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Wetland identification through remote sensing: Insights into wetness, greenness, turbidity, temperature, and changing landscapes

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ABSTRACT

Wetlands are important in many ways, including hydrological cycles, ecosystem diversity, climate change, and economic activity. Despite the Ramsar Convention's awareness programmes, the importance of wetlands is frequently disregarded in underdeveloped countries. The Ramsar Convention recognises 2491 wetlands worldwide, 19 of which are in Pakistan. The goal of this study is to use satellite sensor technology to identify neglected wetlands in Pakistan. The key goals of this research are to analyse water quality, monitor ecological changes, and comprehend the impact of climate change on the aforementioned wetlands. We used approaches like supervised classification and TCW to identify wetlands. To detect climate-induced changes, a change detection index was used to Quick Bird imagery. TCG and the NDTI were also employed to examine the water quality and ecological changes in these wetlands. Sentinel-2 data between 2016 and 2019 were used in the analysis. Furthermore, watershed analysis was carried out using ASTER DEM data. Modis data was used to calculate the LST (°C) of the selected wetlands, while rainfall (mm) data was collected from ANN databases. According to the study's findings, in 2016, Borith, Phander, Upper Kachura, Satpara, and Rama Lake held 22.73%, 20.79%, 23.01%, 24.63%, and 23.03% water, respectively. In 2019, the water ratios for these lakes were 23.40%, 22.10%, 22.43%, 25.01%, and 24.56%. These findings emphasise the need of taking preventative actions to protect these wetlands in order to improve ecosystem dynamics in the future. As a result, it is critical that the relevant authorities implement the necessary conservation measures.

1. Introduction

Wetlands are valuable ecosystems that provide various ecological, economic, and social benefits. They are an important source of freshwater, support biodiversity, regulate climate, and contribute to the livelihoods of millions of people worldwide. However, wetlands are under threat due to various human activities, including urbanization, agriculture, and industrialization. In Pakistan, wetlands are facing significant threats, including land-use change, pollution, and climate change, leading to their degradation and loss.

Remote sensing techniques have proven to be useful tools for identifying and monitoring wetlands. These techniques use satellite data to detect and analyze changes in wetland extent, vegetation, and water quality. They provide valuable information for wetland management and conservation, which is crucial for their sustainable use. Despite the significance of wetlands in Pakistan, many of them remain neglected due to the lack of comprehensive studies and data on their extent and distribution. Through remote sensing techniques, this study intends to uncover time-varying wetlands that have been neglected in Pakistan. The study will use satellite data to analyze wetland dynamics in selected study areas in Pakistan over a period of ten years. The research will also examine the impact of human activities on wetland dynamics and the

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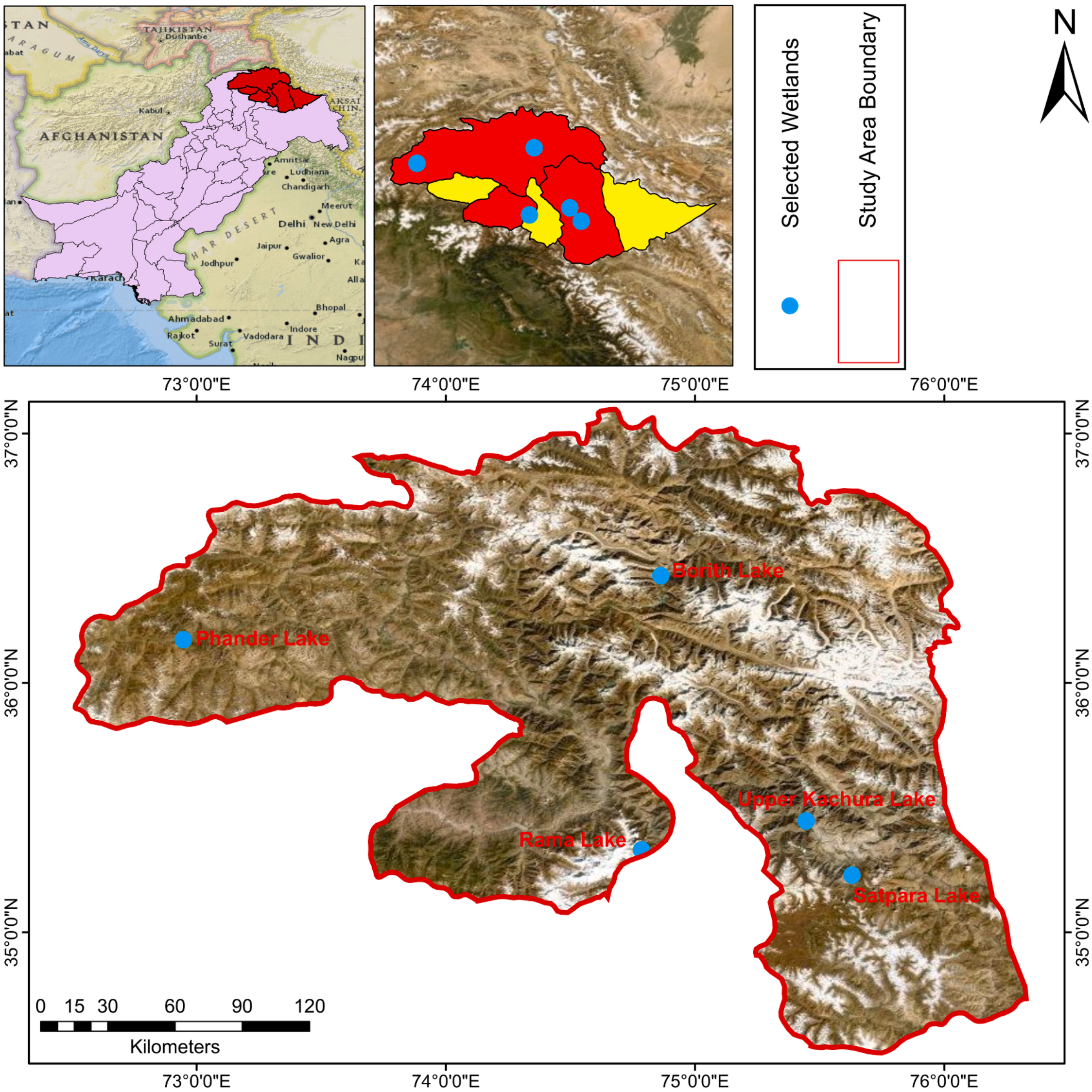

