ANALYSING THE TEMPORAL CHANGES IN UDAIPUR LAKES USING SENTINEL 2

INTRODUCTION

- Within the intricate tapestry of Earth's hydrological systems, lakes stand as indispensable reservoirs of water resources, shaping the terrain, sustaining biodiversity, and serving as essential lifelines for human societies
- These bodies of water form a critical link in facilitating water-atmosphere exchange on land and play a pivotal role in the broader context of the global water cycle, whilst contributing significantly to maintaining ecological equilibrium
- The dynamics of lake formation, disappearance, expansion, and contraction, as well as the evolution of water ecology, result from intricate interactions among regional and local structures, climate, and the environment
- Nestled in the heart of Rajasthan lies the enchanted city of Udaipur, often referred to as the “City of Lakes” where its landscape, punctuated by shimmering water bodies, holds profound cultural and ecological significance.
- These lakes, emblematic of the city's heritage, have played a pivotal role in Udaipur's historical and contemporary narrative; sustaining ecosystems and livelihood while baring witness to the rise and fall of empires, making their monitoring and management imperative for sustainable development and a paramount significant in the region’s history.
- Therefore, such lakes can be used as a terminal indicator of regional hydrological cycles and environmental change.

LAKES OF UDAIPUR

- The lakes of Udaipur exhibit a unique blend of natural and artificial reservoirs, each possessing distinctive origins and characteristics.
- **Lake Fateh Sagar**, an artificial lake, was constructed in the 17th century under the reign of Maharana Jai Singh II, while **Lake Pichola**, also artificial in nature, finds its origins in the 14th century and stands as a testament to the visionary endeavours of Maharana Udai Singh II.
- Conversely, **Udaisagar Lake**, located in the eastern periphery of Udaipur, is a natural lake formed through the damming of the Berach River.
- Additionally, **Badi Lake**, another artificial water body, serves as an integral part of Udaipur's aquatic tableau, contributing to the city's idyllic charm.
- Howbeit, over the past decade, the dynamic nature of these lakes have witnessed transformative changes, both in terms of water quality and quantity, particularly in the last decade.
- These are influenced by complex interplay of factors such as increased climate anomalies and extensive human interference, which include altered hydrology, encroachment, declining water quality, and shifts in the aquatic ecosystems that fluctuates its hydrological regime.

LITERATURE REVIEW

Multispectral Satellite Imagery in Temporal Analysis

- Recent studies have emphasized the utility of multispectral satellite imagery in unraveling the temporal intricacies of lake ecosystems.
- Smith et al. (2019) demonstrated the efficacy of different band combinations, showcasing their correlation with diverse water quality parameters, allowing researchers to capture nuanced variations in water quality over time

Quantitative Assessment of Spatial Changes

- Quantitative evaluations of changes in the spatial extent of lakes have emerged as crucial components of spatio-temporal analyses.
- Anderson et al. (2017) emphasized the importance of assessing alterations in lake boundaries over defined time series, shedding light on the relationship between climate variability and temporal dynamics in lake water quality.

Correlation of Spectral Data with Water Quality Parameters

- Johnson and Patel (2020) delved into the correlation between spectral data and key water quality parameters, emphasizing the need for comprehensive approaches that consider both natural and anthropogenic factors in understanding the ecological dynamics of lakes over time.
- This integration provides a more nuanced perspective, linking remote sensing data directly to ecological changes in lake ecosystems.

LITERATURE REVIEW

Impact of Urbanization on Water Quality

- Gupta et al. (2019) highlighted the impact of urbanization on water quality and ecological health of Udaipur's lakes, emphasizing the multifaceted challenges faced, including altered hydrology and declining water quality

Land-Use and Land-Cover Changes

- Jagadish et al. (2020) contributed to spatio-temporal analysis by examining land-use and land-cover changes in Udaipur city, shedding light on the broader environmental transformations influencing lake ecosystems.
- This research establishes a crucial link between urban expansion and its impact on the lakes, urging for a comprehensive temporal assessment.

Water Spread Dynamics of Fateh Sagar Lake

- Jain and Bandyopadhyay (2005) employed remote sensing practices to assess the water spread dynamics of Fateh Sagar Lake, contributing valuable insights into the temporal changes in this water body.
- This approach provides a template for understanding how spatial temporal analyses can unravel the evolving patterns of Udaipur's lakes.

