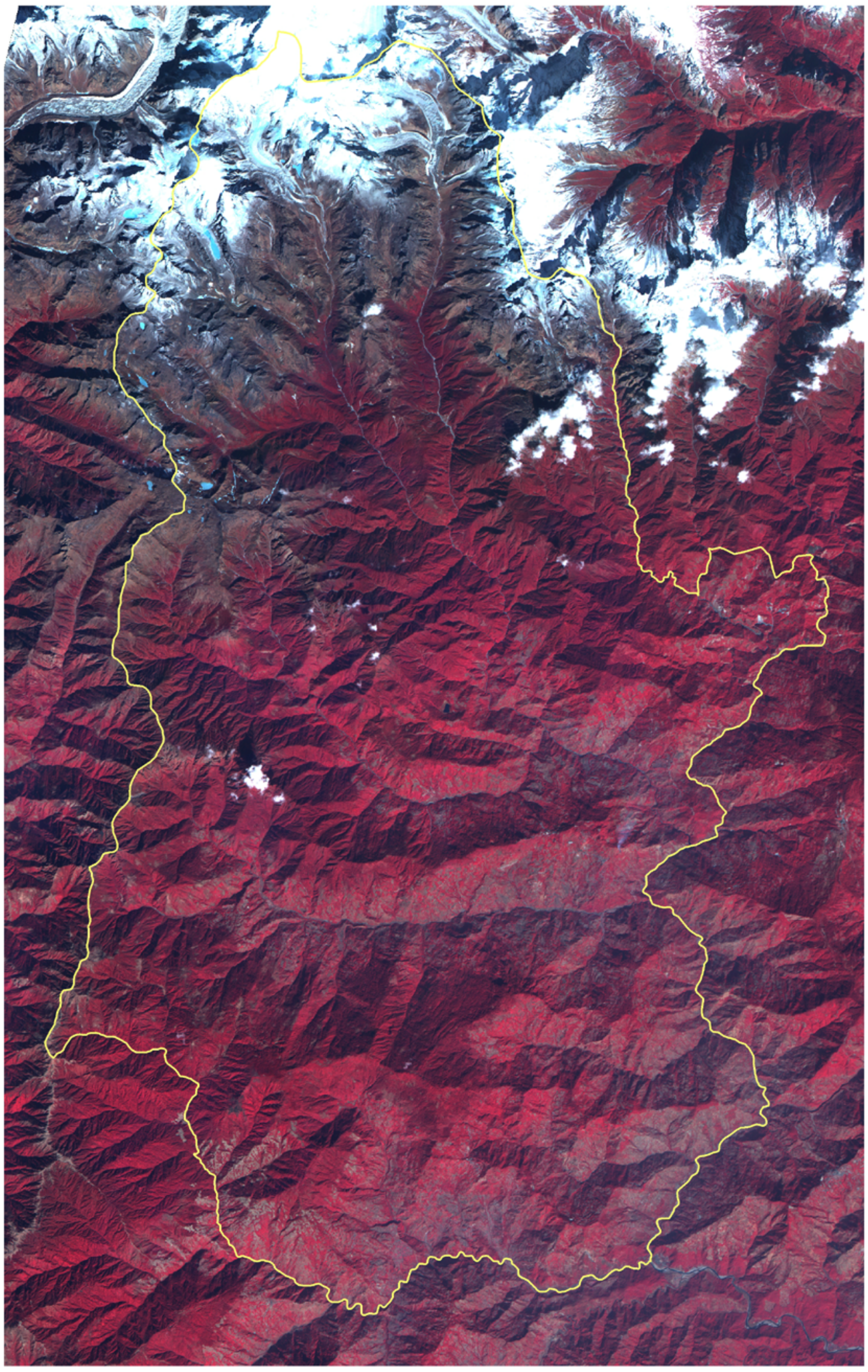
Government of India



IRS P6 LISS-III post-monsoon data (2005)

7.1.3 South

South district with its district headquarter at Namchi (85km from Gangtok), has the total geographic area of 750 sq km. Its location is 88°15’00” E to 88°32’00” E longitude and 27°04’00” N to 27°32’00” N latitude. The district is bounded by Tista River in the East, Rangit River in the south and west, Dzongu area of North district in the North. There are two subdivision viz. Namchi and Ravongla. Namchi is the fast growing town of Sikkim with the development of various tourist spots and other small scale industries. Agriculture is the main occupation of the people in the district. The total population of the district is 1, 31,525 (census 2001). The district receives least rainfall in comparison with the other district hence regarded as the driest district of Sikkim. The district has least presence of wetlands excepting river/stream. The wetland area estimated is 926 ha, which is only due to the presence of river/stream. Small wetlands, which are less than minimum mapable units (MMU), are 3 in the district. Due to perennial nature, the open water extents (737 ha) of river/stream have remained unchanged irrespective of seasons. Details of the wetland statistics of the district is given in Table 8.

As mentioned earlier, wetlands where open water features have not been manifested on satellite data were excluded in spite of the fact that these wetlands are associated with water. Only wetland type is assessed for turbidity namely River/Stream. The extent of open water in post-monsoon of 2005 is 737 ha which comprised of moderate turbidity. The turbidity of open water remained moderately turbid in both seasons.

Table 8: Area estimates of wetlands in South

Area in ha

Sr. No.	Wettcode	Wetland Category	Number of wetlands	Total wetland area	% of wetland area	Open Water	
						Post-monsoon area	Pre-monsoon area
	1100	**Inland Wetlands - Natural**					
1	1101	Lakes/Ponds	-	-	-	-	-
2	1103	High altitude wetlands	-	-	-	-	-
3	1106	River/Stream	1	923	99.68	737	737
		Sub-Total	1	923	99.68	737	737
		Wetlands (<0.50 ha)	3	3	0.32	-	-
		Total	**4**	**926**	**100.00**	**737**	**737**

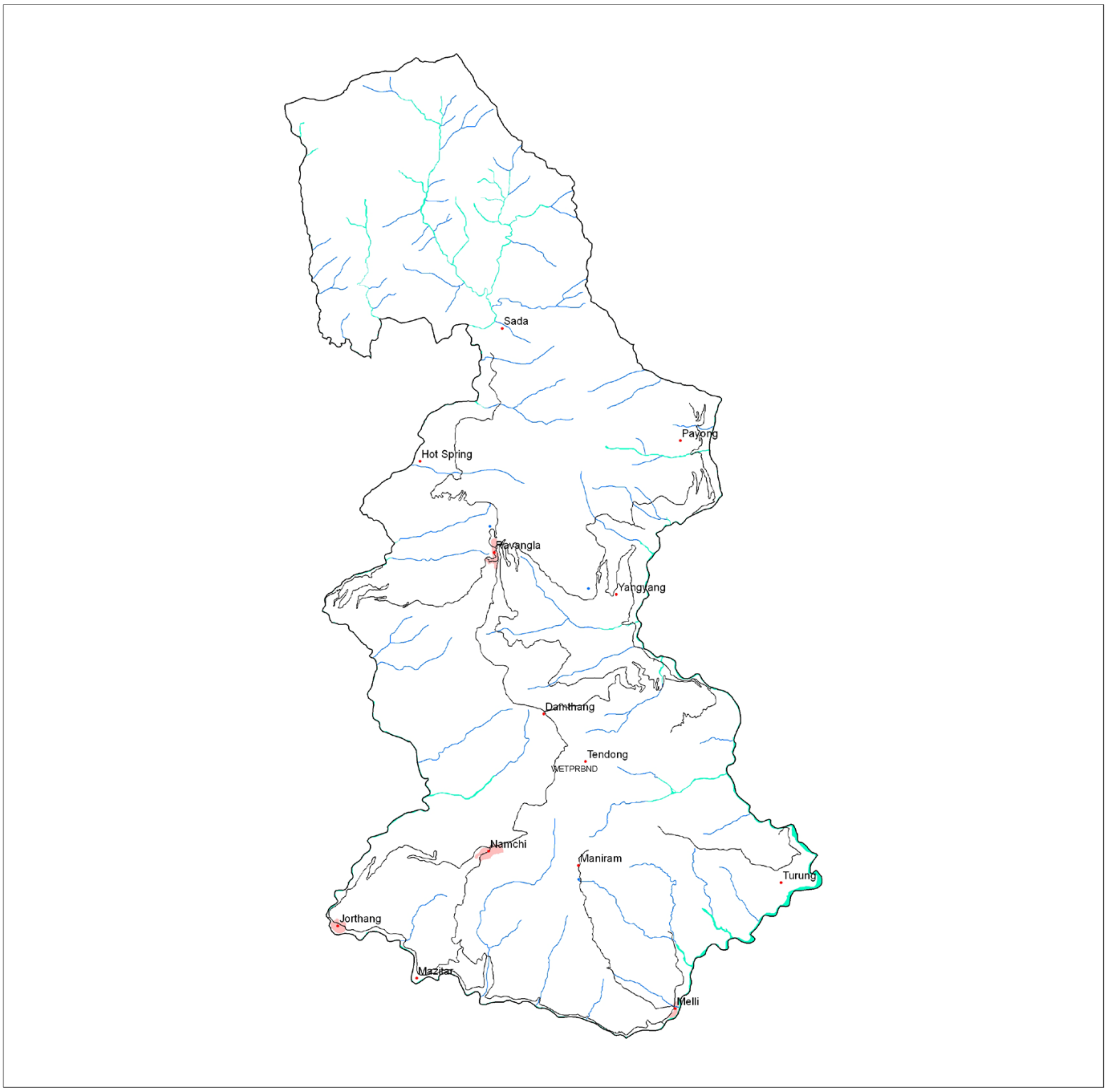
Area under Aquatic Vegetation	-	-

Area under turbidity levels		
Low	-	-
Moderate	737	737
High	-	-

State : Sikkim

WETLAND MAP

District : South

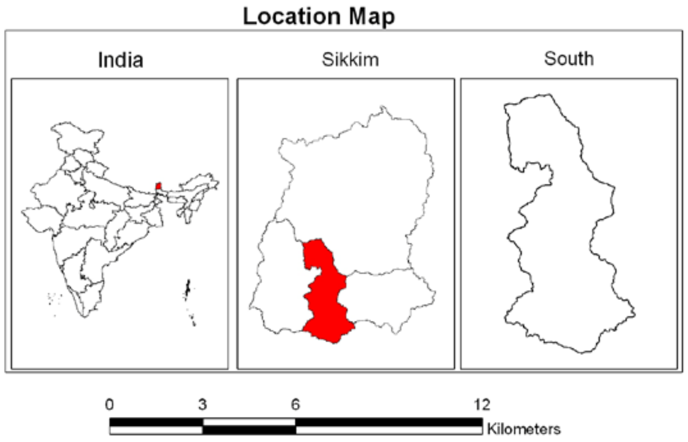


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Major Roads
- Railway
- Town/Settlements
- District Boundary
- State Boundary
- International Boundary

Location Map



Data Source : IRS P6 LISS IV data (2008-09)

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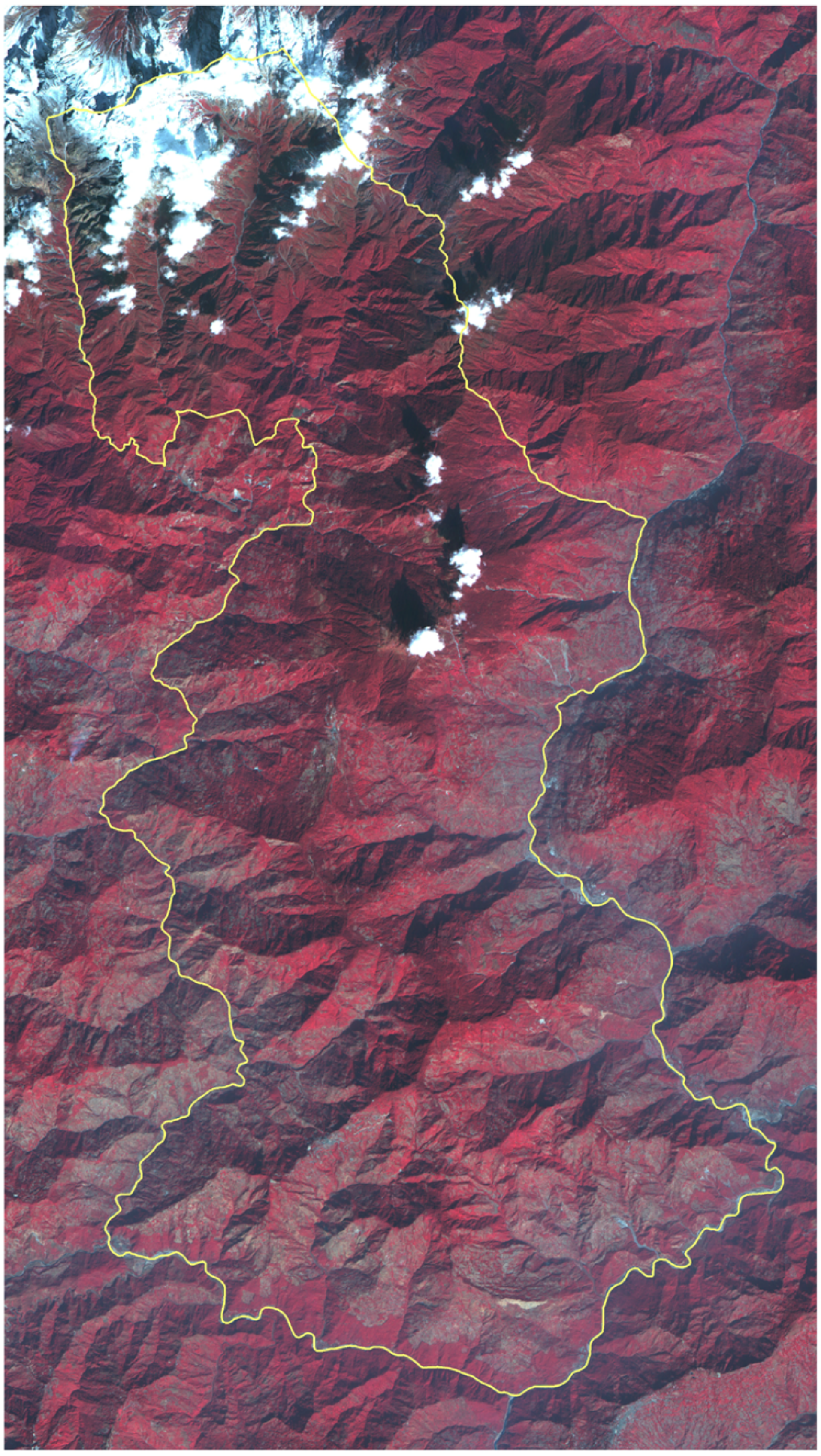


IRS P6 LISS-III post-monsoon data (2005)

7.1.4 East

East district, with headquarter at Gangtok, located in the south eastern corner of Sikkim. Its location is 88°26'00" E to 88°55'00” E and 27°08'00” N to 27°25'00”N and has an area of 954 sq. km. According to 2001 census, the total population of the district is 2, 45,040. The district is divided into 3 revenue Sub-divisions, namely Gangtok subdivision, Pakyong subdivision and Rongli subdivision. The district is mainly drained by tributaries of Tista River, Rangpo chu, Ronghichu. Tshangu Lake is the important lake of the East District which attracts many tourists to the state. The wetland area estimated is 1221 ha. Small wetlands, which are less than minimum mapable units (MMU), are 30 in the district. This is mainly due to presence of river/streams and high altitude lakes. River/stream dominates the wetland area comprising 78.64 % of area with perennial nature. High altitude lakes show reduction in extent of open water from post-monsoon to pre-monsoon owing to non-melting. Details of the wetland statistics of the district is given in Table 9.

For assessment of qualitative turbidity based on signature statistics of NDWI image for open water features has been considered as explained in the methodology. Accordingly, wetlands where open water features have not been manifested on satellite data were excluded in spite of the fact that these wetlands are associated with water. Overall two wetland types are assessed for turbidity namely lakes, High altitude wetlands and River/Stream. The extent of open water in post-monsoon of 2005 is 863 ha which comprised 51 ha of low and 812 ha of moderate turbidity. The extent under turbidity classes changed marginally in the pre-monsoon of 2005 which is estimated as 52 ha of low and 698 ha of moderate turbidity out of 750 ha of open water features.