Figure 1. Study area and location of wetlands.

factors affecting wetland distribution and change. Wetlands encompass various types of land, including swamps and marshes, formed by ground-water and rain-water [1]. They might be permanent or temporary, and they can hold fresh or saline water. Wetlands comprise areas such as marshlands, flood plains, ponds, lakes, and water plant vegetation, and they can be natural or man-made [2]. These ecosystems play a crucial role in global climate formation, hydrological cycles, and the protection of diverse ecosystems [3]. Wetlands offer direct and indirect benefits to humans, such as economic values and natural services. In fact, they contribute to 47% of the value of ecosystems worldwide, making them highly significant and fruitful. However, historically, wetlands were mistakenly considered as sources of diseases and dangerous insects by our ancestors, rather than being recognized for their economic and natural importance [4]. Fortunately, with time, concerned institutions began to appreciate and reclaim wetlands, utilizing them for recreational activities to their full potential [5]. Despite these efforts, human interventions and natural factors have led to a decrease in wetland area and water quality worldwide, resulting in unhealthy conditions [6]. This reduction highlights the potential economic losses caused by wetland degradation [7]. Unfortunately, both public and private officials continue to disregard the value of wetland ecosystems, resulting to future losses or deterioration of these vital habitats [8]. However, it has been recognised over time that wetlands give tremendous advantages to flora and wildlife, which are essential to the entire ecosystem [9,10]. Recognising the need of wetlands for protection and reasonable use, the concept of conservation was considered, leading to the signing of the Ramsar Convention on Wetlands in 1971. This convention was the world's first environmental pact and the first worldwide intergovernmental treaty targeted at saving wetlands [11]. Today, every country on the planet is interested in wetland conservation research, and the Ramsar list encompasses the world's greatest network of protected areas. According to this list, there are 2491 wetlands of international significance in 169 countries, encompassing over 229 million hectares and accounting for approximately 19% (1210 million hectares) of worldwide wetland area [12]. Pakistan signed on to the Ramsar Convention in 1976, mostly for the conservation of waterfowl habitat. Under the Ramsar Convention, nineteen wetlands in Pakistan had earned international designation for outstanding global importance by 2002. These wetlands have unique habitats and species, and they provide a living for nearly 130 million people, including 3-4 million displaced people from other nations [13]. Spatial knowledge of the these wetlands is crucial for their development, management, policy implementation, and productive usage [14,15]. However, wetland inventory reviewers have noticed a lack of standard and comprehensive ways to