RESEARCH GAP

- While these studies contribute significantly to our understanding of the impacts of urbanization on Udaipur's lakes, critical research gaps persist, necessitating a more comprehensive spatio-temporal analysis.

Holistic Spatio-Temporal Assessment

- Existing studies primarily focus on specific aspects, such as water quality assessments or land-use changes, often neglecting the comprehensive spatio-temporal analysis required to unravel the intricacies of temporal changes.
- The urgency lies in adopting a holistic approach that integrates various dimensions to discern evolving patterns in Udaipur's lakescape.

Spatial Dimension in Temporal Monitoring

- While temporal monitoring approaches are noteworthy, they lack the spatial dimension crucial for understanding how different regions within Udaipur may respond differently to changing conditions.
- An integrated approach that combines temporal changes with spatial variations is imperative for a comprehensive understanding of the lakes' dynamics.

Correlation of Spectral Data with Water Quality Parameters

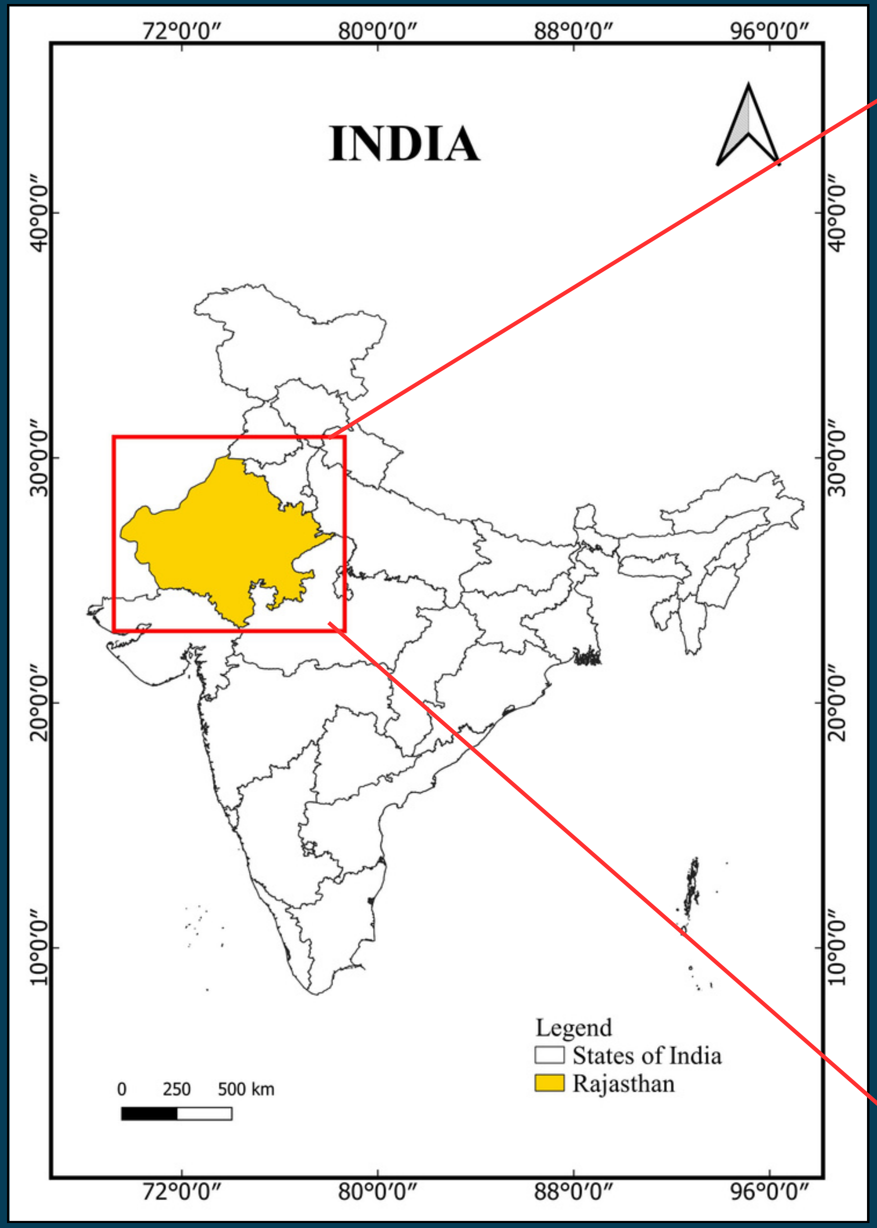
- The correlation between spectral data and key water quality parameters, as demonstrated in studies elsewhere, remains unexplored in the context of Udaipur's lakes.
- Integrating this aspect into the analysis could offer a more nuanced understanding of the ecological dynamics over time.