Table 9: Area estimates of wetlands in East

Area in ha

Sr. No.	Wettcode	Wetland Category	Number of wetlands	Total wetland area	% of wetland area	Open Water	
						Post-monsoon area	Pre-monsoon area
	1100	**Inland Wetlands - Natural**					
1	1101	Lakes/Ponds	2	2	0.18	-	-
2	1103	High altitude wetlands	67	229	18.73	198	85
3	1106	River/Stream	1	960	78.64	665	665
		Sub-Total	**70**	**1191**	**97.54**	**863**	**750**
		Wetlands (<0.50 ha)	30	30	2.46	-	-
		Total	**100**	**1221**	**100.00**	**863**	**750**

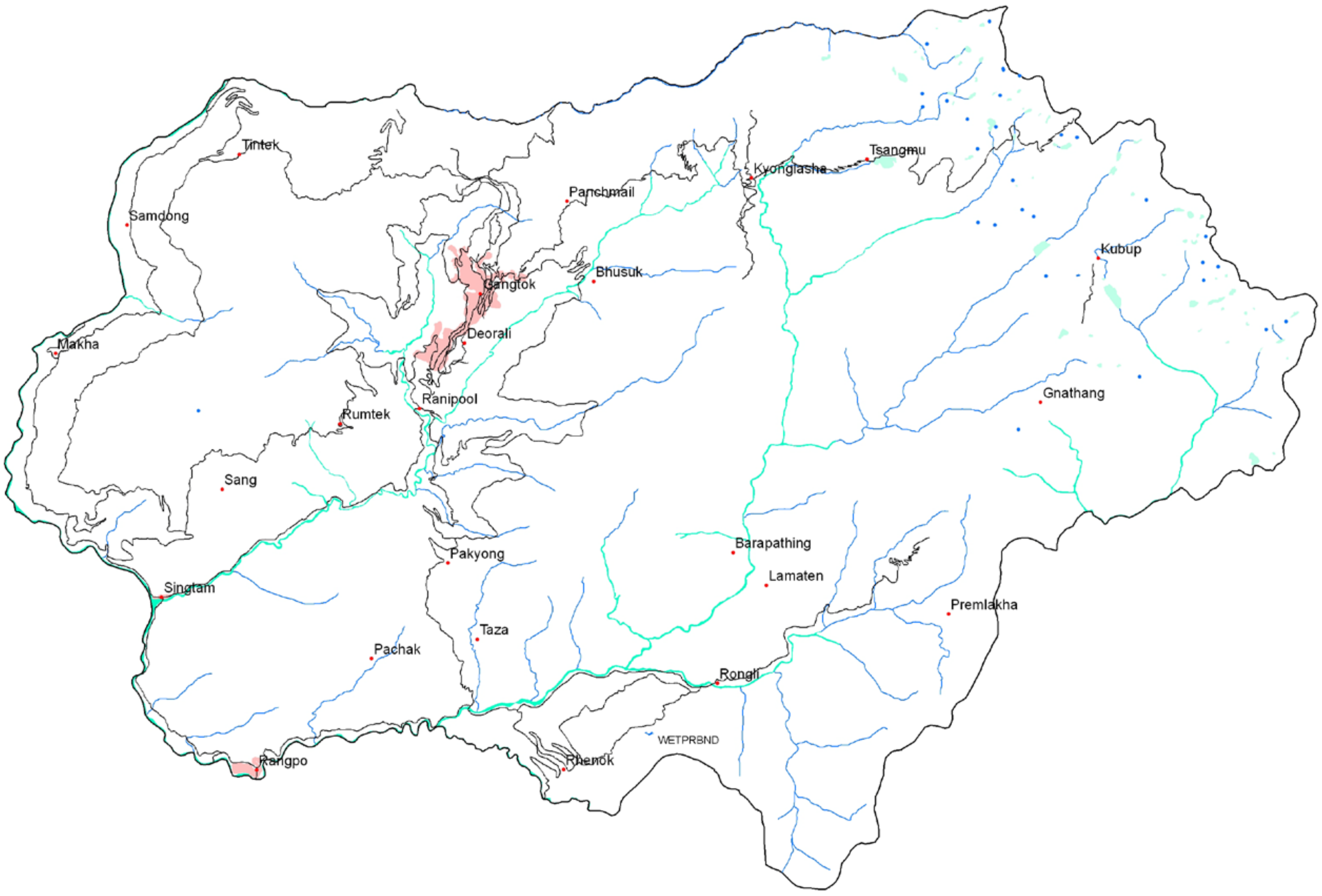
Area under Aquatic Vegetation	-	-

Area under turbidity levels		
Low	51	52
Moderate	812	698
High	-	-

State : Sikkim

WETLAND MAP

District : East

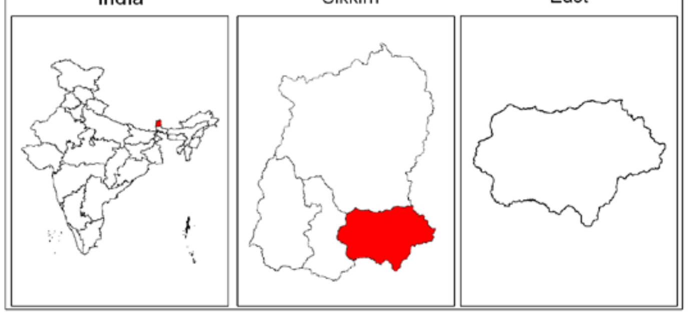


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Major Roads
- Railway
- Town/Settlements
- District Boundary
- State Boundary
- International Boundary

Location Map



0 3 6 12 Kilometers

Data Source :
IRS P6 LISS IV data (2008-09)

Prepared By :
Space Applications Centre (ISRO), Ahmedabad

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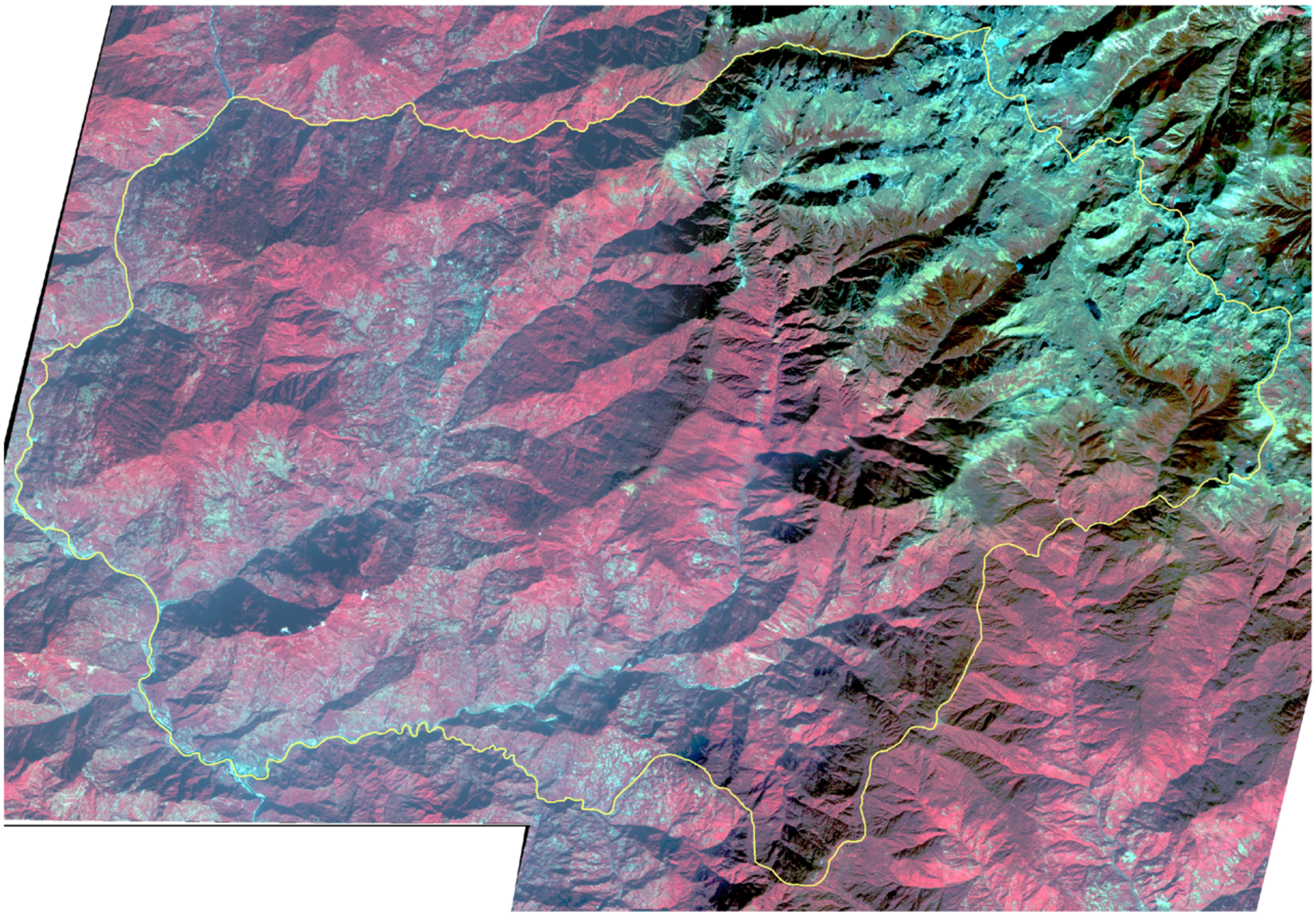


IRS P6 LISS-IV post-monsoon data (2009)

MAJOR WETLAND TYPES

8.0 MAJOR WETLAND TYPES OF SIKKIM

Major wetland types observed in the state are Lakes, High-altitude lakes, Rivers and lake with aqua-vegetation (Plate 1). Ground truth data was collected for selected wetland sites. A standard proforma was used to record the field data. Field photographs are also taken to record the water quality (subjective), status of aquatic vegetation and water spread. The location of the features was recorded using GPS. Field photographs of different wetland types are shown in Plate 2a, and 2b.

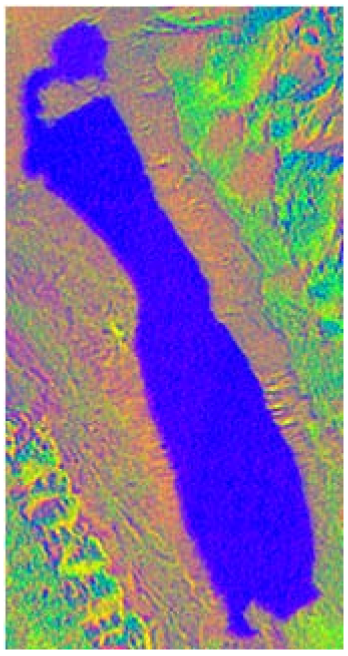
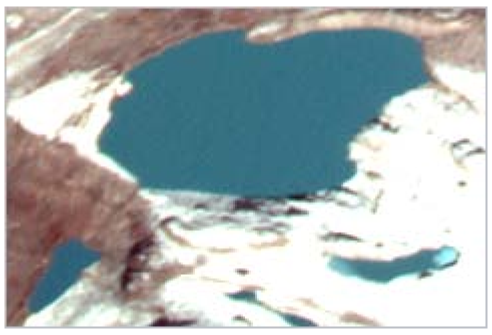
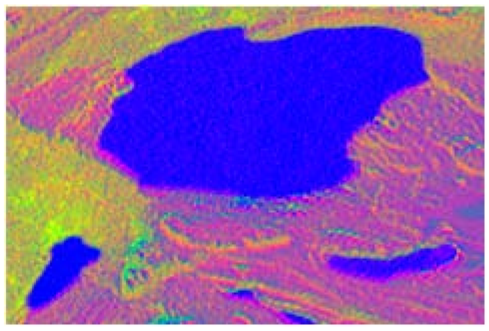
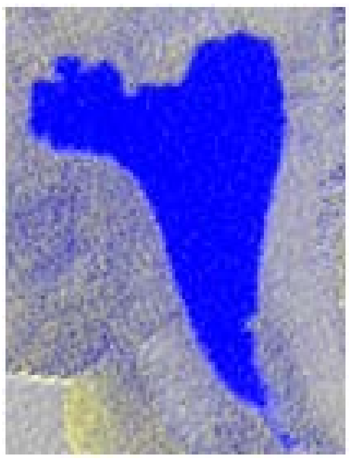
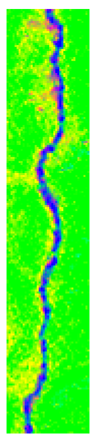
IRS P6 LISS-IV FCC (G R NIR)	FCC of Indices (NDWI NDVI NDTI)
 Glaciated Lake	
 High Altitude wetland	
 High Altitude wetland	
 River/Stream	

Plate 1: Major wetland types of Sikkim

Sr. No.	Description	Field photograph
1.	Wetland Type: (Khechodpalri Lake) Location: latitude: 27^0 21' 10.13" longitude: 88^0 11' 25.23" Altitude: 1820 m Turbidity: moderate Aquatic Vegetation on the periphery	
2.	Wetland Type: High altitude lake (Gurudogmar Lake) Location: latitude: 28^0 02' 07.88" longitude: 88^0 42' 44.36" Altitude: 5,134 m Turbidity: Low Aquatic Vegetation: NIL	
3.	Wetland Type: High altitude lake (Tsomgo Lake) Location: latitude: 27^0 21' 28.36" longitude: 88^0 46' 00.40" Altitude: 3,759 m Turbidity: Moderate Aquatic Vegetation: No	
4.	Wetland Type: River (River Tista) Turbidity: Moderate	

Plate-2a: Field photographs and ground truth data of pertaining to High altitude lakes

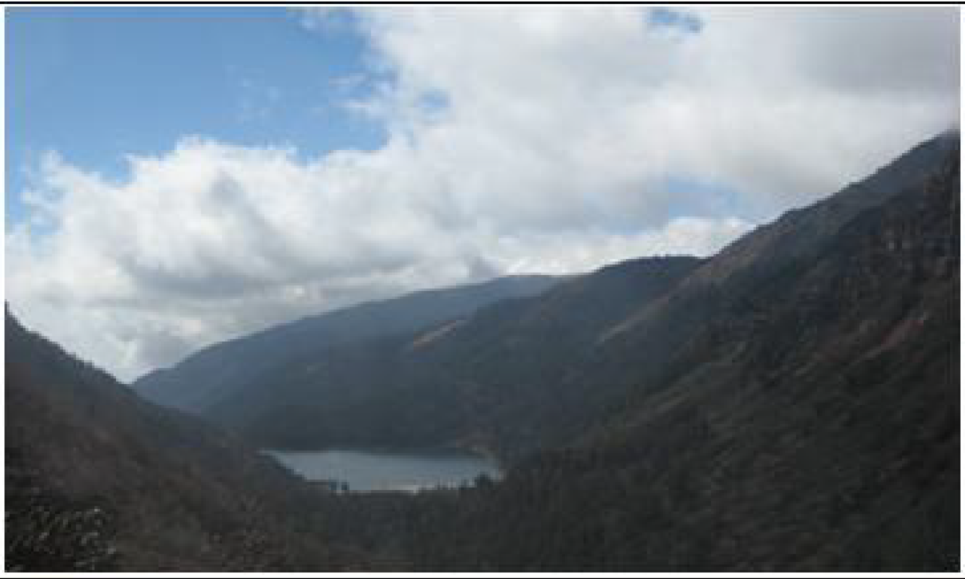
Sr. No.	Description	Field photograph
5.	Wetland Type: High altitude lake (Tso Lhamu Lake) Location: latitude: 28⁰ 01' 08.62" longitude: 88⁰ 45' 33.79" Altitude: 5096 m Turbidity: Low Aquatic Vegetation: No	
6.	Wetland Type: High altitude lake (Memencho Lake) Location: latitude: 27⁰ 20' 59.43" longitude: 88⁰ 49' 36.17" Altitude: 3669 m Turbidity: Moderate Aquatic Vegetation: No	
7.	Wetland Type: High altitude lake (Lampokhari Lake) Location: latitude: 27⁰ 19' 46.07" longitude: 88⁰ 53' 10.73" Altitude: 4300 m Turbidity: Moderate Aquatic Vegetation: No	
8.	Wetland Type: River (River Rangit) Turbidity: Moderate	

Plate-2b: Field photographs and ground truth data of pertaining to High altitude lakes in Sikkim

IMPORTANT WETLANDS OF SIKKIM

9.0 IMPORTANT WETLANDS OF SIKKIM

Sikkim has many lakes even though they are not very big in volume. The Lakes are spring fed as well as river fed and most of the lakes in sikkim are considered sacred and are revered by the people.

The North Sikkim plateau adjoining Tibet has a number of mountain lakes of which Gurudongmar and Chho lamo are the most famous. Chho lamo is the source of the Teesta river. The Tsomgo Lake in east Sikkim is the most popular with tourists while Khecheopalri in West Sikkim is one of the most beautiful and sacred.

On the Gangtok and Nathu la highway, 34 kms from Gangtok lies the serene Tsomgo (Changu) lake at an altitude of about 11,000 feet. Khecheopalri lake is another well known lake that lies on a bifurcation of the route between Gyalshing and yuksom. Menmecho lake, green lake and Samiti lake are some other beautiful lakes. Lakshmi Pokhari and Bidan Chu Lake are the graceful lakes of Sikkim.

Extensive field work was carried out for these wetland areas. Wetland maps have been prepared for 5km buffer area of wetland site. Details of each wetland and wetland map of 5 km buffer area are shown in plates.

9.1 KHECHEOPALRI LAKE

Khecheopalri Lake (also called Khachoedpaldri Lake and Chhejo pokhari) in Sikkim is also known as the wishing lake and it can be easily reached from Geyzing via Pemayangtse at about 30 km and located between 27^0 21' 10.13" N and 88^0 11' 25.23" E at about 1820 m altitude. At an altitude of 1820 m amsl (above mean sea level), this unusually tranquil lake is surrounded by blooming forest and is considered as one of the sacred lakes of Sikkim. It is in the fact worshipped both by the Buddhists as well as the Hindus.

The real name of the lake is Sho Dzo Sho, meaning "Oh Lady, Sit Here", but is commonly known as Khachoedpaldri Lake because it sits on the lap of Khachoedpaldri, a very sacred hill.

The origin of the lake as narrated in the sacred scriptures of Sikkimese Buddhism starts after the Nepali invasion of the medieval kingdom in the 1780s. The Nepali army destroyed the original (third) palace of the Namgyal Dynasty situated at Rabdentse. They also desecrated a holy lake at Yosum, West Sikkim.

The lake is enveloped in a dense forest cover of temperate vegetation and bamboo. The placid waters of the lake are visited by many pilgrims and tourists. The closest town is Pelling. From the main gate, where are small shops and the road ends, to the lake is about a ten to fifteen minutes walk through a lovely tropical forest.

It is gaining popularity within the tourism sector due to its landscape and rich biodiversity, in addition to the various ethnic religio-cultural aspects and sacred beliefs associated with it. Studies show that the lake is facing immense pressure from the surrounding catchments and its longevity is under threat mainly because of anthropogenic pressure. By promoting traditional sacred beliefs and its folklores and linking ecotourism with social and economic development of the local populace, it may be possible to conserve the natural and cultural heritage of the lake and the Himalayan region as a whole.

The significance of Khecheopalri Lake the serene waters of this lake appear to comprise a celestial charisma. Hence, no water sport or other activities besides prayers are allowed around the lake. It is believed that birds do not permit even a single leaf to float on the Lake's surface. This is explained by the duck population which are known to remove the leaves as soon as they fall on the surface, giving it a clear and smooth surface.

It is believed that the deity of the lake one day appeared to a monk and beseeched to be taken out of the desecrated lake, and she would guide him to the right place. The monk took a vessel of water from the lake and through divine guidance, reached Khachoedpaldri hill. Finally, the deity, Goddess Tara, directed him to a place below the hill, where he prayed and in a shallow depression of the lake, poured the water. Gradually and miraculously, the lake filled up.

Today there is pier that leads to the front of the lake and one can pray and offer incense. An annual Buddhist ritual from the readings of the Naysul prayer book describes the origin of Sikkim and has several tantric secret prayers, is offered at the Lake.

Long time back this place used to be a grazing ground, troubled by nettle. Then on a certain day, conchshells were seen falling on the ground. This was followed by severe shaking of the ground and water emerged from below. This lake was then termed as the footprints of Goddess Tara. From a high enough vantage point the contours of the lake look like a footprint - believers hold that it is situated in Shiva's footmarks. The surrounding of the lake is an ideal place to find the Lepcha Houses and their communities. Pilgrims and tourists from all parts of the world come to visit this placid lake.

The lake represents the original névé (that is, compact granular snow that eventually forms a glacier) region of an ancient hanging glacier and the depression is formed by the scooping action of the glacier. A moraine ridge forms the southern bank of the Lethang valley. The lake has been estimated to be more than 3500 years old. Khecheopalri Lake is surrounded by the forested Ramam watershed (named after Ramam Mountain) and covers an area of 12 square kilometers. It falls on the southern boundary of the Khangchendzonga Biosphere Reserve (Buffer Zone IV), limiting on the reserved forest boundaries of Khecheopalri Village. It has an open water surface area of 3.79 hectares with a mean water depth of 7.2 meters. The lake is well drained from the watershed with internal seepage flows from 2 perennial and 5 seasonal inlets and is drained out through a major perennial outlet. The lake drainage area constitutes of 91 hectares from the total area of the Ramam watershed. The lake is a halting place for Trans-Himalayan migratory birds. In addition to being a pilgrimage site, the lake provides recreational tourism opportunities. A large number of religious festivals are performed every year and these attract pilgrims (7,800 in 1998) from within the state as well as the nearby countries of Nepal and Bhutan. About 8,000 national and 2,000 international tourists visit the lake annually. Khecheopalri Lake as seen on satellite image as well as in the field is depicted in the plate 3 along with specific information on the lake. Wetland map for 5 km buffer area of Khechodpalri Lake and corresponding satellite image are shown in plate 4 and 5 respectively.