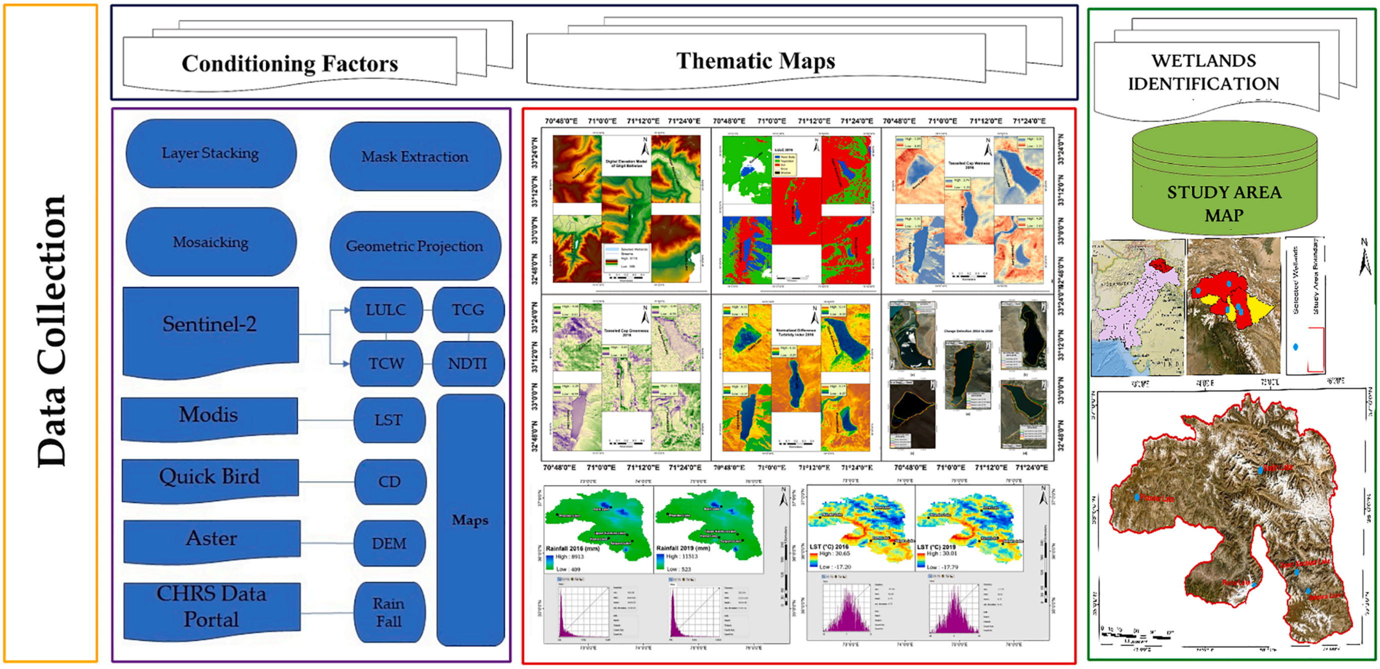

Figure 2. Flowchart of the methodolgy.

Table 1
Details anf description of dataset used.

Product Name	Type of Sensor	Bands	Date of Acquisition	Resolution (Spatial)
Sentinel	S2-A	12	2016-2019	10m
MODIS	MOD-11-A2	32	2016-2019	250m
DEM	ASTER	N/A	2016	15m
Quick-bird	Digital-globe	4	2016-2019	2.62m

studying wetlands across Asia [16]. Regardless of the problems, wetlands are important ecosystems that offer crucial roles such as food chains, plant and animal reservoirs, biodiversity centres, tourist attractions, water reservoirs, and major players in flash flood reduction [17,18]. Traditional procedures have been superseded by remote sensing tools to modernise the research of wetlands [19]. Using

Table 2
Rainfall Pattern in 2016 and 2019.

Lakes	Rainfall (mm) 2016	Rainfall (mm) 2019
Borith	3363	2673
Satpara	595	702
Upper Kachura	648	824
Satpara	428	894
Rama	935	1491

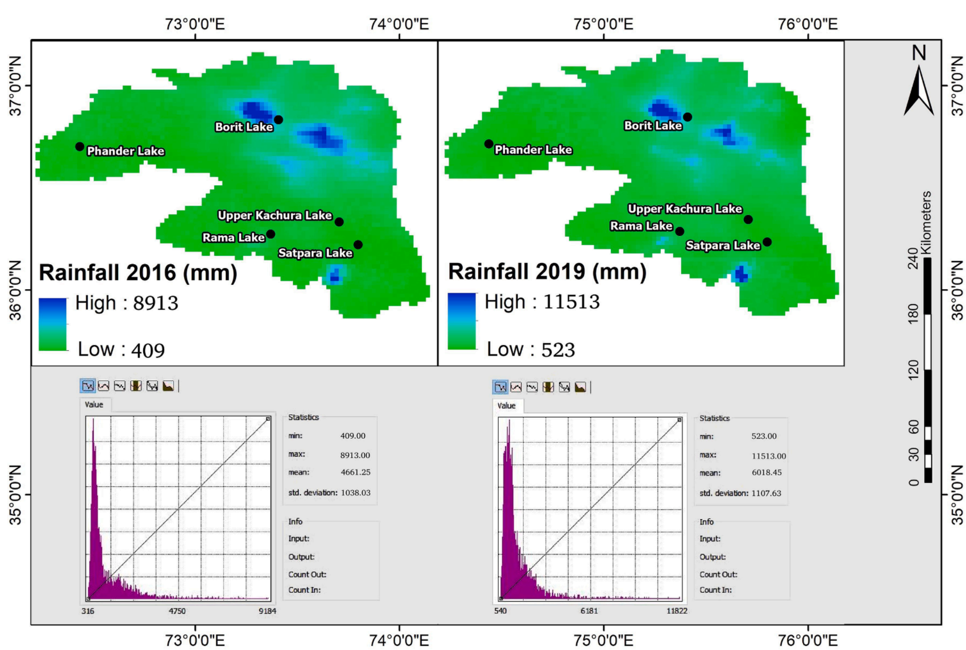

Figure 3. Rainfall Pattern in 2016 and 2019.