9.2 GURUDONGMAR LAKE

Gurudongmar Lake (also known as Gurudogmar Lake) is the largest, perhaps the highest lake in Sikkim, India lies between 28^0 02’ 07.88” and 88^0 42’ 44.36” E at altitude of 5148 m. The very appearance of serene waters of the lake brings a sense of relief to the beholder. Situated at an elevation of 17,100 feet (5,148 m), Gurudogmar Lake rests on the northern side of the Khangchengyao Range, close to the Indo-China Border in the province of North Sikkim, Sikkim, India in a high plateau area next to the Tibetan Plateau. Gurudongmar Lake is a watercourse of high reverence for the Sikkimese and Buddhists the stream emerging from the lake is one of the source-streams of the Tista River and is revered by both Buddhists and Hindus as a sacred lake.

The lake is named after Padmasambhava, the Indian tantric Buddhist who conducted rituals here. It is said that this is why even at the height of winter one portion of the lake never freezes. Guru Nanak, also known as Nanak Lama, who was a devotee of Padmasambhava, visited many of the places where Padmasambhava prayed at, including this lake in North Sikkim.

The lake is highly revered by the Sikkimese and Buddhists and the waters are supposed to have curative properties. The Indian Army got into a conflict with the Sikkim Government when they erected a Gurdwara (a Sikh temple) near the lake in the 1990s: the Gurudwara has now become a 'Sarva Dharma Sthal' (House of worship for All Religions), and ruffled feathers have been smoothened.

Due to the extremely inhospitable terrain and the difficulties associated with reaching the place, the lake sees only a handful of visitors each year. Access is strictly controlled at the Army check post at Giagong. Due to the altitude, there is a scarcity of oxygen. Visitors are advised to acclimatise overnight at Lachen, carry medicines like Coca 10, Deryphyllin etc., and to descend quickly in case of acute or persistent discomfort. Over-excitement and loud, stressful talking should be avoided.

Encircled all around by snow-covered mountains the lake freezes during the winter, except at one spot said to be blessed by Guru Rimpoche. The water of the lake is believed to have the miraculous power of granting children to issueless couples. Gurudongmar Lake as seen on satellite image as well as in the field is depicted in the plate 6 along with specific information on the lake. Wetland map for 5 km buffer area of Gurudongmar Lake and corresponding satellite image are shown in plate 7 and 8 respectively.

9.3 TSOMGO LAKE:

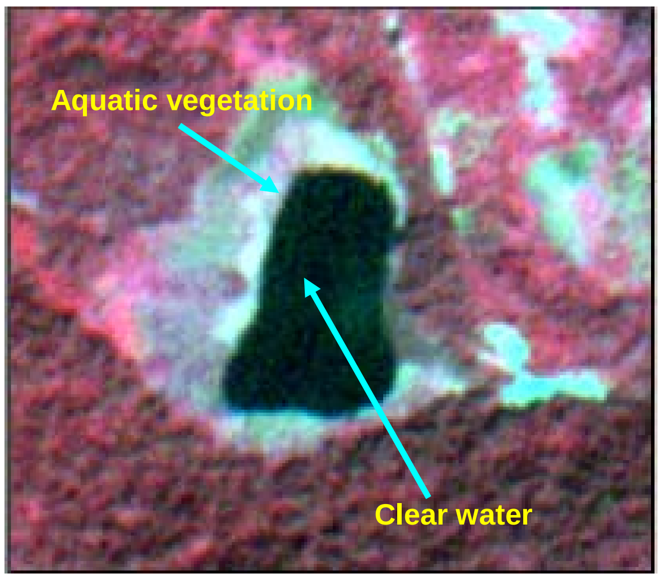
Tsomgo Lake (also called Changu Lake or Tsongmo Lake) is located between 27^0 21’ 28.36” N and 88^0 46’ 00.40” E at an altutude of 3780 m in the north eastern part of Sikkim. Etymologically *"Tso"* means *lake* and *"Mgo"* means *head*, thus literally meaning "source of the lake" in the Bhutia language. The cerulean lake is about 40 kilometres away from the capital Gangtok at an altitude of 3,780 m (12,400 feet). It is oval-shaped, with a length of nearly a kilometre and has an average depth of fifteen metres. The tarn with its refulgent waters is situated on the Gangtok-Nathula highway, which makes a role of the erstwhile trade route from India to China. This lake has been worshipped as a holy lake by Sikkimese. During the winter season, the lake would be in frozen condition up to mid-May. A moderate-sized temple of lord Shiva is present on the lakeshore.

It falls in the restricted area and hence an inner line permit is required by Indians to visit this place. Foreign nationals are not permitted to visit this lake without special permission. It is also a home of brahminy ducks. It's cool, placid water harmonizes with the scenic beauty around.

Between May and August it is possible to see a variety of flowers in blooms, including the Rhododendrons, various species of Primulas, blue and yellow Poppies, and Irises etc. It is also an ideal habitat for the Red Panda and various species of birds. Due to the heavy promotion of tourism in the state, many locals have set up shop here offering yak rides, yak cheese, trinkets, and local curios. Indian Postal Service released a commemorative stamp on the lake on 6 November 2006.

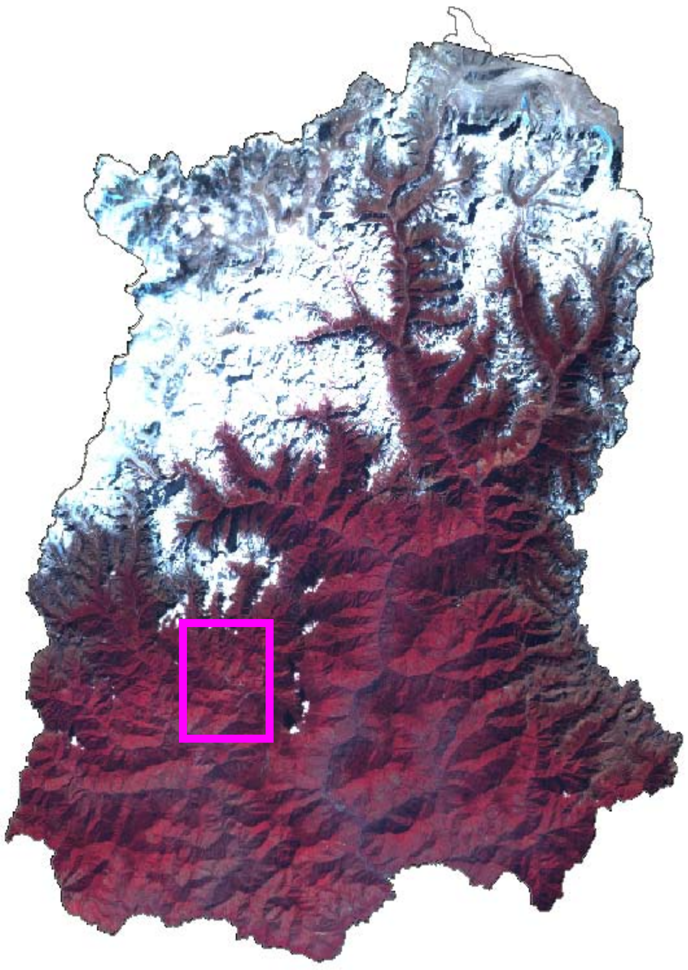
Many tributary glaciers feed the trunk glacier. The side valleys, in which these glaciers lie, open into the main Zemu Valley from different directions. Icefalls and waterfalls have formed at the junction of the tributary glaciers with the Zemu glacier. Tsomgo Lake as seen on satellite image as well as in the field is depicted in the plate 9 along with specific information on the lake. Wetland map for 5 km buffer area of Tsomgo Lake and corresponding satellite image are shown in plate 10 and 11 respectively.

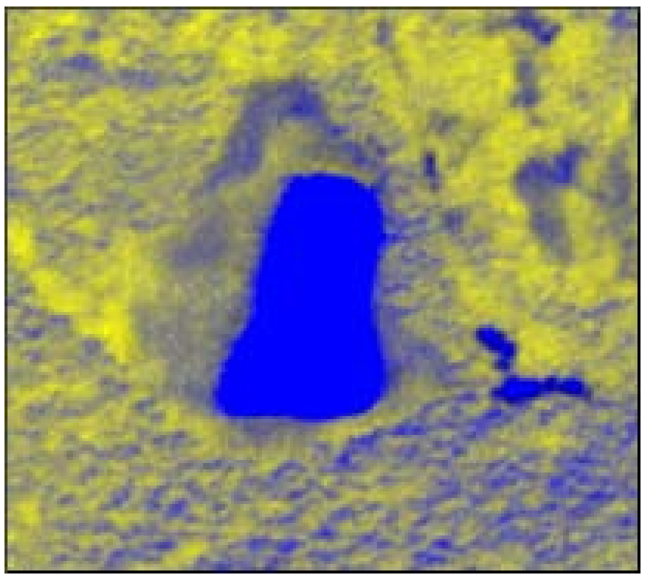
Name	**Khechodpalri Lake**
Location	Upper left: 27^0 21' 11.04" N, 88^0 11' 09.13" E Lower right: 27^0 20' 53.12" N, 88^0 11' 22.61" E
Area	15.08 ha
	The lake has 7.11 ha of clear water area and 7.97 ha of aqua- vegetation area, which is marshy land.
Altitude	1820 m
Climate	Average annual rainfall: 1183 mm Temperature: 15^o to 28^o C.
Morphometric features	Maximum length: 547m Maximum breadth: 352m Maximum depth: 9 m Average depth: 7.2 m
Turbidity	Moderate
Vegetation	The Important vegetation of the around the lake area recorded are *Symplocos thaefolia, Eurya acuminata*
Fauna	A great diversity of invertebrate and vertebrate fauna are associated with khechodpalri lake.
	The lake is enveloped in a dense forest cover of temperate vegetation and bamboo. Various ethnic religio-cultural aspects and sacred beliefs associated with it. Studies show that the lake is facing immense pressure from the surrounding catchments and its longevity is under threat mainly because of anthropogenic pressure.



IRS P6 LISSIV, October 2009

FIELD PHOTOGRAPH

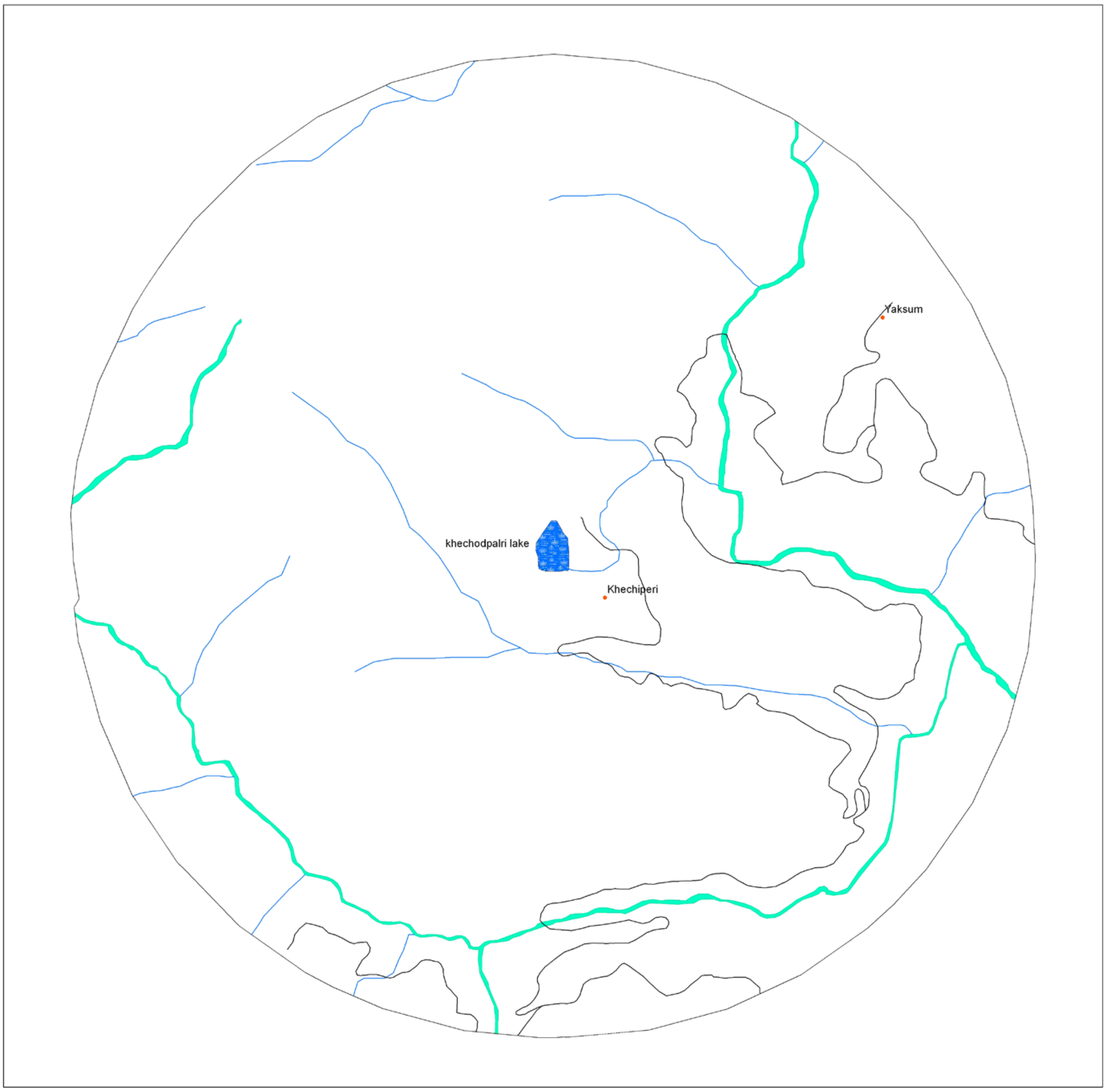




NDWI NDVI NDTI from LISS-IV data

Plate 3: Khechodpalri Lake

State : Sikkim **WETLAND MAP** Khechodpalri lake

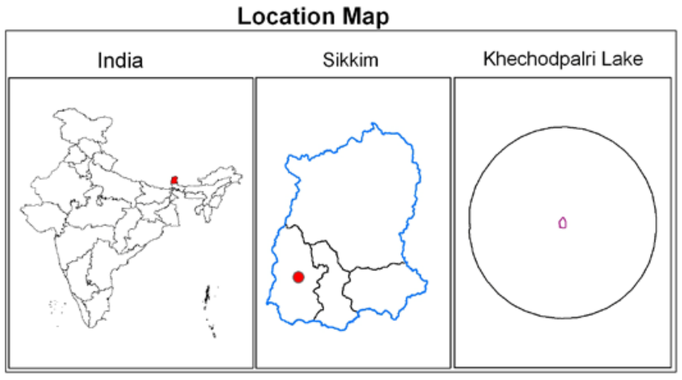


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Reverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<2.25ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



0 0.5 1 2 Kilometers

Data Source:
IRS P6 LISS III data (Pre-monsoon and Post-monsoon Seasons: 2005)

Prepared By:
Space Applications Centre (ISRO), Ahmedabad
and
Sikkim State Council of Science and Technology, DST

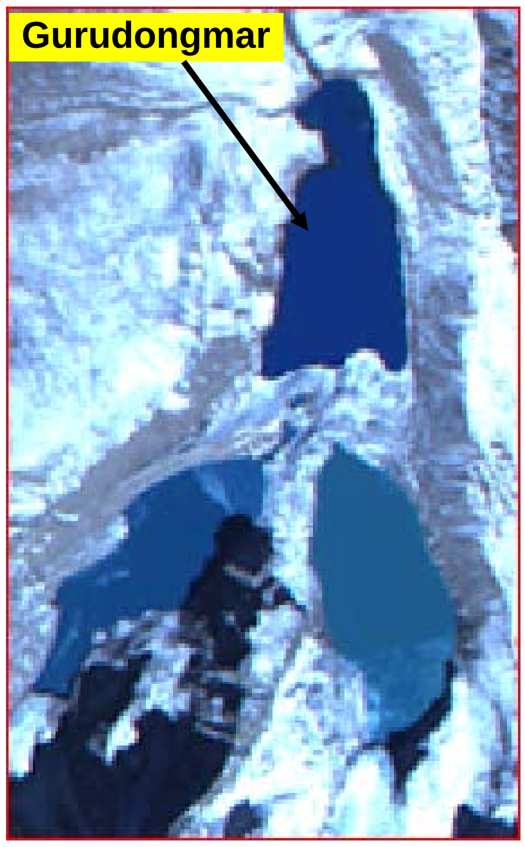
Sponsored By:
Ministry of Environment and Forests
Government of India

Plate 4: Wetland map - 5 km buffer area of Khechodpalri Lake

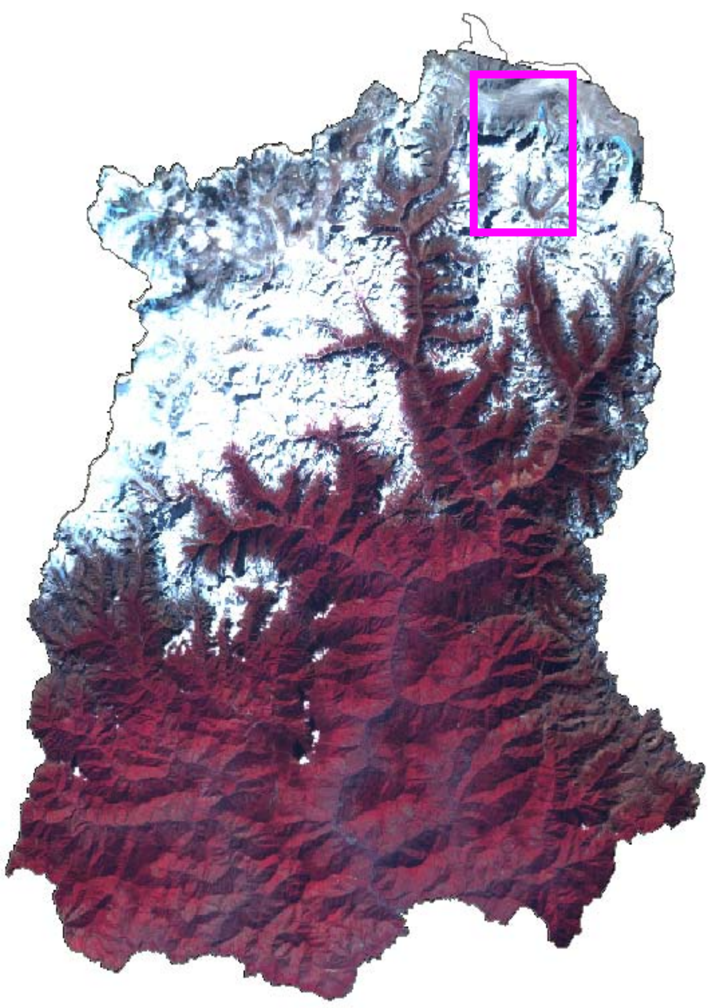
IRS P6 LISS-IV post-monsoon data (2009)

Plate 5: Khechodpalri Lake as seen on IRS P6 LISS-IV image with 5 km buffer area

Name	**Gurudongmar Lake**
Location	Upper left: 28^0 02’ 07.05” N, 88^0 42’ 18.15” E Lower right: 28^0 01’ 04.61” N, 88^0 42’ 52.62” E
Area	118 ha
Altitude	5,148 M
	The lake is encircled all around by snow-covered mountains and freezes during the winter except one spot believed of having curative properties.
Climate	Average annual rainfall : 1183 mm Temeperature : 0^o to 35^o C.
Morphometric features	Maximum lengh : 1954m Maximum breadth : 963m Maximum depth : 4.58 m Average depth : 2.07 m
Turbidity	Low
Vegetation	Sparse alpine vegetation aroud the lake.
Fauna	Few or no fauna is associated with the lake.
	The lake is situated at very high elevation and rests on the northern side of the Khangchengyao Range, close to the Indo-China Border in the province of North Sikkim, in a high plateau area next to the Tibetan Plateau. The lake is highly revered by both Buddhists and Hindus as a sacred lake.