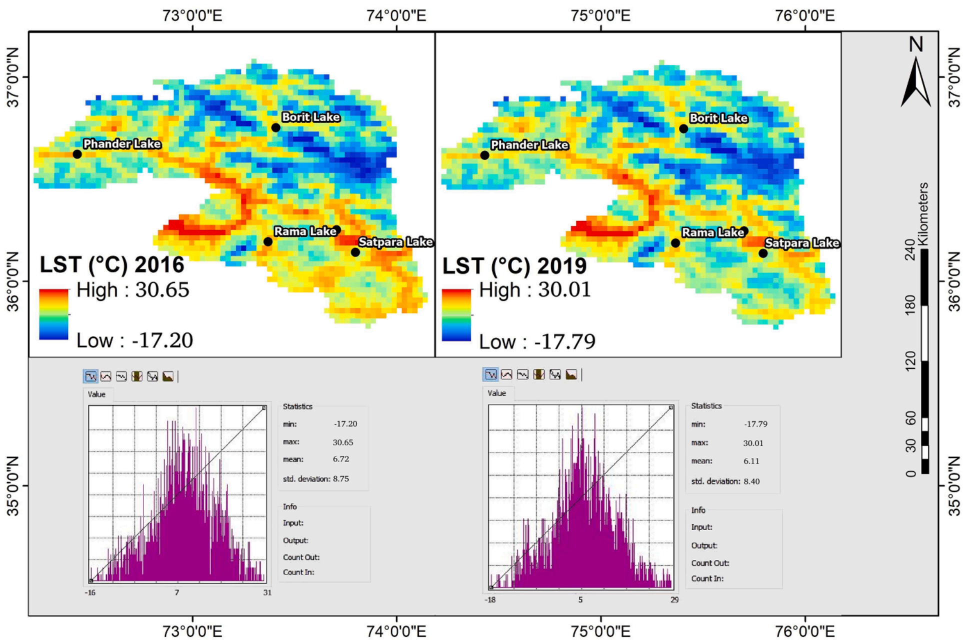

Figure 4. Land Surface Temperature (LST) in 2016 and 2019.

Table 3
LST in 2016 and 2019.

Lakes	LST (°C) 2016	LST (°C) 2019
Borith	12.84	11.21
Phander	19.77	16.81
Upper Kachura	21.58	15.26
Satpara	7.98	5.98
Rama	18.12	15.13

Sentinel-2, MODIS, and ANN datasets, the current study aims to simulate and map wetland dynamics [19–21]. Given the influence of climate change on the Earth's surface, it is critical to use remote sensing techniques to identify, monitor, and evaluate changes in wetlands [22,23]. This study aims to investigate the serious dangers posed by wetland degradation, which can have an impact on ecosystems, water quality, flood rates, and the environment [24].

The main problem is that many significant wetlands in Pakistan remain unrecognized and neglected, facing degradation. Remote sensing techniques can identify these neglected wetlands and provide insights into their Spatio-temporal dynamics [6,25]. The novelty is harnessing big satellite datasets to uncover neglected wetlands at a national scale and analyze their changing patterns. The overall aim is to utilize remote sensing to identify neglected wetlands in Pakistan and analyze their dynamics from 2016-2019. Specific goals are to assess water quality, ecological changes, climate impacts, and spatial changes. The scope is limited to selected case study wetlands in Pakistan using available remote sensing data from 2016-2019 [5]. By leveraging multiple large remote sensing datasets, this research exemplifies the application of big data analytics to uncover spatio-temporal patterns and dynamics in environmental systems and inform wetland monitoring and management [26]. The findings of this research will contribute to the knowledge base of wetland distribution and dynamics in Pakistan. The results will also provide valuable information for wetland management and conservation, which can guide policymakers and stakeholders in making informed decisions [27,28].

2. Materials and Methods

2.1. Study Area

Gilgit Baltistan (GB), a province of Pakistan often referred to as the northern area, is renowned for its breathtaking natural landscapes and unique flora and fauna. It shares international borders with Afghanistan to the north, China to the east and northeast, and the disputed region of Jammu and Kashmir to the southeast. To the west lies Pakistan's provincial border with Khyber Pakhtunkhwa. The geographical coordinates of Gilgit Baltistan are approximately 35.35°N 75.9°E. This region is home to some of the world's highest peaks, such as the Karakoram and Himalayas, and it boasts the longest glaciers globally, including the Baifo Glacier, Baltoro Glacier, and Batura Glacier. Temperature varies from area to area of GB. Area surrounding by mountains has severe weather variation. Western Himalaya's eastern part has moist region as compared to Hindu Kush and Karakoram. In summer GB and Chilas towns are very hot in day and cold at night but Yasin, Nagar, Khaplu, Hunza and Astore valleys remain cold even in summer. Pakistan now has 19 internationally designated wetland habitats covering a total area of 3320619.4 acres. In Gilgit Baltistan, numerous freshwater wetlands exist, but none of them are not listed as a wetland in the Ramsar Convention, an international treaty for wetland conservation. Therefore, efforts have been made to identify some of these unlisted wetlands. These wetlands contribute significantly to the ecological diversity and natural beauty of Gilgit Baltistan, making them worthy of recognition and conservation efforts [28,29] (Fig. 1).

2.2. Data and processing

A range of methodologies and datasets were used to simulate and map the dynamics of wetlands, including Sentinel-2 [30], MODIS, Quick Bird, Aster DEM, and ANN datasets. These data sources enabled the detection of complete geographical and temporal changes in the selected wetlands. To successfully analyse the data, various GIS and RS approaches were used. Remote sensing indices such as TCW (Tasseled Cap Wetness) and TCG (Tasseled Cap Greenness) were used to measure changes in the wetlands over time. A CNN embedded genetic algorithm for hyperspectral band selection. Hyperspectral imagery provides detailed spectral information valuable for wetland characterization, but

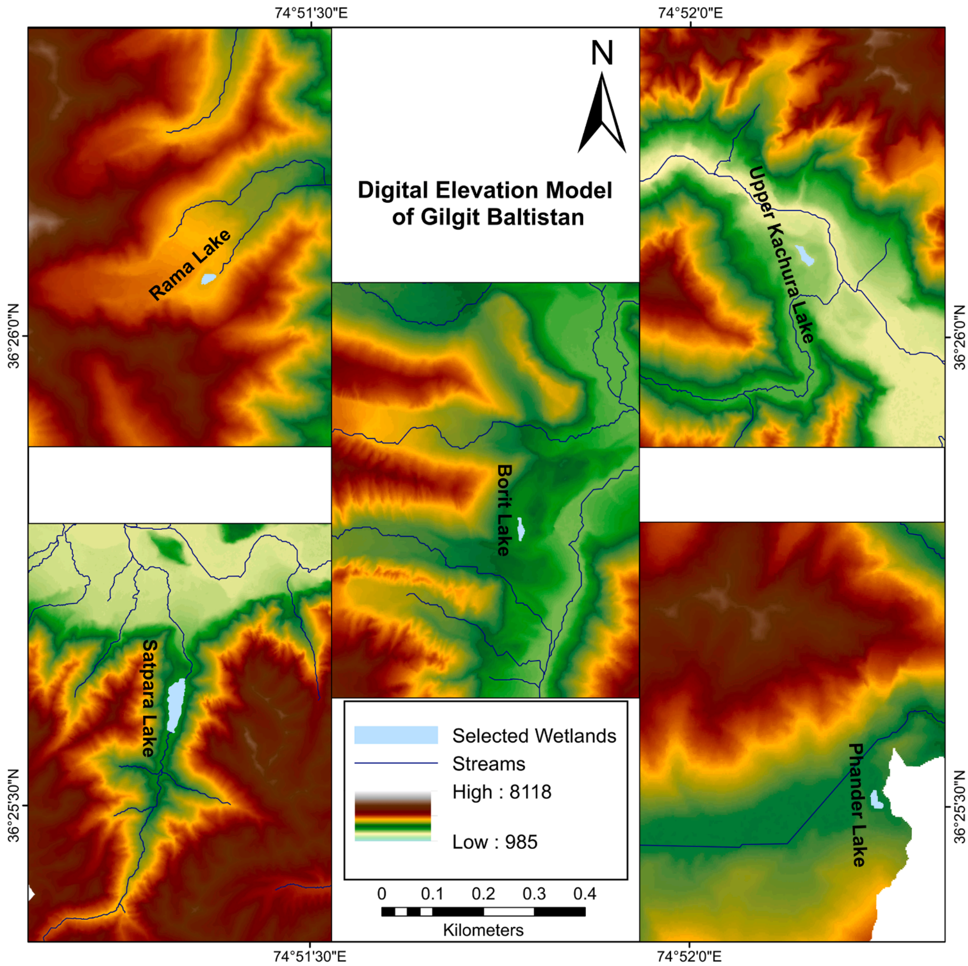

Figure 5. Digital Elevation Map of Lake.

band selection is important for dimensionality reduction [1]. To perform land cover mapping, the researchers employed the supervised classification technique on the Sentinel-2 data. This method involves training the algorithm with known land cover classes to allow it to classify the rest of the pixels in the image accurately. By utilizing satellite images with different spatial resolutions, the researchers were able to capture various aspects of the wetlands and gain a comprehensive understanding of their dynamics. The higher-resolution images from Sentinel-2 and Google Earth provided detailed information on specific features and changes in the wetlands, while the lower-resolution images from MODIS and Aster offered a broader perspective, allowing for a more extensive analysis of larger areas. Overall, the integration of multiple satellite datasets and the application of supervised classification techniques facilitated a robust assessment of land cover changes and wetland dynamics.These indexes provide useful information regarding wetland conditions and vegetation changes. Supervised Classification was also utilised to categorise and identify distinct land cover categories inside the wetlands [31]. LST data was used in the study to better understand temperature fluctuations in the wetlands. This data is critical for understanding the thermal dynamics of wetland areas. Furthermore, the researchers employed the Normalised Difference Turbidity Index to analyse water quality, allowing them to assess the health of the wetland ecosystems. Change Detection (CD) techniques were implemented to identify and analyze alterations in the wetlands due to various factors, including climate change and human interventions. To enhance the accuracy of the research, additional data sources were considered [32]. Information on slope and aspect was integrated to better understand the topography and terrain characteristics of the wetlands. Furthermore, rainfall data was incorporated to analyze its potential influence on the wetland dynamics. The flow chart below (Fig. 2) illustrates the systematic process adopted in the research to gather, analyze, and interpret the data for modeling and mapping the wetlands' dynamics [29,33,34].

In this research, a combination of satellite images from various sources was utilized to study wetland dynamics. The satellite images used in the research, along with their respective spatial resolutions, are listed in Table 1:

To perform land cover mapping, the researchers employed the supervised classification technique on the Sentinel-2 data. This method involves training the algorithm with known land cover classes to allow it to classify the rest of the pixels in the image accurately. By utilizing satellite images with different spatial resolutions, the researchers were able to capture various aspects of the wetlands and gain a comprehensive understanding of their dynamics. The higher-resolution images from Sentinel-2 and Google Earth provided detailed information on specific features and changes in the wetlands, while the lower-resolution images from MODIS and Aster offered a broader perspective, allowing for a more extensive analysis of larger areas. Overall, the integration of multiple satellite datasets and the application of supervised classification techniques facilitated a robust assessment of land cover changes and wetland dynamics [35–37].