IRS P6 LISSIII, 15 November 2005



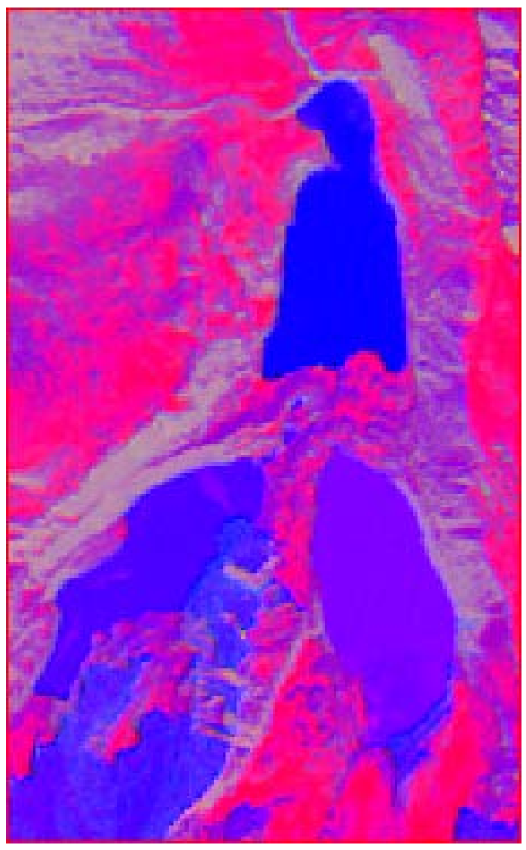
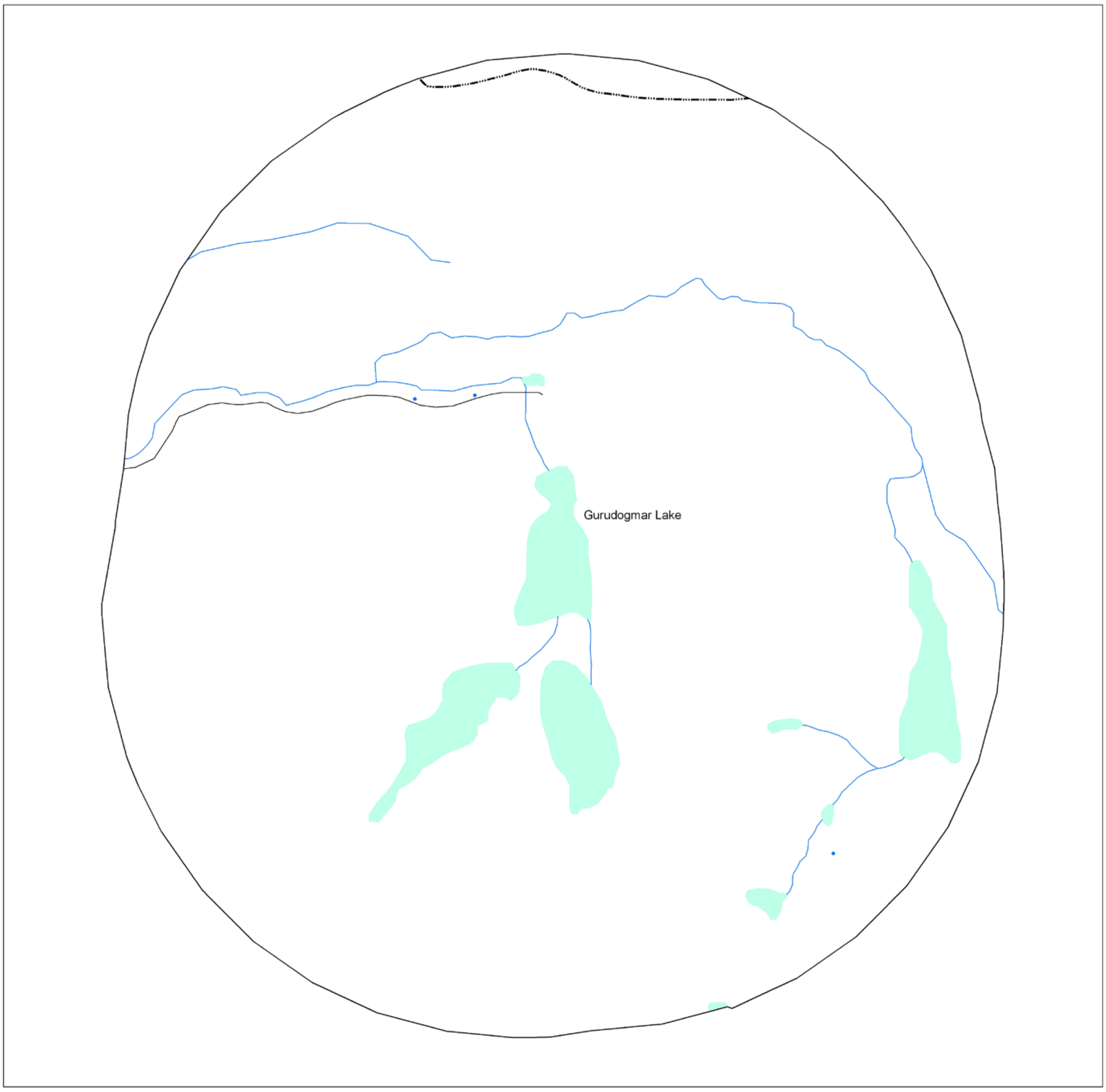

MNDWI NDPI NDVI from LISS-III data

Plate 6: Gurudogmar Lake

State : Sikkim

WETLAND MAP

Gurudogmar lake

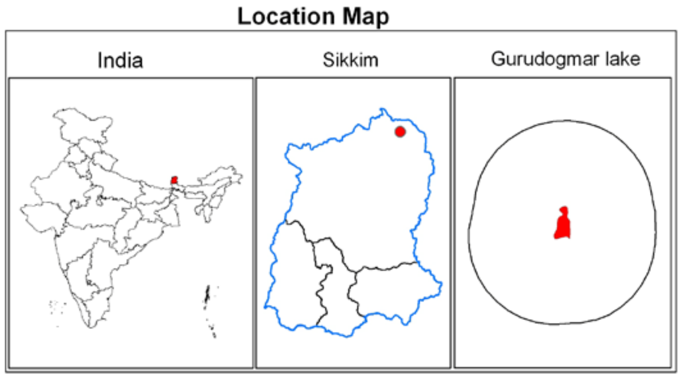


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Reverine wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<2.25ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



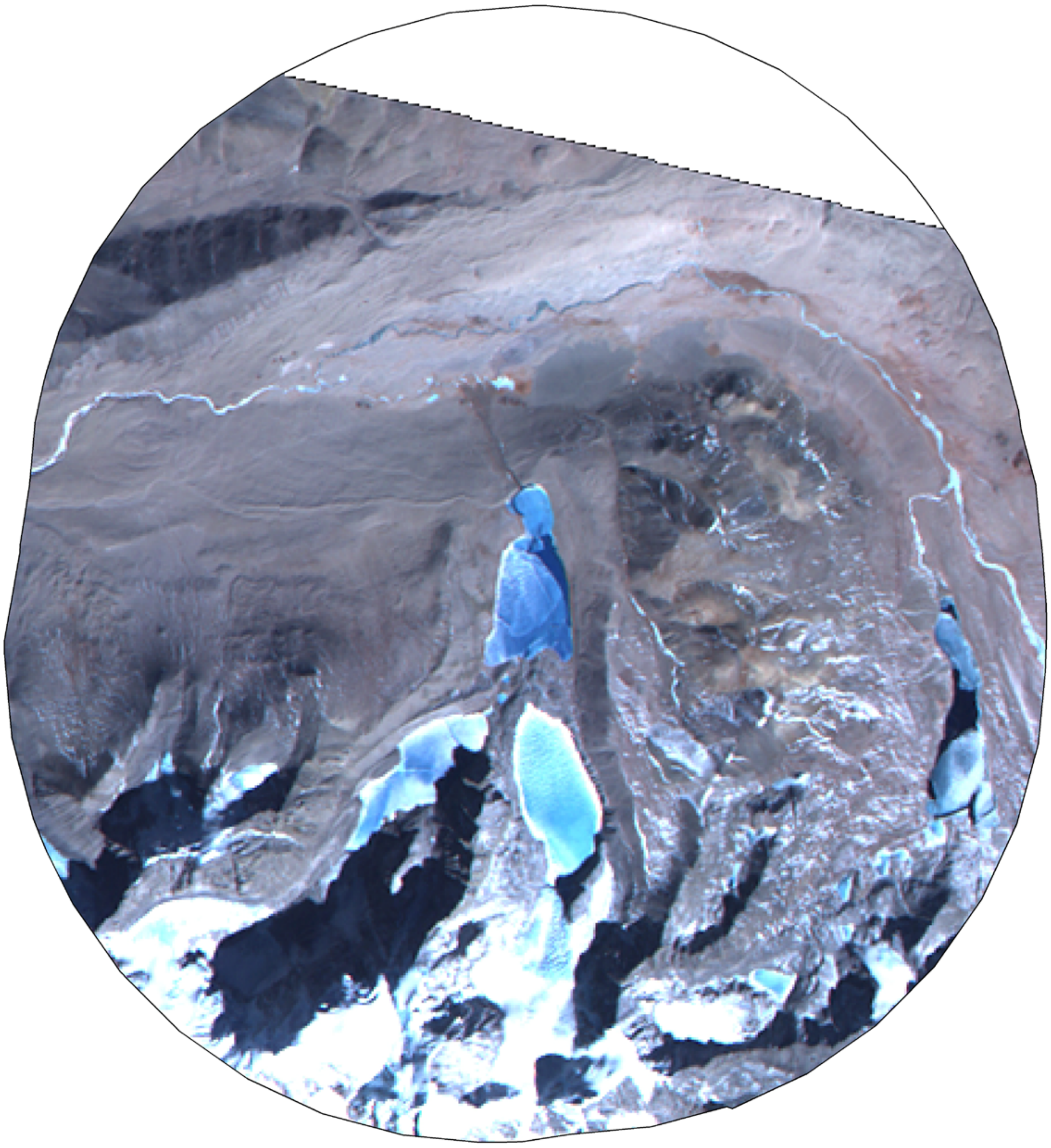
0 0.5 1 2 Kilometers

Data Source:
IRS P6 LISS III data (Pre-monsoon and Post-monsoon Seasons: 2005)

Prepared By:
Space Applications Centre (ISRO), Ahmedabad
and
Sikkim State Council of Science and Technology, DST

Sponsored By:
Ministry of Environment and Forests
Government of India

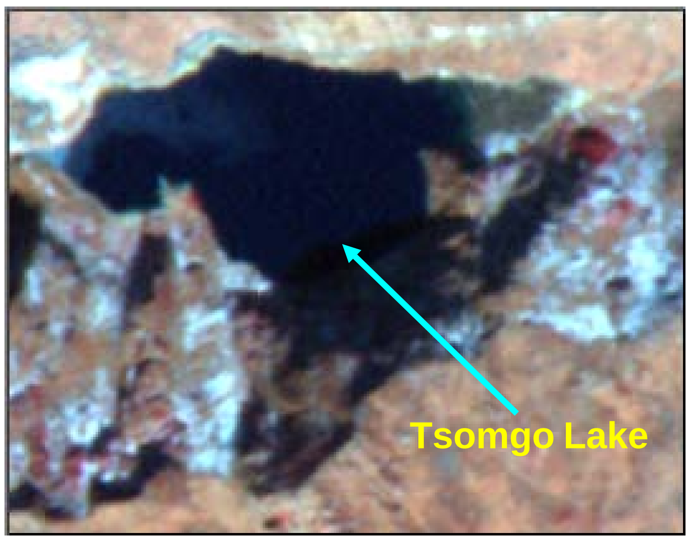
Plate 7: Wetland map - 5 km buffer area of Gurudogmar Lake



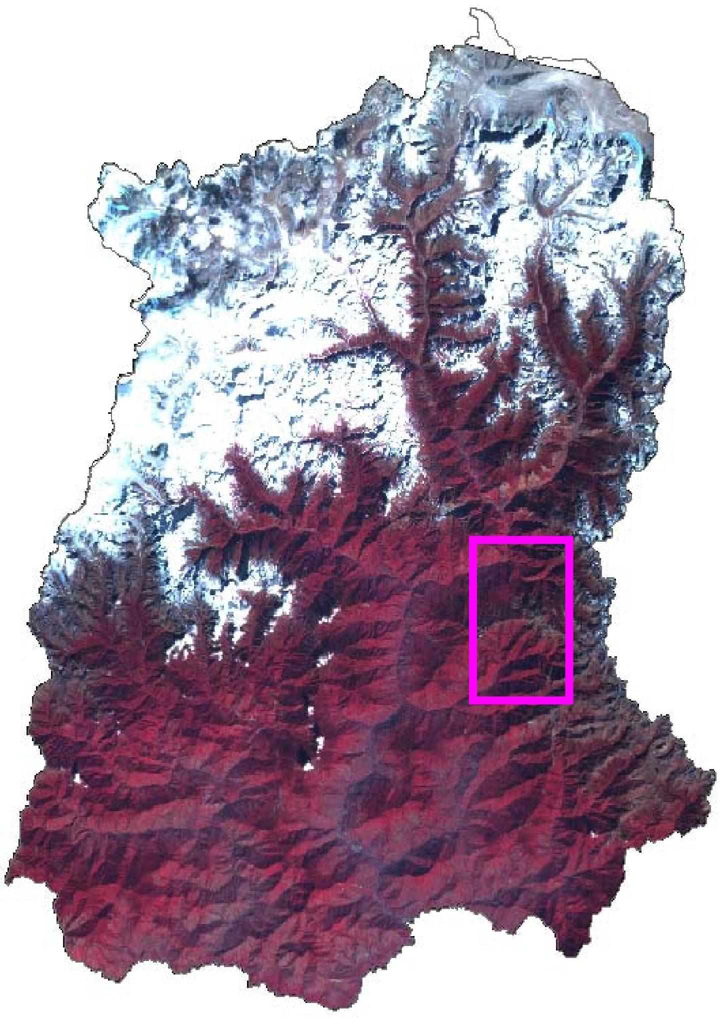
IRS P6 LISS-III post-monsoon data (2005)

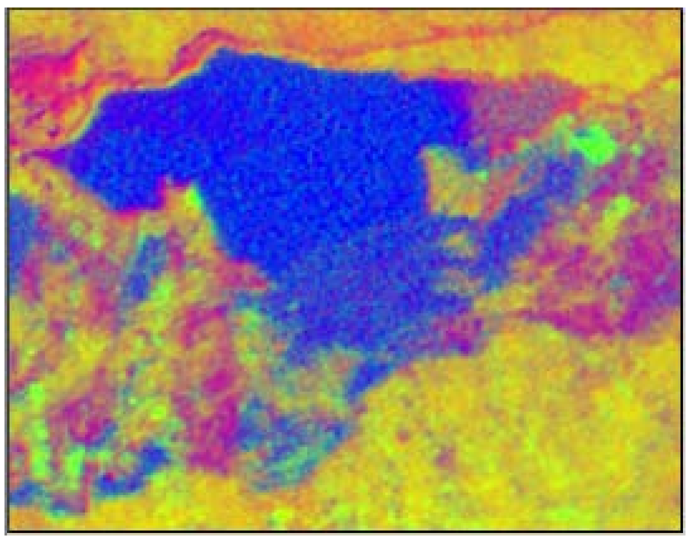
Plate 8: Gurudogmar Lake as seen on IRS P6 LISS-III image with 5 km buffer area

Name	**Tsomgo Lake**
Location	Upper left: 27^{0} 22' 36.68" N, 88^{0} 45' 28.24" E Lower right: 27^{0} 22' 22.47" N, 88^{0} 45' 58.85" E
Area	24.47 ha
Altitude	3,759 M
	The lake is nearly oval-shaped and freezes during the winter season up to mid-May.
Climate	Average annual rainfall : 1183 mm Temeperature : 0^{o} to 35^{o} C.
Morphometric features	Maximum length : 836m Maximum breadth: 427m Maximum depth: 4.58 m Average depth : 15 m
Turbidity	Moderate
Vegetation	Mainly Alpine vegetation includig Rhododendrons, Primula species, blue and yellow Poppies, Irises
Fauna	A great diversity of invertebrate and vertebrate fauna is associated with Tsomgo Lake. Red Panda, Brahminy ducks and various species of birds are found.
	Indian Postal Service released a commemorative stamp on the lake on 6 November 2006.
	The lake falls in restricted area and hence permit is required to visit the place. It is a major hotspot for tourism in Sikkim hence anthropogenic pressure is mounting on the lake.