2.3. Land-use Land-cover

Supervised classification is a fundamental remote sensing technique employed to manually classify land covers into distinct classes by assigning them specific names based on their numerical values. This

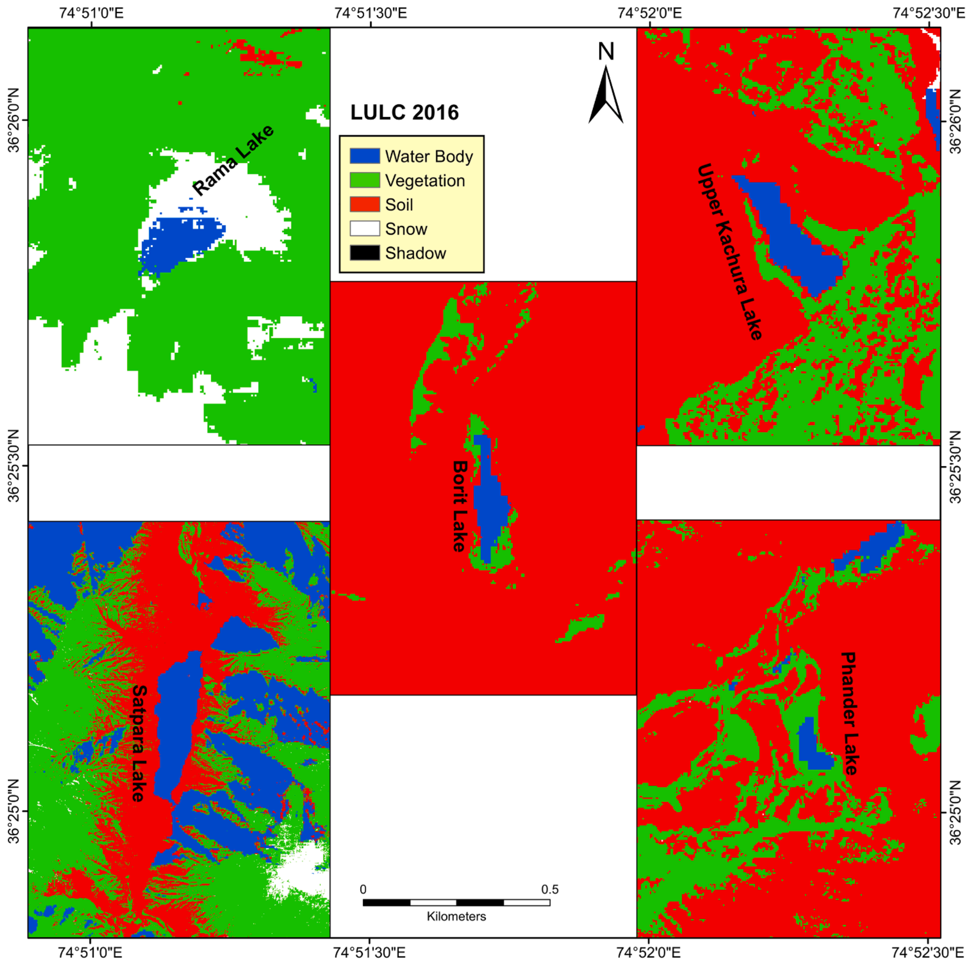

Figure 6. Land Use Land Cover in 2016.

approach enables easy identification of various land covers through the creation of multiple classes. To perform land cover mapping, the researchers employed the supervised classification technique on the Sentinel-2 data. This method involves training the algorithm with known land cover classes to allow it to classify the rest of the pixels in the image accurately. Representative training samples were collected for each land cover type based on field surveys and visual interpretation of high-resolution imagery. The algorithm uses these training samples to develop spectral signatures that are then applied to categorize all pixels in the image. An advantage of supervised over unsupervised classification is the incorporation of expert knowledge to guide the classification process for greater accuracy [38]. Prior to assigning classes, the selection of training sites becomes pivotal in accurately identifying pixel characteristics and their surroundings. Thanks to its guided nature, incorporating prior knowledge and human input, supervised classification is widely regarded as more accurate than unsupervised classification, ensuring reliable results and minimizing the risk of misclassification. The accuracy of the supervised classification was assessed using ground truth points and an error matrix approach. An overall accuracy of 82% was achieved, with individual class accuracies ranging from 78% to 91%.

2.4. Watershed analysis

The process described involves using raster and Digital Elevation Model (DEM) data to identify the specific points where water flows, forming streams. These points are known as watersheds. However, the term "watershed" is not widely understood by the general public, which can lead to miscommunication [44]. To minimise such misunderstandings and create a comprehensive national-level database, watershed boundaries must be correctly delineated. In this aspect, automated extraction of topographical characteristics from digital elevation models is a less expensive alternative to traditional surveying and manual review of topographic maps. The watershed database for the study area was built using Aster DEM satellite imagery with a spatial resolution of 10 metres, which supplied detailed data in this study.

- The process involved several steps:
- Filling depression spots: Depression spots in the DEM were addressed to ensure smooth water flow.
- Flow direction: Determining the direction in which water flows across the terrain.
- Flow accumulation: Calculating the accumulated flow at each cell to identify potential stream locations.
- Stream network: Using the flow accumulation values, a detailed drainage network system was obtained, outlining the streams.
- Watershed boundary identification: Based on the stream network and flow accumulation, the boundaries of watersheds were identified.

By following this procedure, the research team was able to create an accurate and detailed watershed database for the study area. This approach offered a more efficient and automated method compared to manual techniques, enabling the extraction of essential topographic features from the DEM.

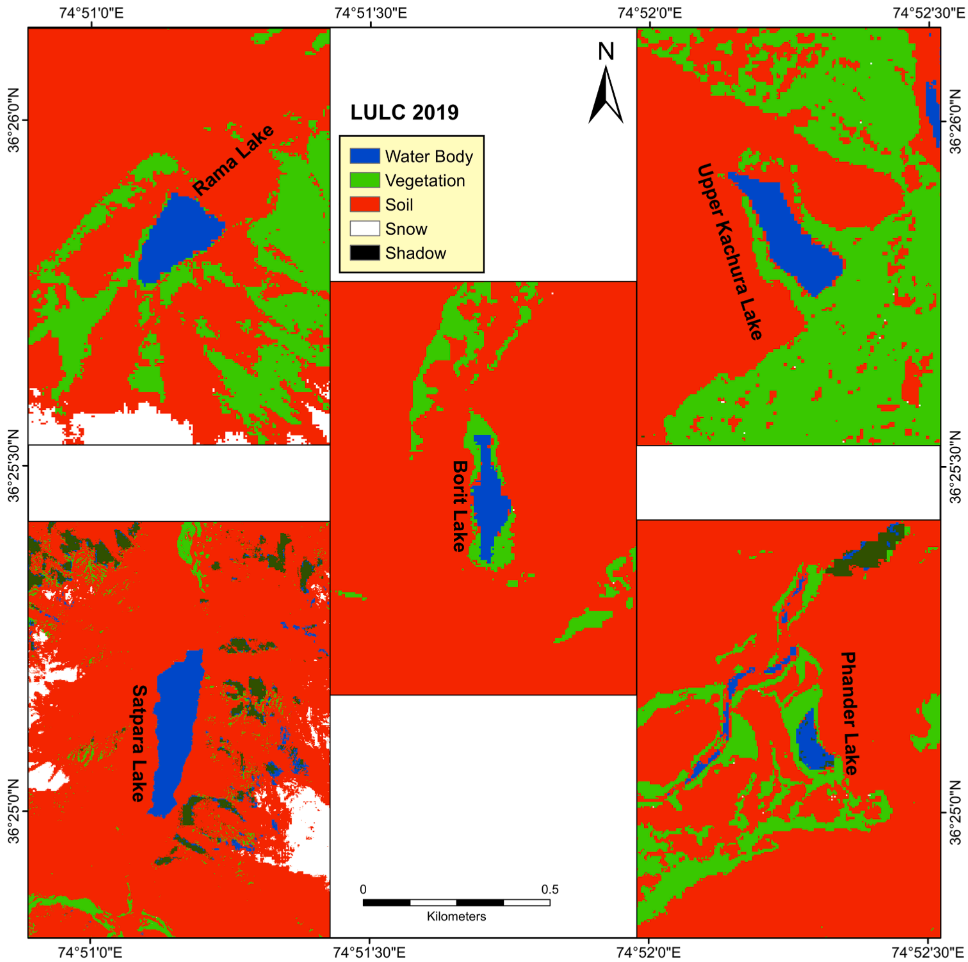

Figure 7. Land Use Land Cover in 2019.

Table 4
LULC supervised classification of 2016-2019.

Lakes	2016				2019			
	Snow	Soil	Vegetation	Water	Snow	Soil	Vegetation	Water
Borith	0.1	85.5	3.9	4.1	4.4	0.1	87.7	5.8
Phander	0.3	76.0	22.9	1.7	3.1	0.3	77.2	16.7
Upper Kachura	0.1	72.0	21.7	7.5	8.6	0.1	59.5	30.9
Satpara	0.4	31.2	28.6	27.6	10.0	5.1	81.6	1.9
Rama	19.9	01.0	69.3	4.8	6.9	0.0	62.8	28.3

2.5. *Land surface temperature (LST) and Rainfall*

In this research, the MODIS (NASA) satellite was utilized to obtain Land Surface Temperature (LST) data. LST is influenced by various factors, including vegetation degradation, soil moisture, and temperature increases, which are often triggered by human activities. This global phenomena is a threat to sustainable development and is directly related to development difficulties. The researchers gained valuable insights into temperature variations and trends by acquiring and processing the MODIS LST data using these procedures, providing important information to comprehend the impact of human-induced and environmental changes on the land surface temperature in the study area [39].

2.6. *Digital number*

To collect the LST data, digital numbers (DN) were obtained from the United States Geological Survey (USGS) website. Initially, the DN values were transformed to radiance by multiplying them by 0.02. Afterward, the radiance values were converted to degrees Celsius by subtracting 273.15, which is the conversion factor from Kelvin to Celsius [28].

2.7. *Tasseled cap wetness (TCW)*

To identify the neglected wetlands, we utilized the TCW index on Sentinel-2 imagery. This index involved deriving coefficients for wetness from the visible, NIR, and MIR bands. The objective was to accurately delineate the lowland wetlands based on their distinctive spectral characteristics.