IRS P6 LISS IV, January 07, 2008





NDWI NDVI NDTI from LISS-IV data

Plate 9: Tsomgo Lake

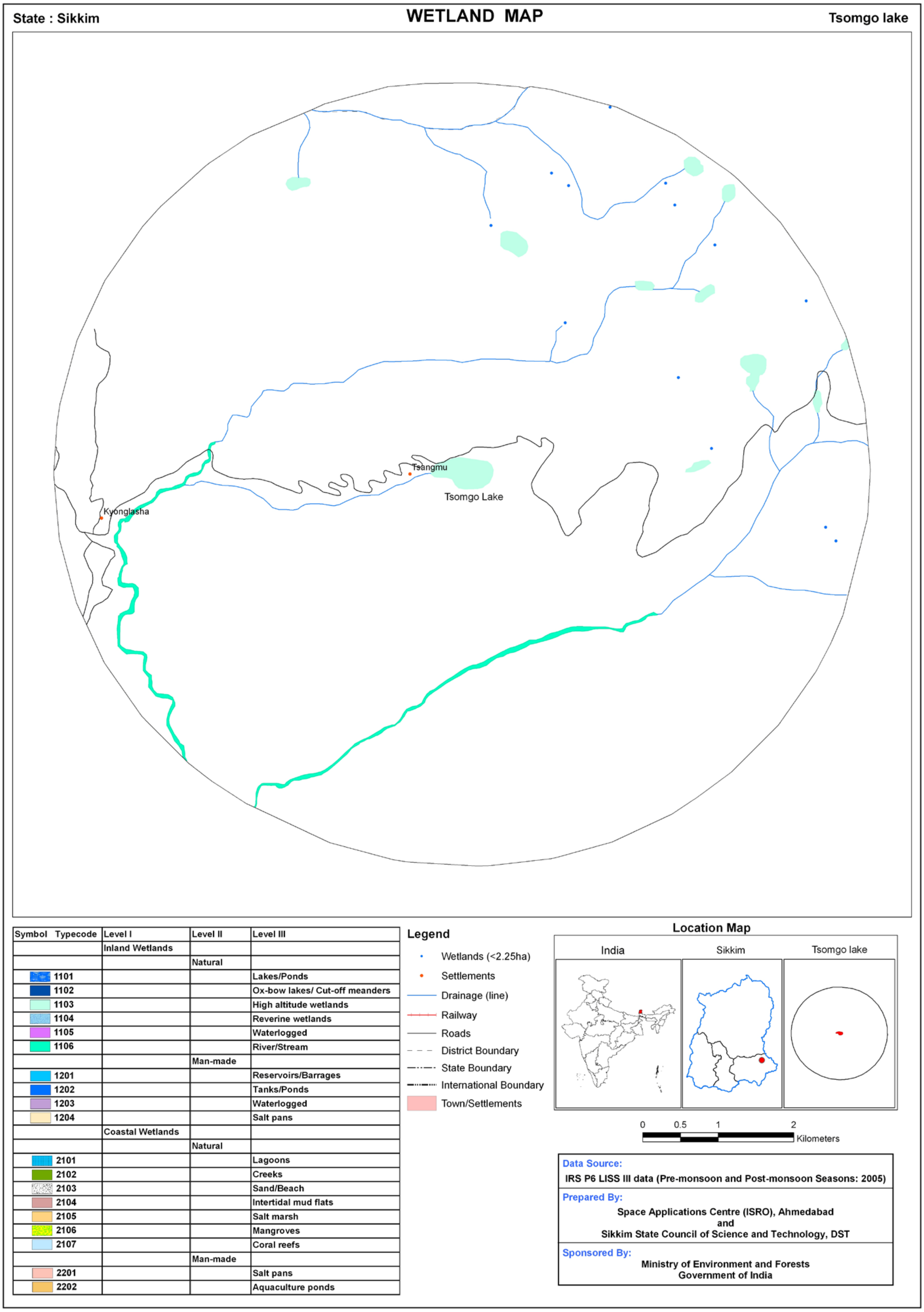
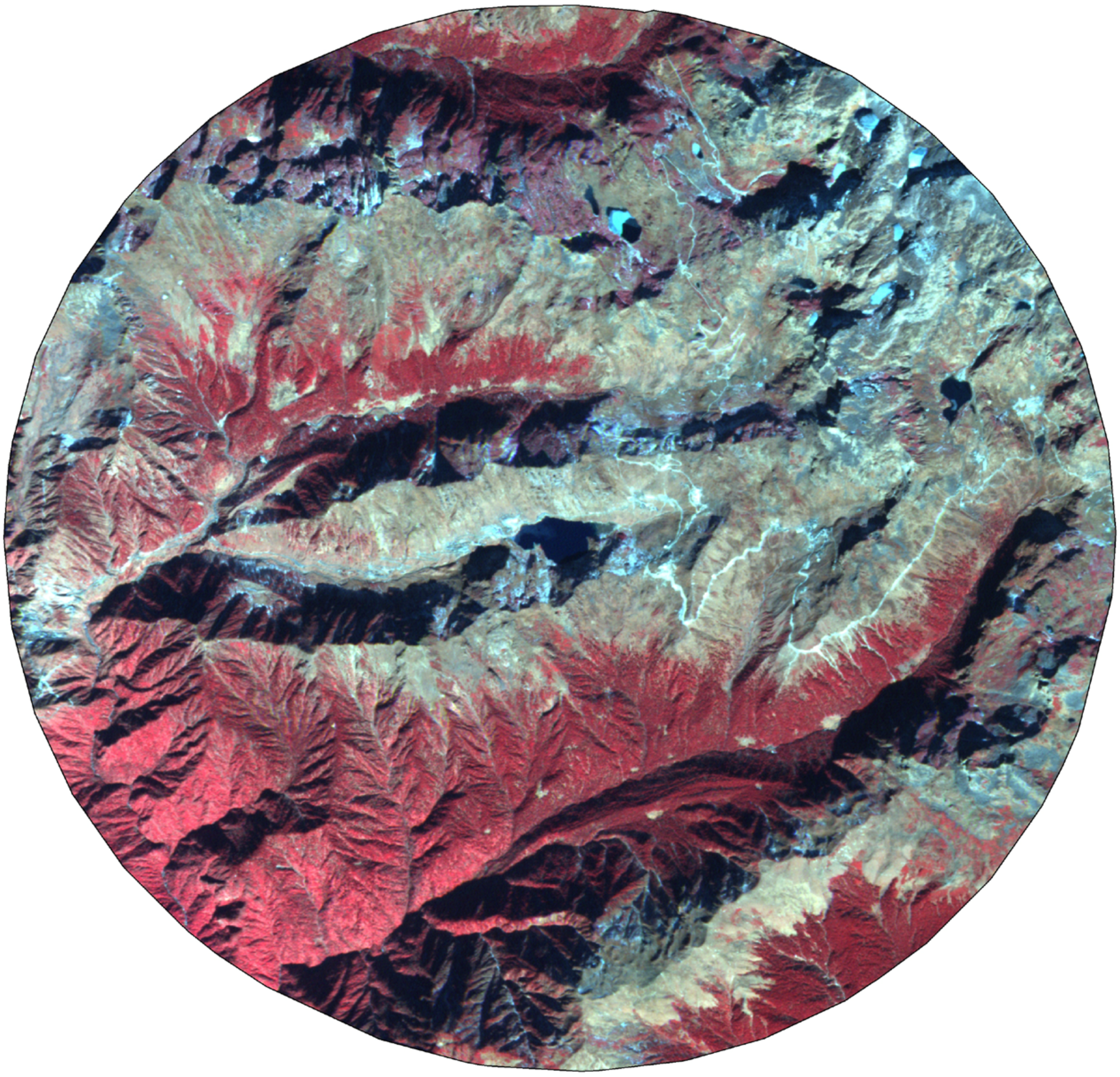


Plate 10: Wetland map - 5 km buffer area of Tsomgo Lake



IRS P6 LISS-IV post-monsoon data (2009)

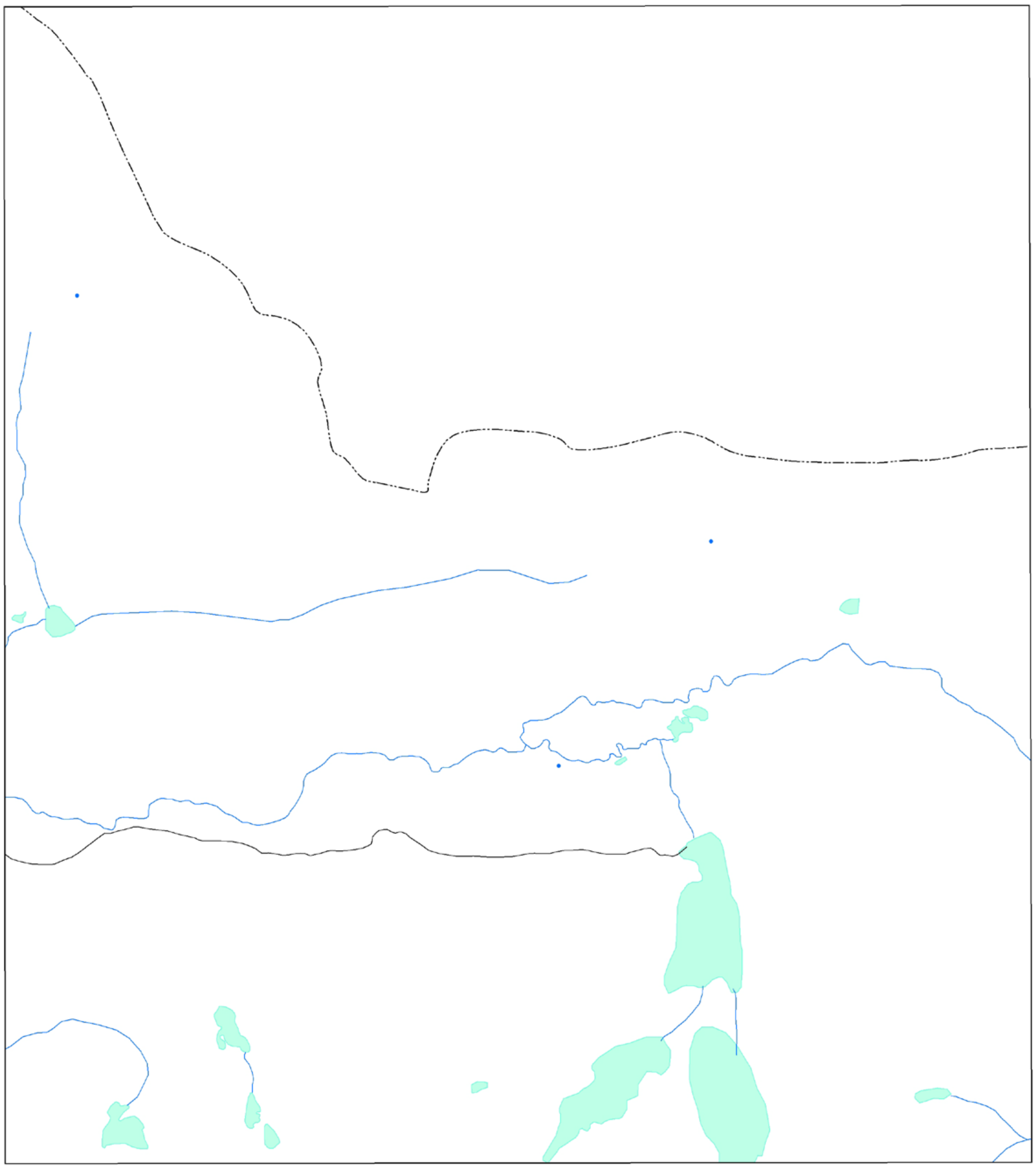
Plate 11: Tsomgo Lake as seen on IRS P6 LISS-IV image with 5 km buffer area

SOI MAP SHEET-WISE WETLAND MAPS (SELECTED)

State : Sikkim

WETLAND MAP

Sheet : 77D/12 SE

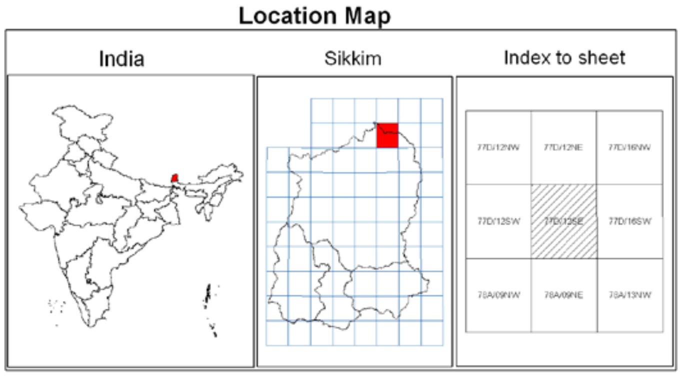


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine Wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



Data Source :

IRS P6 LISS IV data (2008-09)

Prepared By :

Space Applications Centre (ISRO), Ahmedabad

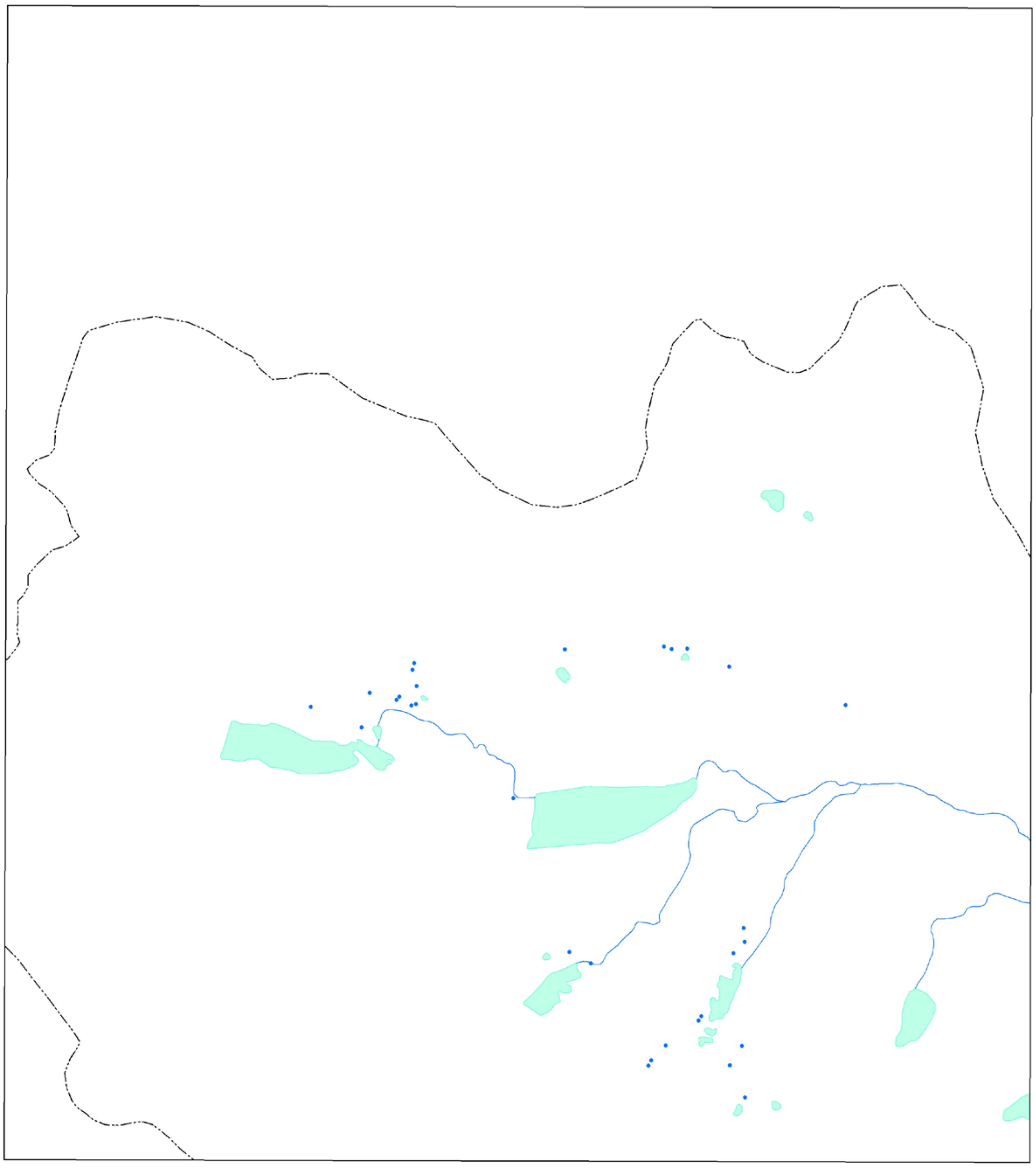
Sponsored By:

Ministry of Environment and Forests
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/01NE

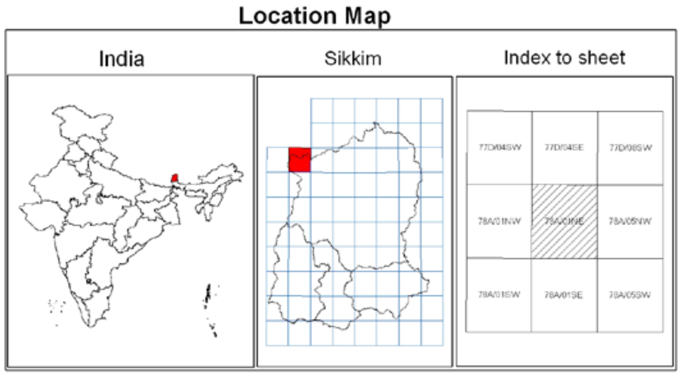


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine Wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



0 1 2 4 Kilometers

Data Source :

IRS P6 LISS IV data (2008-09)

Prepared By :

Space Applications Centre (ISRO), Ahmedabad

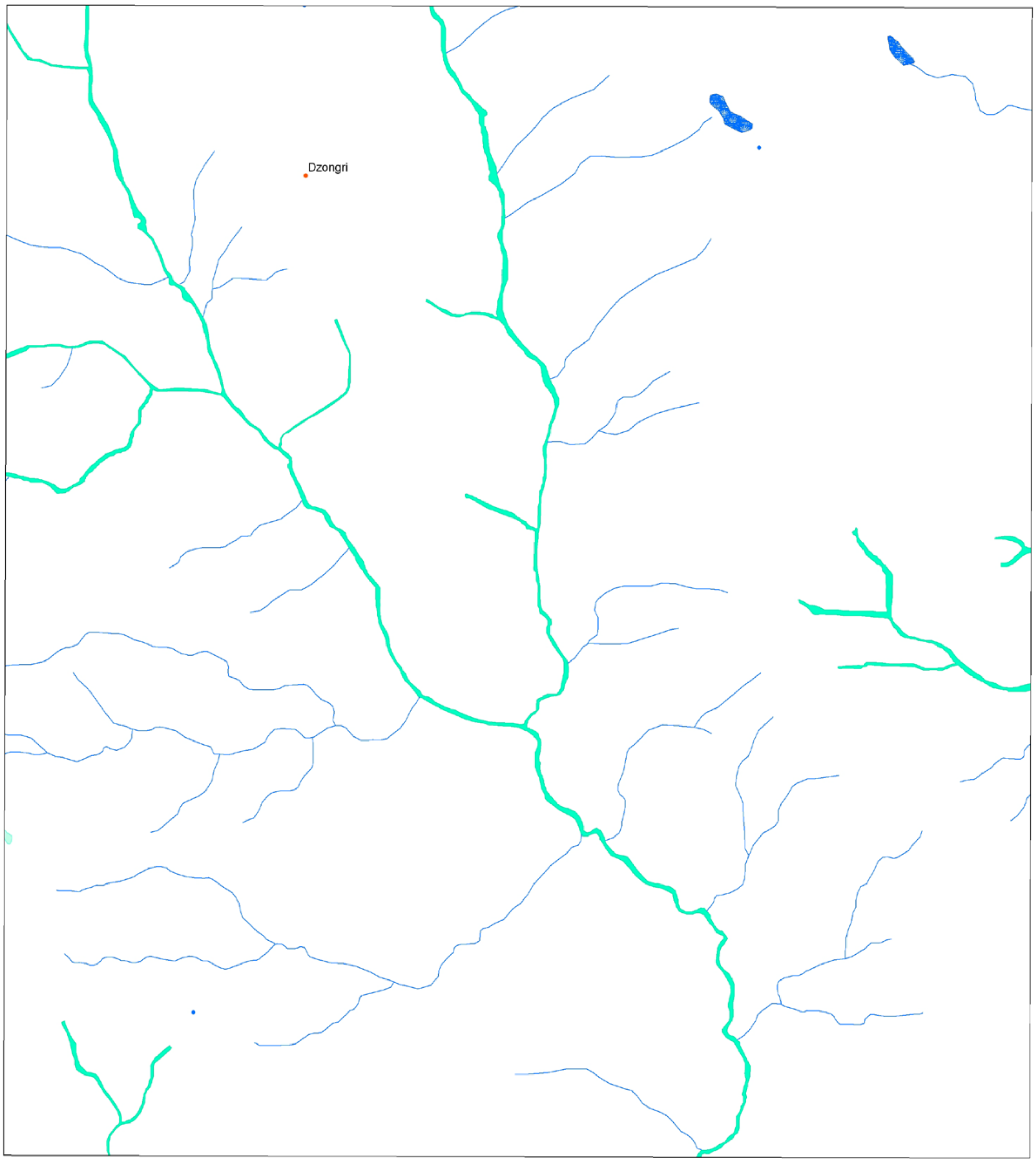
Sponsored By:

Ministry of Environment and Forests
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/03NE



Symbol	Typecode	Level I	Level II	Level III
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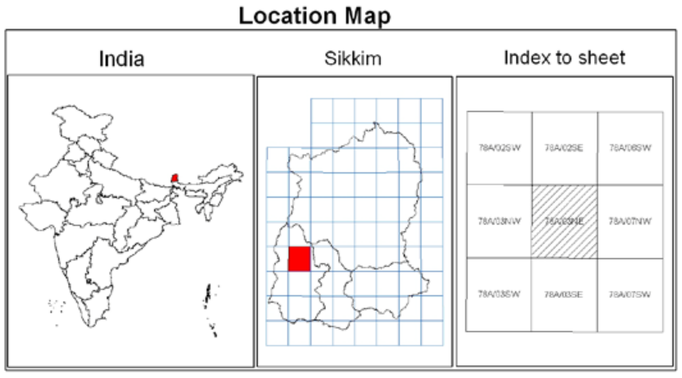
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine Wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



0 1 2 4 Kilometers

Data Source :
IRS P6 LISS IV data (2008-09)

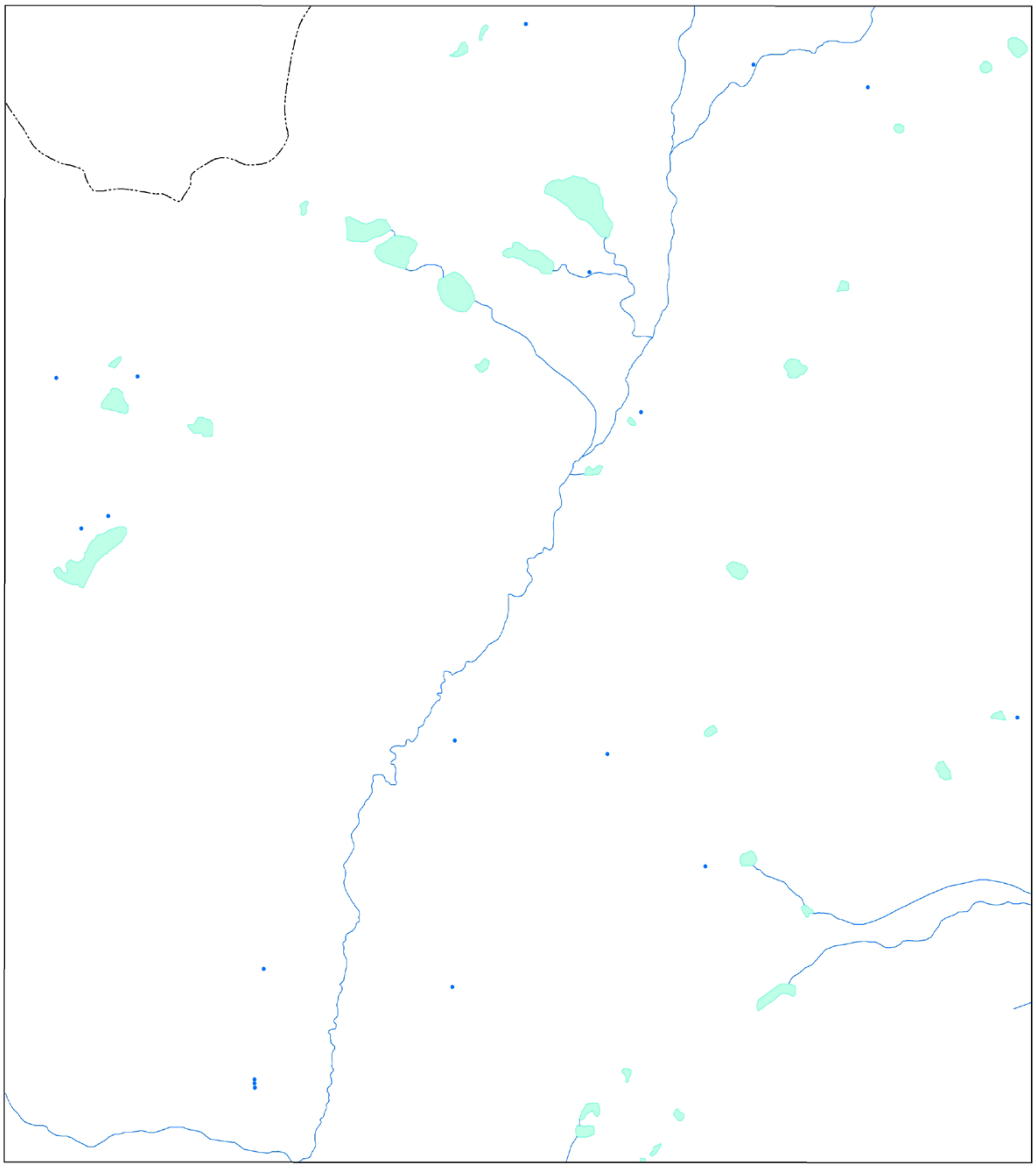
Prepared By :
Space Applications Centre (ISRO), Ahmedabad

Sponsored By:
Ministry of Environment and Forests
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/05NE



Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine Wetlands
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			Man-made	
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	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
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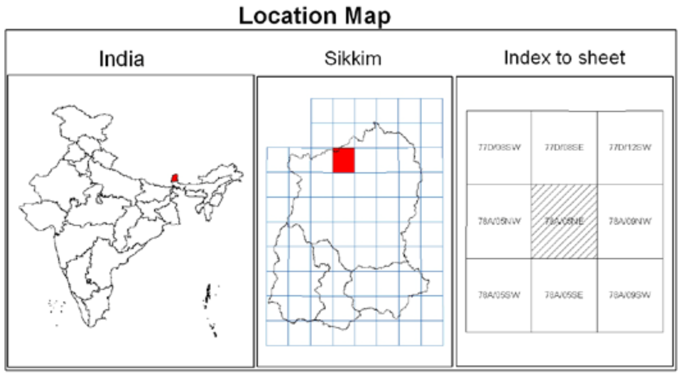
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



Data Source :

IRS P6 LISS IV data (2008-09)

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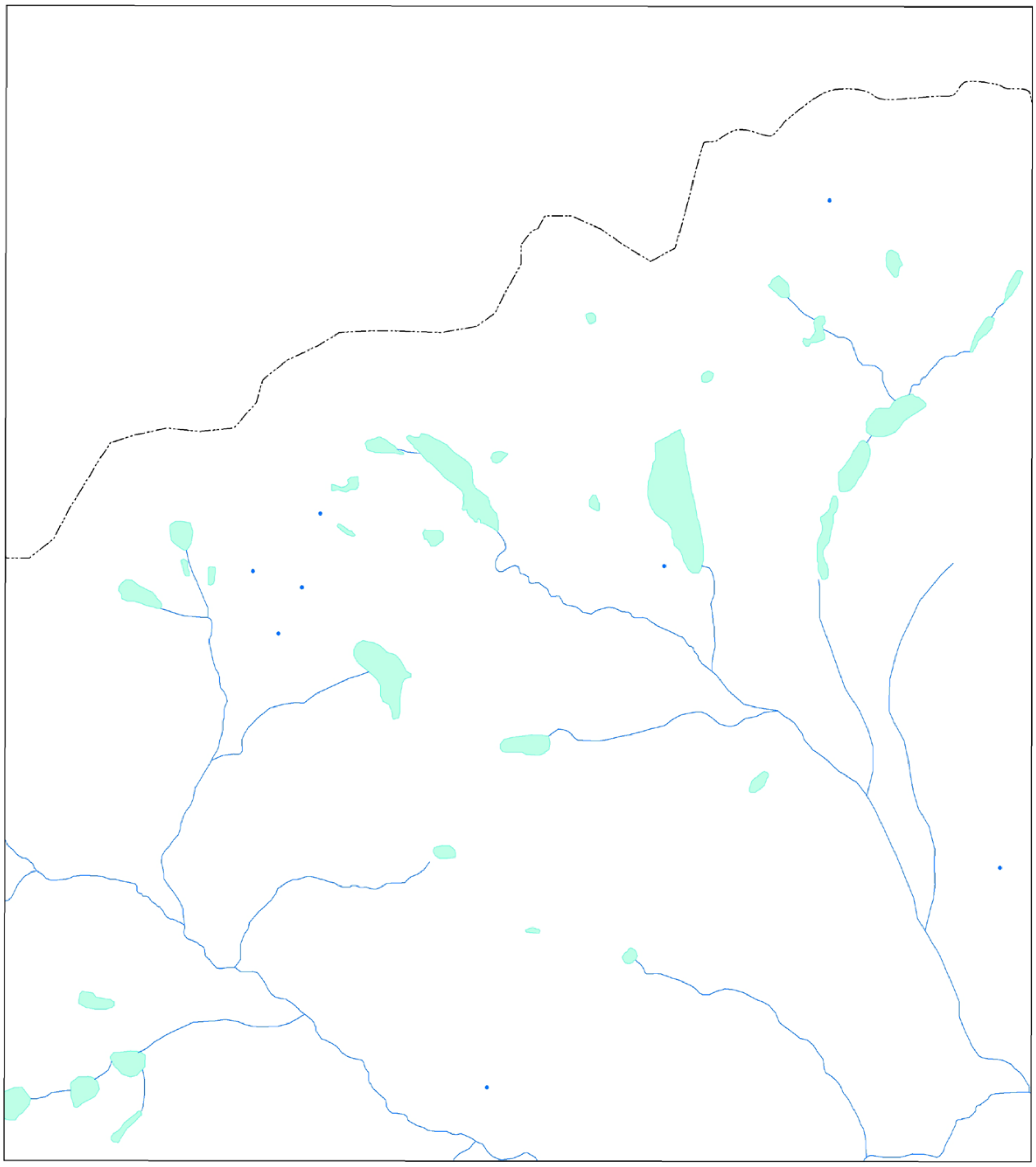
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/05NW

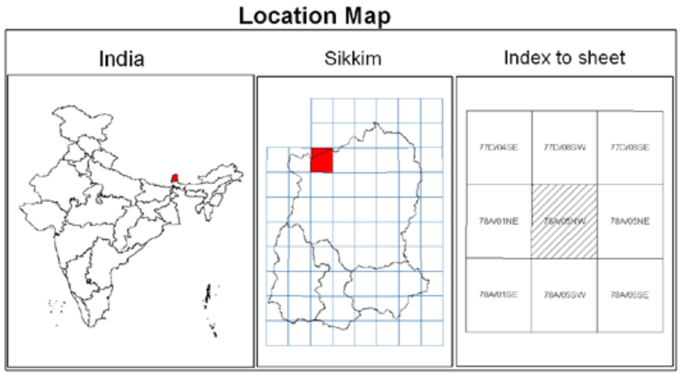


Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
	1103			High altitude wetlands
	1104			Riverine Wetlands
	1105			Waterlogged
	1106			River/Stream
			Man-made	
	1201			Reservoirs/Barrages
	1202			Tanks/Ponds
	1203			Waterlogged
	1204			Salt pans
		Coastal Wetlands		
			Natural	
	2101			Lagoons
	2102			Creeks
	2103			Sand/Beach
	2104			Intertidal mud flats
	2105			Salt marsh
	2106			Mangroves
	2107			Coral reefs
			Man-made	
	2201			Salt pans
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



Data Source :
IRS P6 LISS IV data (2008-09)

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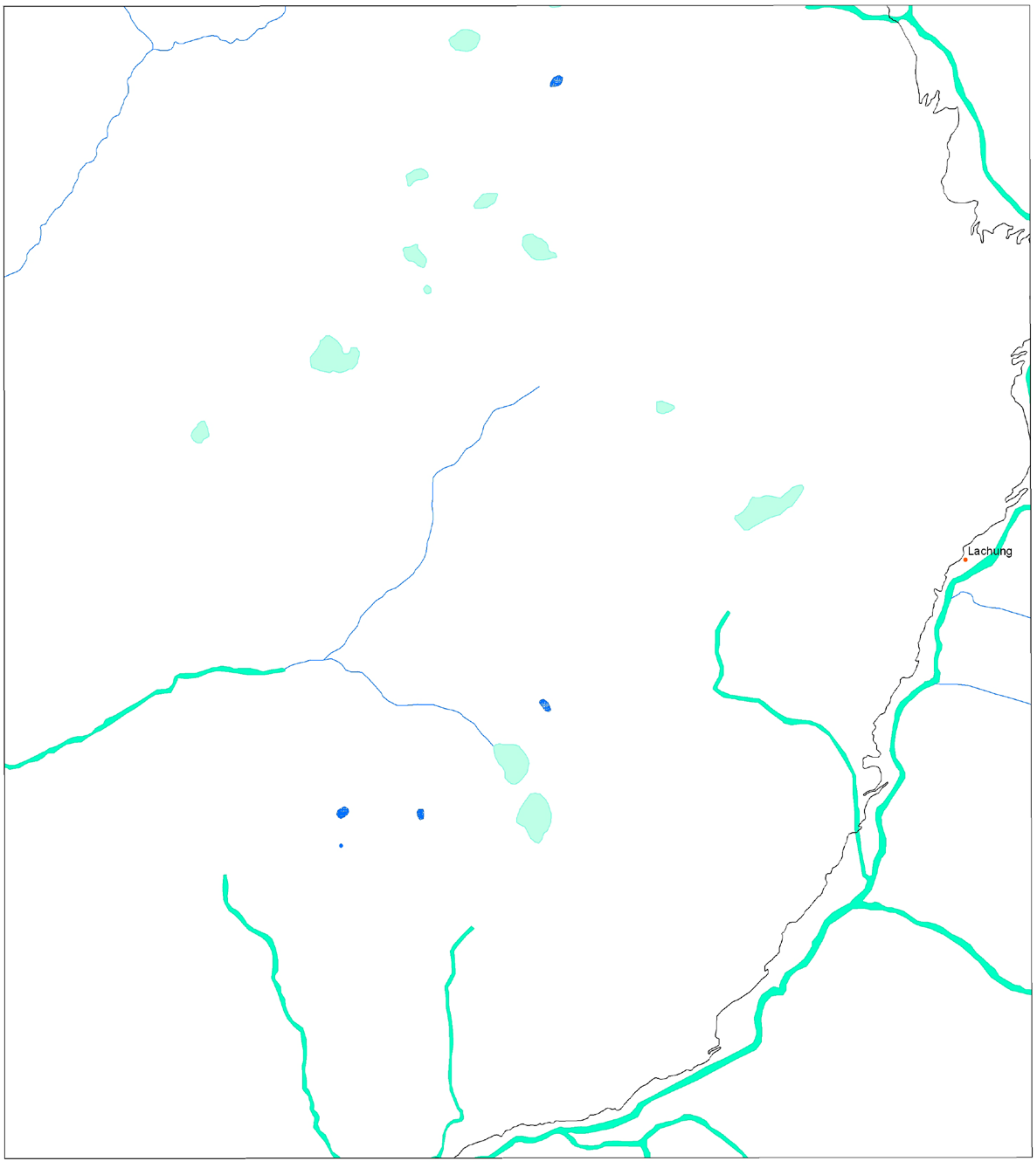
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/10NE



Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
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	2105			Salt marsh
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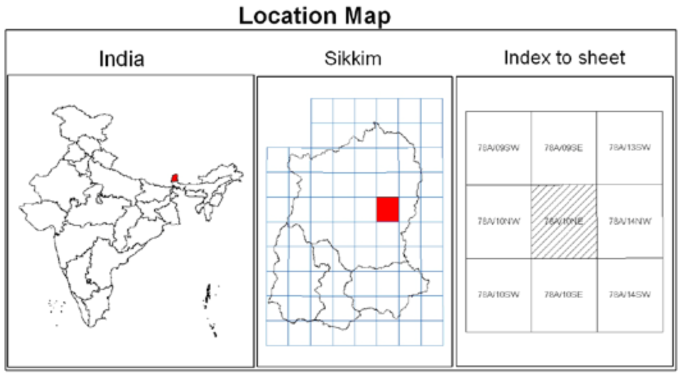
	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
- Drainage (line)
- Railway
- Roads
- District Boundary
- State Boundary
- International Boundary
- Town/Settlements

Location Map



Data Source :
IRS P6 LISS IV data (2008-09)

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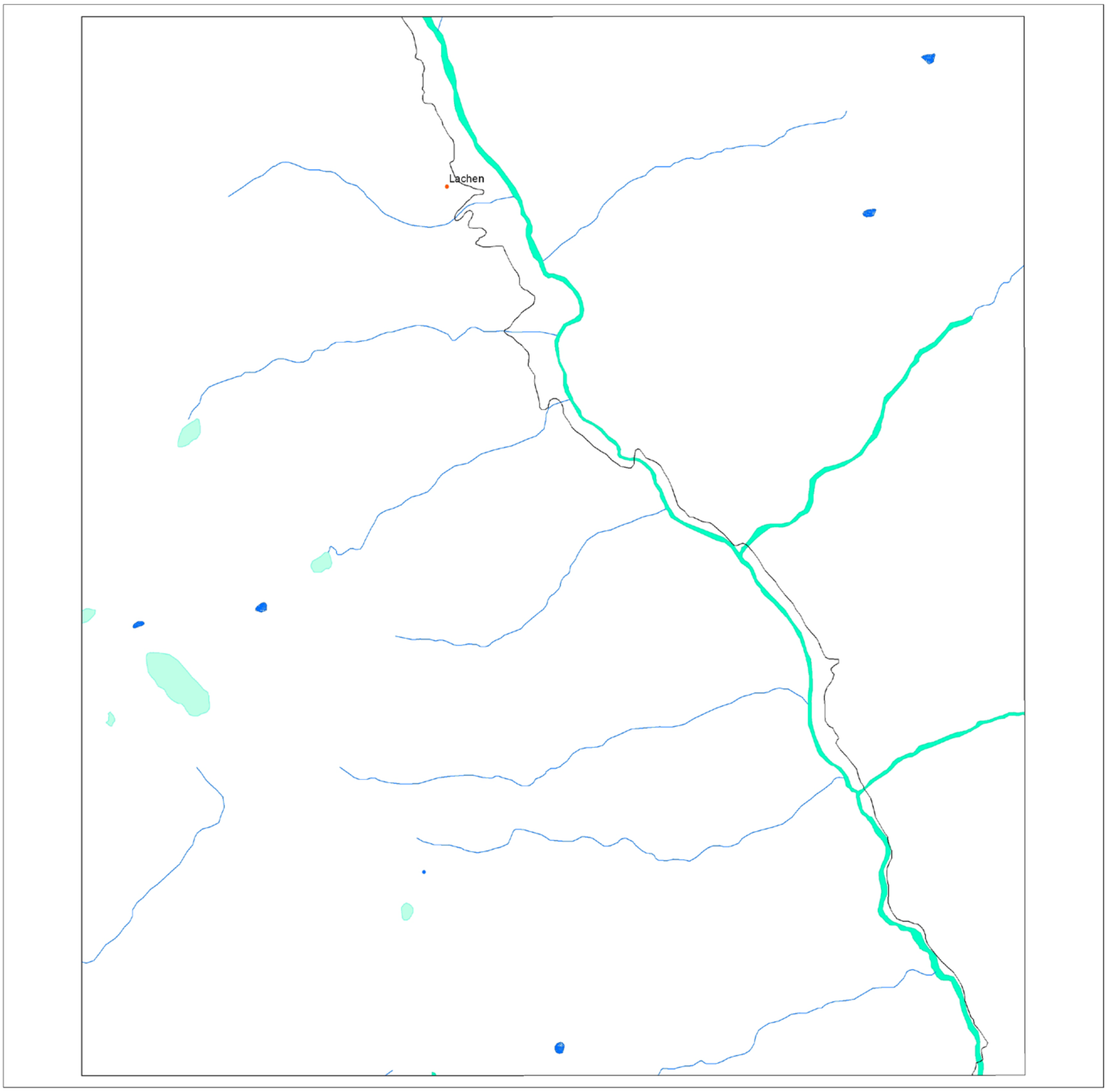
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/10NW



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Legend

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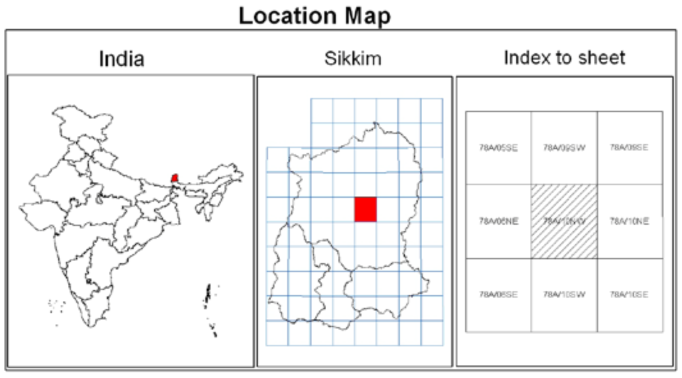
Location Map



Data Source :
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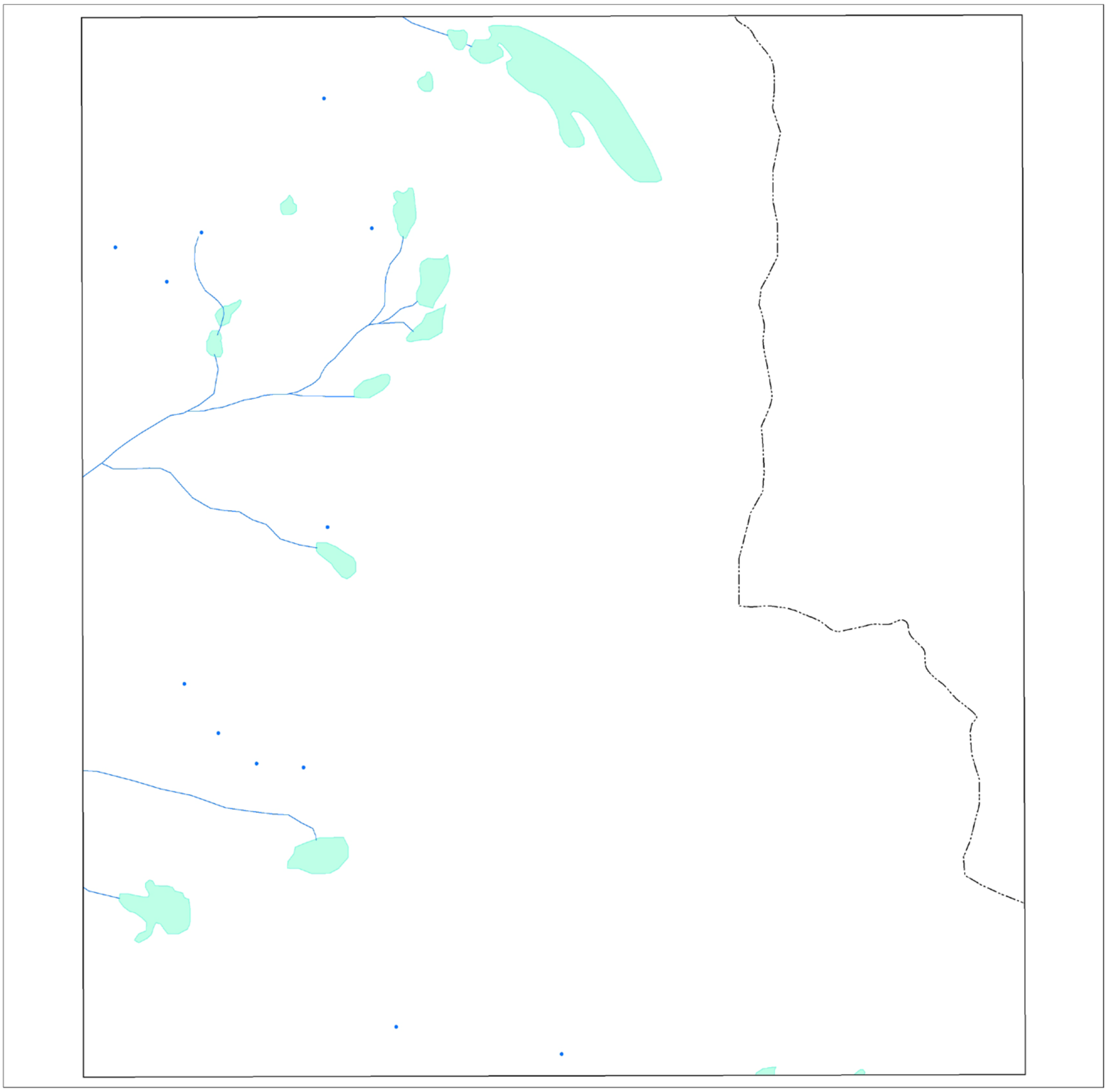
WETLAND MAP

Sheet : 78A/13NW



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			Natural	
	1101			Lakes/Ponds
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			Man-made	
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	2202			Aquaculture ponds

Legend

- Wetlands (<0.50 ha)
- Settlements
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- State Boundary
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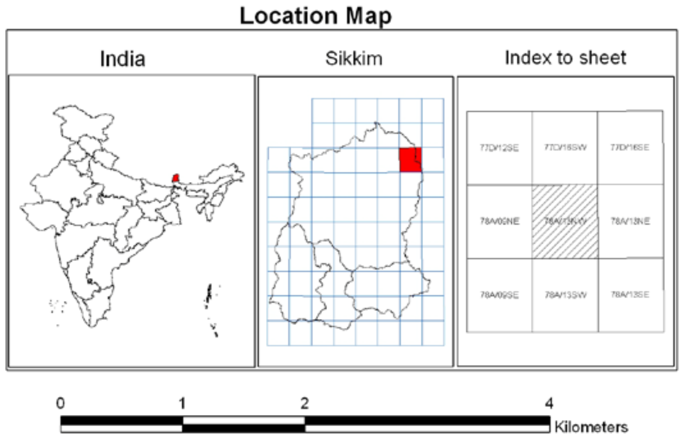
Location Map



Data Source :
IRS P6 LISS IV data (2008-09)

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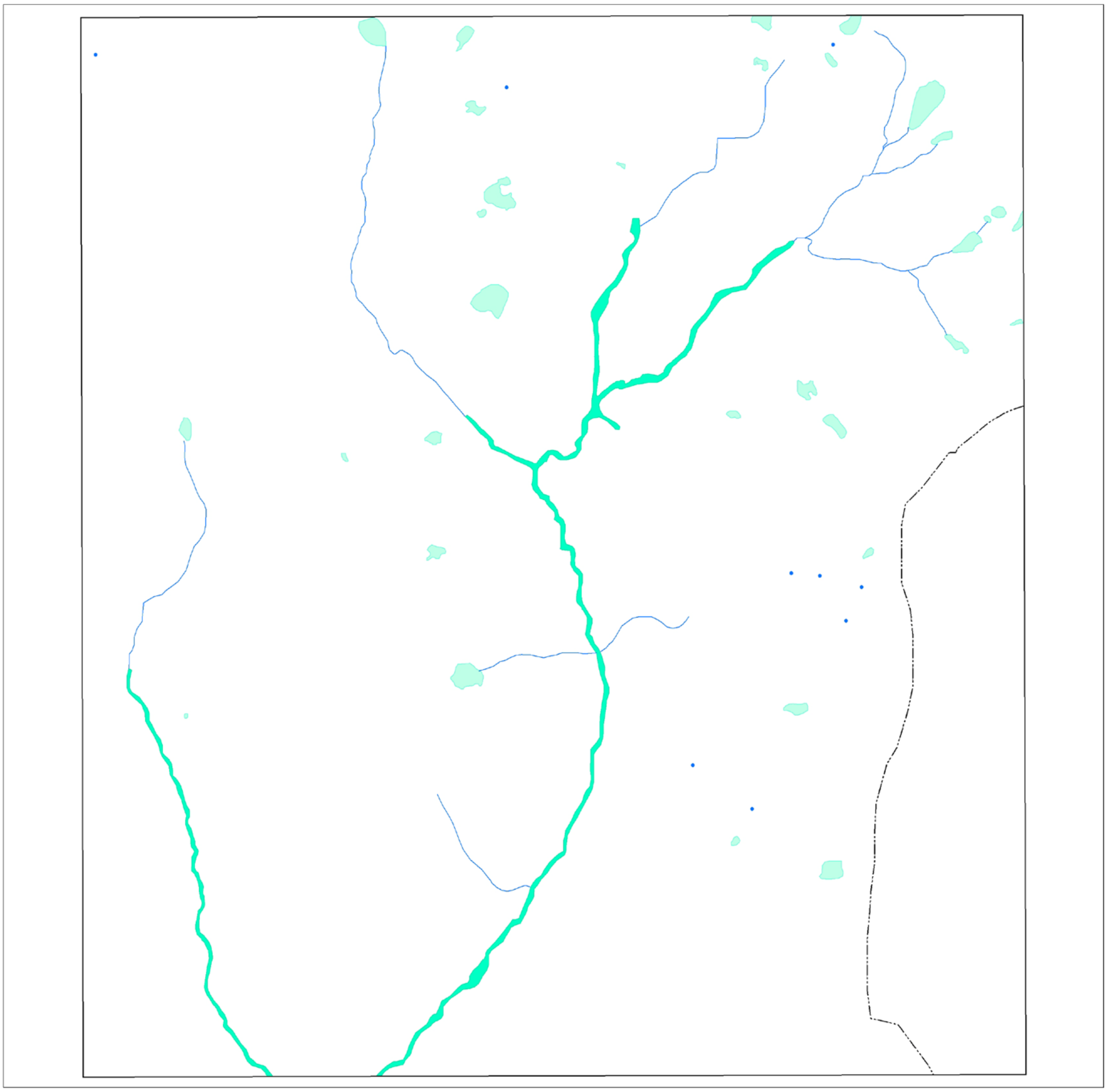
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/13SW



Symbol	Typecode	Level I	Level II	Level III
		Inland Wetlands		
			Natural	
	1101			Lakes/Ponds
	1102			Ox-bow lakes/ Cut-off meanders
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Legend

- Wetlands (<0.50 ha)
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- International Boundary
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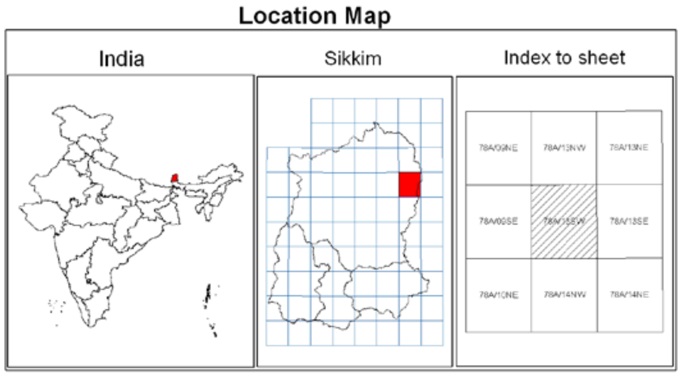
Location Map



0 1 2 4 Kilometers

Data Source :
IRS P6 LISS IV data (2008-09)

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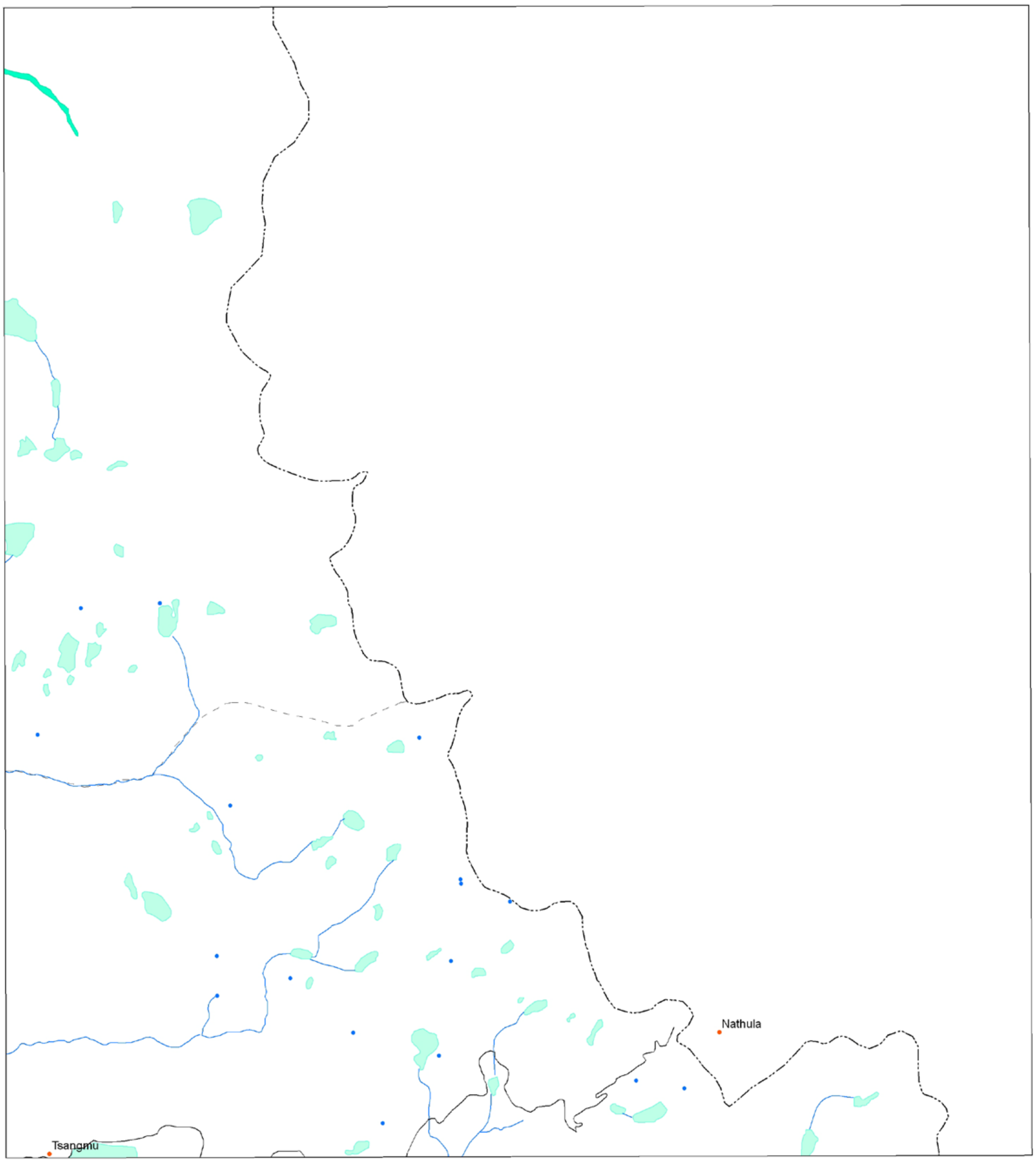
Government of India

State : Sikkim

WETLAND MAP

Sheet : 78A/15NW



Symbol	Typecode	Level I	Level II	Level III
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			Natural	
	1101			Lakes/Ponds
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Legend

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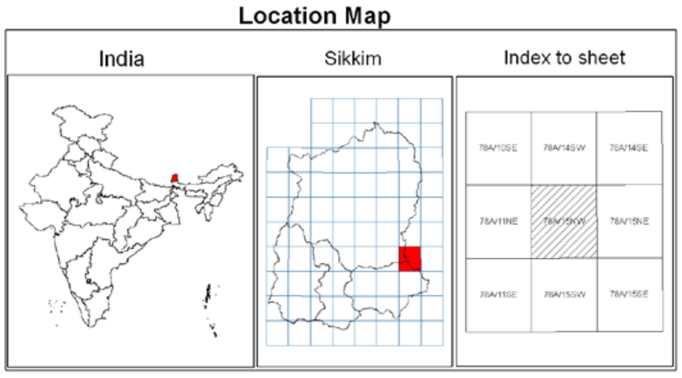