2.8. *Tasseled cap greenness (TCG)*

The Tasseled Cap Greenness (TCG) index is a valuable tool for detecting vegetation regrowth and distinguishing areas with vegetation from those with bare soil. This index is computed by deriving visible,

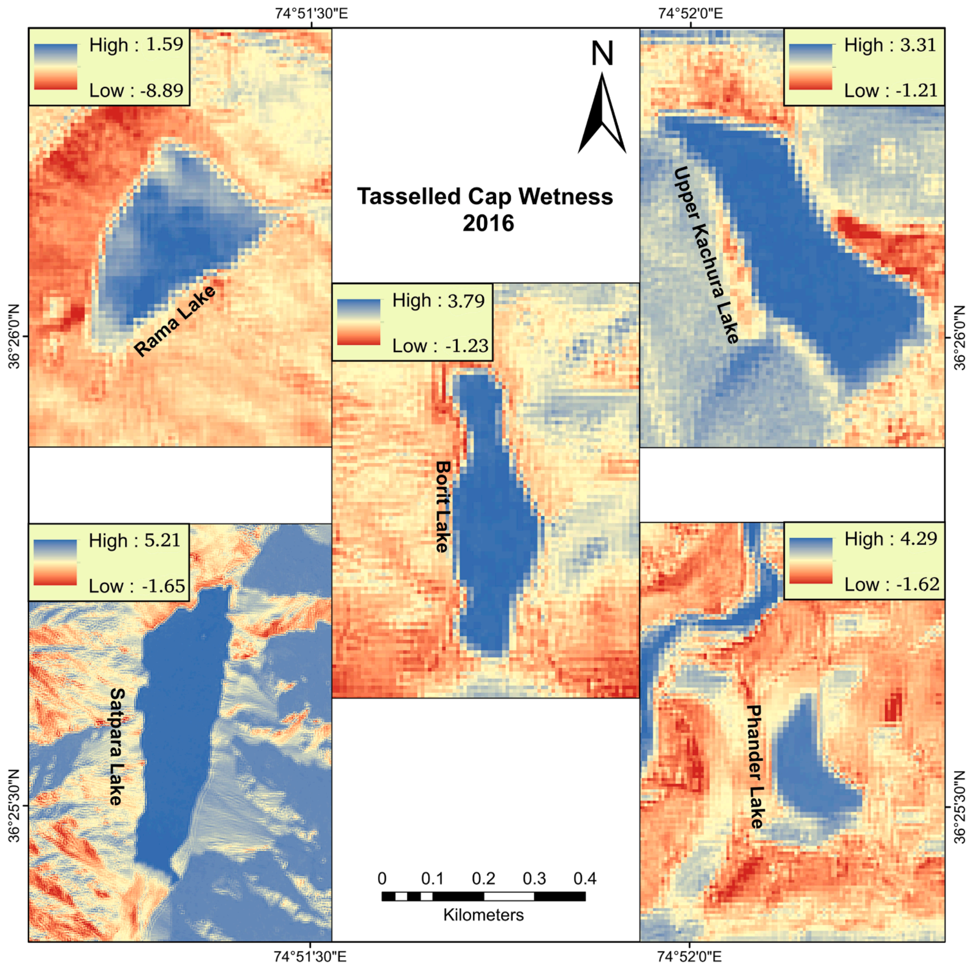

Figure 8. Tasseled Cap Wetness TCW 2016.

NIR, and MIR coefficients to effectively delineate greenland wetlands. By using the TCG index, we can identify regions with active vegetation and distinguish them from areas where the land is predominantly bare soil. This information is crucial for monitoring changes in vegetation cover and understanding the dynamics of greenland wetlands [12].

2.9. Normalized Difference Turbidity Index (NDTI)

To monitor the water quality of the wetlands, we analyzed Sentinel-2 datasets from 2016 to 2019. For this purpose, the NDTI technique was utilized, which is a highly effective method to assess water quality. NDTI is calculated as the ratio of the red and green bands in the satellite imagery [40]. By using this index, we were able to gain valuable insights into the water quality of the wetlands over the specified time period.

2.10. Change detection

GE images from 2016 to 2019 were used for the change detection investigation. Remote sensing images serve as a valuable primary source for detecting changes in wetlands over time. Additionally, ancillary data, such as topographic maps, soil maps, coastal navigation charts, and time-varying images, were integrated with the GE data to enhance the analysis. The choice of timing and the quality of the images are crucial factors in accurately determining wetland change detection [41]. The images must be acquired at appropriate intervals to capture significant changes in the wetland area. The temporal resolution of the images is essential to observe any trends or fluctuations in the wetland over the selected time frame. Moreover, the quality of the images is critical to ensure that the detected changes are reliable and accurate. High-resolution images with clear visibility are preferred for precise change detection analysis. The use of ancillary data further aids in validating and interpreting the changes observed in the wetland area. By combining remote sensing images with ancillary data and carefully considering the timing and quality of the images, the change detection analysis provides valuable insights into the dynamics of wetland areas and their response to environmental and human-induced changes over time. The post-classification comparison method was selected because of its simplicity and ability to quantify land cover changes. However, pixel-based change detection techniques like image differencing and change vector analysis were not used as they cannot explicitly identify the types of change. For better characterization of change trajectories, more advanced methods like Land Change Modeler could be explored in the future.

3. Results and Discussion

Wetlands are ecologically diverse ecosystems that provide a vital habitat for a wide range of species, making them ecologically and economically valuable. These areas are home to various unique fishes and migratory birds that hold significant commercial importance [42]. According to research, more than one-third of vulnerable species in the United States are intimately related with wetlands, spending their entire existence or a portion of it in these ecosystems. As a result, several wetlands have been designated globally as biodiversity conservation sites. The restoration and maintenance of biodiversity are directly linked to wetlands, and the health of wetlands is influenced by factors such as