0 1 2 4 Kilometers

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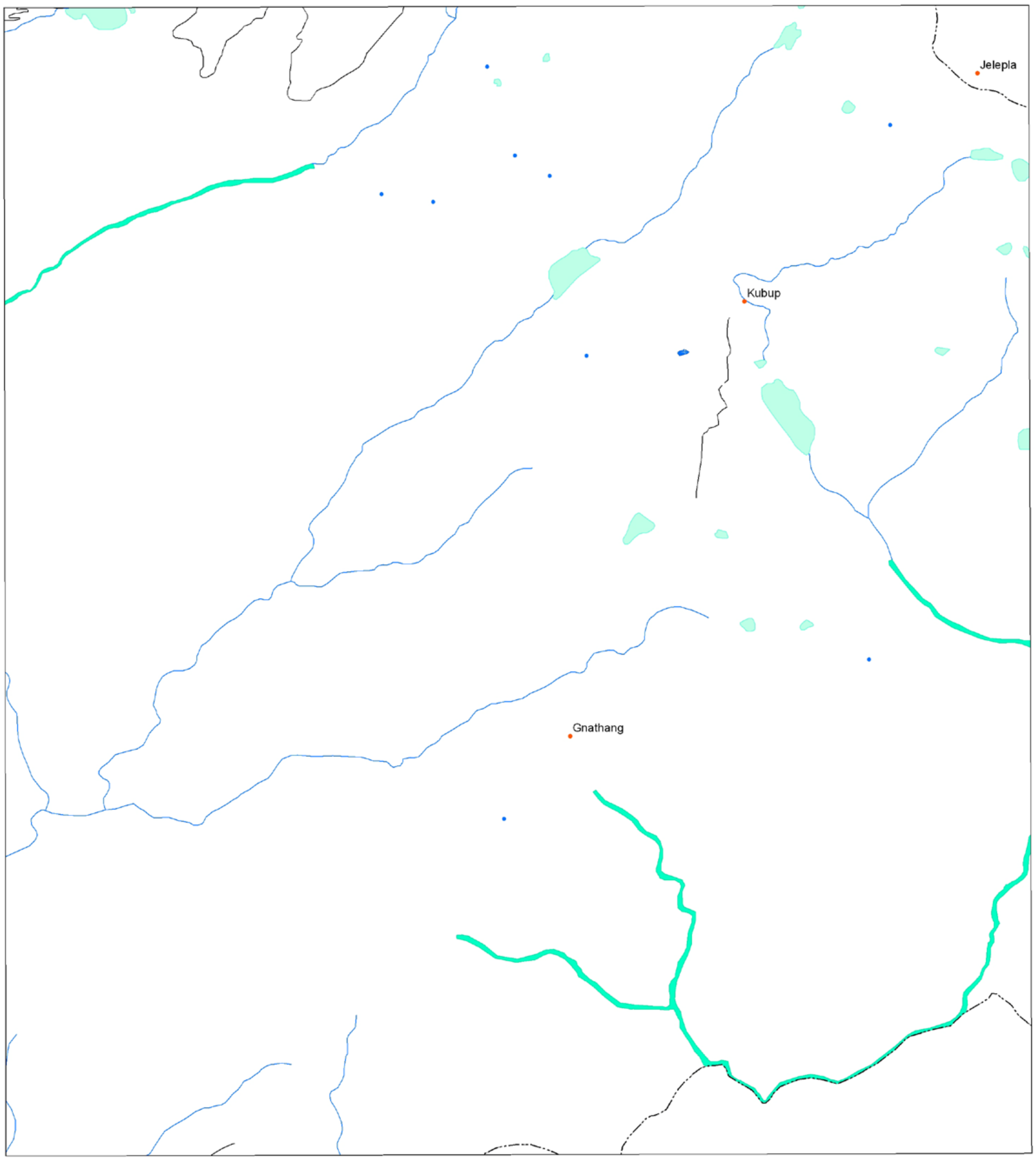
WETLAND MAP

Sheet : 78A/15SW



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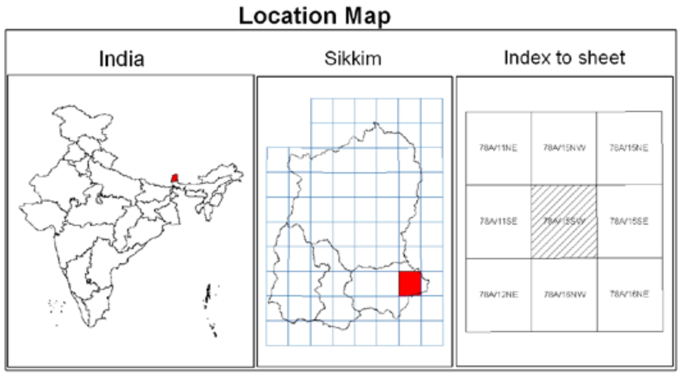

0 1 2 4 Kilometers

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Annexure I
Definitions of wetland categories used in the project

For ease of understanding, definitions of wetland categories and their typical appearance on satellite imagery is given below:

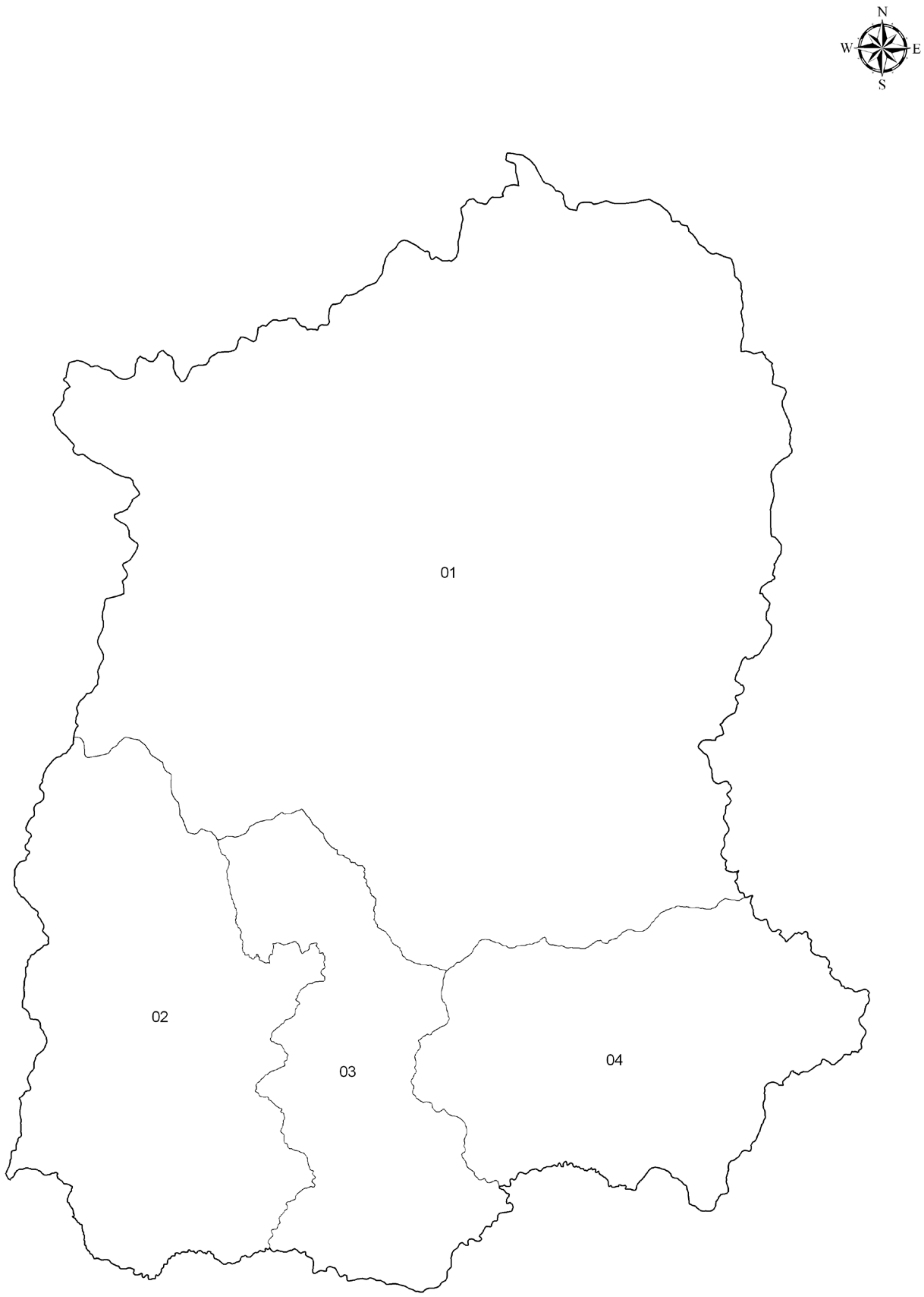
Wetland type code	Definition and description
1000	**Inland Wetlands**
1100	**Natural**
1101	**Lakes**: Larger bodies of standing water occupying distinct basins (Reid *et al*, 1976). These wetlands occur in natural depressions and normally fed by streams/rivers. On satellite images lakes appear in different hues of blue interspersed with pink (aquatic vegetation), islands (white if unvegetated, red in case of terrestrial vegetation). Vegetation if scattered make texture rough.
1102	**Ox-bow lakes/ Cut off meanders**: A meandering stream may erode the outside shores of its broad bends, and in time the loops may become cut-off, leaving basins. The resulting shallow crescent-shaped lakes are called oxbow lakes (Reid *et al*, 1976). On the satellite image Ox-bow lakes occur near the rivers in plain areas. Some part of the lake normally has aquatic vegetation (red/pink in colour) during pre-monsoon season.
1103	**High Altitude lakes:** These lakes occur in the Himalayan region. Landscapes around high lakes are characterized by hilly topography. Otherwise they resemble lakes in the plain areas. For keeping uniformity in the delineation of these lakes contour line of 3000 m above msl will be taken as reference and all lakes above this contour line will be classified as high altitude lakes.
1104	**Riverine Wetlands**: Along the major rivers, especially in plains water accumulates leading to formation of marshes and swamp. **Swamps** are 'Wetland dominated by trees or shrubs' (U.S. Definition). In Europe, a forested fen (a peat accumulating wetland that has no significant inflows or outflows and supports acidophilic mosses, particularly *Sphagnum*) could be called a swamp. In some areas reed grass - dominated wetlands are also called swamps). (Mitsch and Gosselink, 1986). **Marsh**: A frequently or continually inundated wetland characterised by emergent herbaceous vegetation adapted to saturated soil conditions. In European terminology a marsh has a mineral soil substrate and does not accumulate peat (Mitsch and Gosselink, 1986). Tone is grey blue and texture is smooth. **Comment**: Using satellite data it is difficult to differentiate between swamp and marsh. Hence, both have been clubbed together.
1105	**Waterlogged:** Said of an area in which water stands near, at, or above the land surface, so that the roots of all plants except hydrophytes are drowned and the plants die (Margarate *et al*, 1974). Floods or unlined canal seepage and other irrigation network may cause water-logging. Spectrally, during the period when surface water exists, waterlogged areas appear more or less similar to lakes/ponds. However, during dry season large or all parts of such areas dry up and give the appearance of mud/salt flats (grey bluish).
1106	**River/stream:** Rivers are linear water features of the landscape. Rivers that are wider than the mapping unit will be mapped as polygons. Its importance arises from the fact that many stretches of the rivers in Indo-Gangetic Plains and peninsular India are declared important national and international wetlands (Ex. The river Ganga between Brajghat and Garh Mukteshwar, is a Ramsar site, Ranganthattu on the Cavery river is a bird sanctuary etc.). Wherever, rivers are wide and features like sand bars etc. are visible, they will be mapped.
1200	**Man-made**
1201	***Reservoir**: A pond or lake built for the storage of water, usually by the construction of a dam across a river (Margarate et al, 1974). On RS images, reservoirs have irregular boundary behind a prominent dyke. Wetland boundary in case of reservoir incorporates water, aquatic vegetation and footprint of water as well. In the accompanying images aquatic vegetation in the reservoir is seen in bright pink tone. Tone is dark blue in deep reservoirs while it is ink blue in case of shallow reservoirs or reservoirs with high silt load. These will be annotated as Reservoirs/Dam.* **Barrage:** Dykes are constructed in the plain areas over rivers for creating Irrigation/water facilities. Such water storage areas develop into wetlands (Harike Barrage on Satluj – a Ramsar site, Okhla barrage on the Yamuna etc. – a bird sanctuary). Water appears in dark blue tone with a smooth texture. Aquatic vegetation appears in pink colour, which is scattered, or contiguous depending on the density. Reservoirs formed by barrages will be annotated as reservoir/barrage.

1202	**Tanks/Ponds:** A term used in Ceylon and the drier parts of Peninsular India for an artificial pond, pool or lake formed by building a mud wall across the valley of a small stream to retain the monsoon (Margarate *et al*, 1974). **Ponds** Generally, suggest a small, quiet body of standing water, usually shallow enough to permit the growth of rooted plants from one shore to another (Reid *et al*, 1976). Tanks appear in light blue colour showing bottom reflectance. In this category **Industrial ponds/mining pools mainly comprising Abandoned Quarries are also included (**Quarry is defined as "An open or surface working or excavation for the extraction of stone, ore, coal, gravel or minerals." In such pits water accumulate (McGraw Hill Encyclopaedia of Environmental Sciences, 1974), **Ash pond/Cooling pond** (The water body created for discharging effluents in industry, especially in thermal power plants (Encyclopaedic Directory of Environment, 1988) and **Cooling pond**: An artificial lake used for the natural cooling of condenser-cooling water serving a conventional power station (Encyclopaedic Directory of Environment, 1988). These ponds can be of any shape and size. Texture is rough and tonal appearance light (quarry) to blue shade (cooling pond).
1203	**Waterlogged:** Man-made activities like canals cause waterlogging in adjacent areas due to seepage especially when canals are unlined. Such areas can be identified on the images along canal network. Tonal appearance is in various hues of blue. Sometimes, such waterlogged areas dry up and leave white scars on the land. Texture is smooth.
1204	**Salt pans:** Inland salt pans in India occur in Rajasthan (Sambhar lake). These are shallow rectangular man-made depressions in which saline water is accumulated for drying in the sun for making salt.
2000	**Coastal Wetlands**
2100	**Natural**
2101	**Lagoons/Backwaters:** Such coastal bodies of water, partly separated from the sea by barrier beaches or bass of marine origin, are more properly termed lagoons. As a rule, lagoons are elongate and lie parallel to the shoreline. They are usually characteristic of, but not restricted to, shores of emergence. Lagoons are generally shallower and more saline than typical estuaries (Reid *et al*, 1976). **Backwater**: A creek, arm of the sea or series of connected lagoons, usually parallel to the coast, separated from the sea by a narrow strip of land but communicating with it through barred outlets (Margarate *et al*, 1974).
2102	**Creek:** A notable physiographic feature of salt marshes, especially low marshes. These creeks develop as do rivers "with minor irregularities sooner or later causing the water to be deflected into definite channels" (Mitsch and Gosselink, 1986). Creeks will be delineated, however, their area will not be estimated.
2103	**Sand/Beach:** Beach is an unvegetated part of the shoreline formed of loose material, usually sand that extends from the upper berm (a ridge or ridges on the backshore of the beach, formed by the deposit of material by wave action, that marks the upper limit of ordinary high tides and wave wash to low water mark(Clark,1977).Beach comprising rocky material is called rocky beach.
2104	**Intertidal mudflats**: Most unvegetated areas that are alternately exposed and inundated by the falling and rising of the tide. They may be mudflats or sand flats depending on the coarseness of the material of which they are made (Clark, 1977).
2105	**Salt Marsh**: Natural or semi-natural halophytic grassland and dwarf brushwood on the alluvial sediments bordering saline water bodies whose water level fluctuates either tidally or non- tidally (Mitsch and Gosselink, 1986). Salt marshes look in grey blue shade when wet.
2106	**Mangroves**: The mangrove swamp is an association of halophytic trees, shrubs, and other plants growing in brackish to saline tidal waters of tropical and sub-tropical coastlines (Mitsch and Gosselink, 1986). On the satellite images mangroves occur in red colour if in contiguous patch. When mangrove associations are scattered or are degraded then instead of red colour, brick red colour may be seen.
2107	**Coral reefs:** Consolidated living colonies of microscopic organisms found in warm tropical waters. The term coral reef, or organic reef is applied to the rock- like reefs built-up of living things, principally corals. They consist of accumulations of calcareous deposits of corals and corraline algae with the intervening space connected with sand, which consists largely of shells of foraminefera. Present reefs are living associations growing on this accumulation of past (Clark, 1977). Reefs appear in light blue shade.
2200	**Man-made**
2201	**Salt pans**: An undrained usually small and shallow rectangular, man-made depression or hollow in which saline water accumulates and evaporates leaving a salt deposit (Margarate *et al*, 1974). Salt pans are square or rectangular in shape. When water is there appearance is blue while salt is formed tone is white.
2202	**Aquaculture ponds**: Aquaculture is defined as "The breeding and rearing of fresh-water or marine fish in captivity. Fish farming or ranching". The water bodies used for the above are called aquaculture ponds (Encyclopaedic Directory of Environment, 1988). Aquaculture ponds are geometrical in shape usually square or rectangular. Tone is blue.

Annexure – II
Details of District information followed in the atlas

State : Sikkim

District Boundary Map



List of Districts

District code	District name
01	North
02	West
03	South
04	East

Legend

State Boundary

District Boundary

Source : Survey of India (Surveyed in 2004 and published in 2005)

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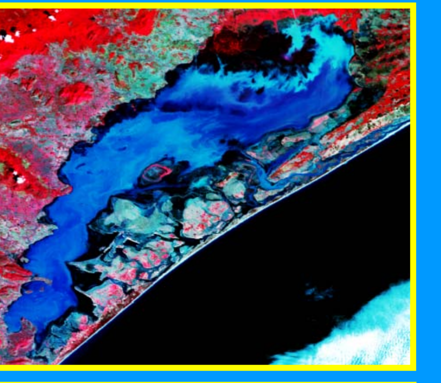
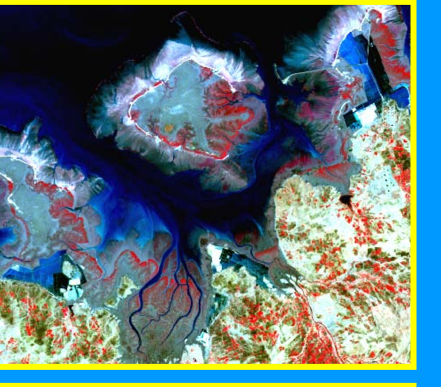

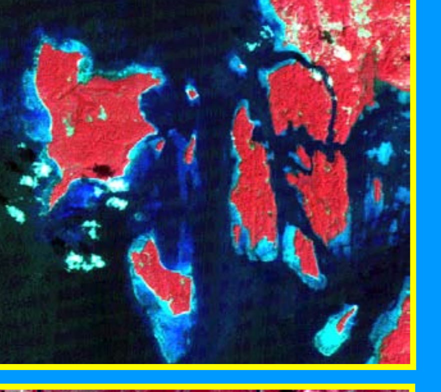

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