OBJECTIVES

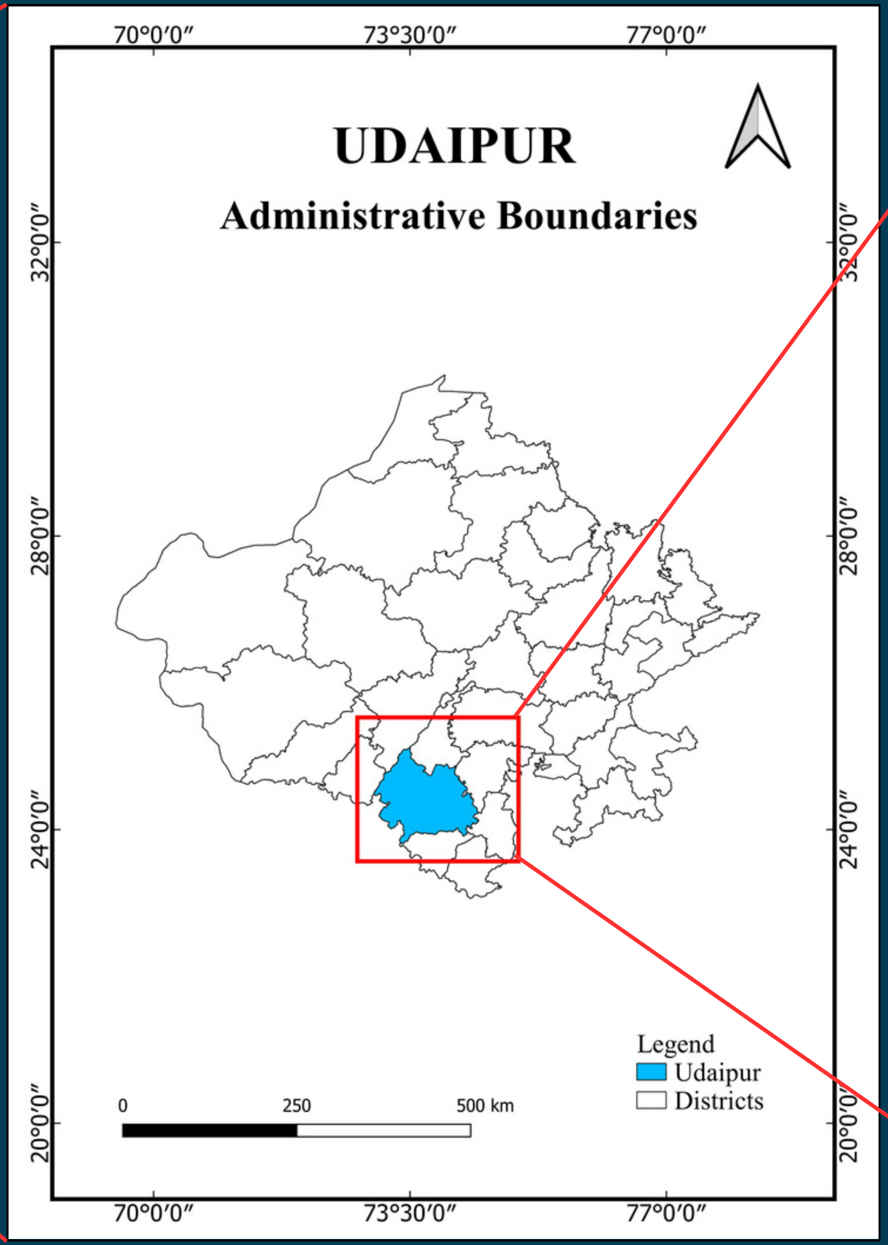
1. Quantitatively evaluate the variations in the spatial extent of the lakes across a specified time series, aiming to discern modifications in the geographical boundaries of the lakes.

2. Utilise multispectral satellite imagery to systematically examine temporal fluctuations in water quality, elucidating diverse band combinations and establishing correlations with pivotal water quality parameters

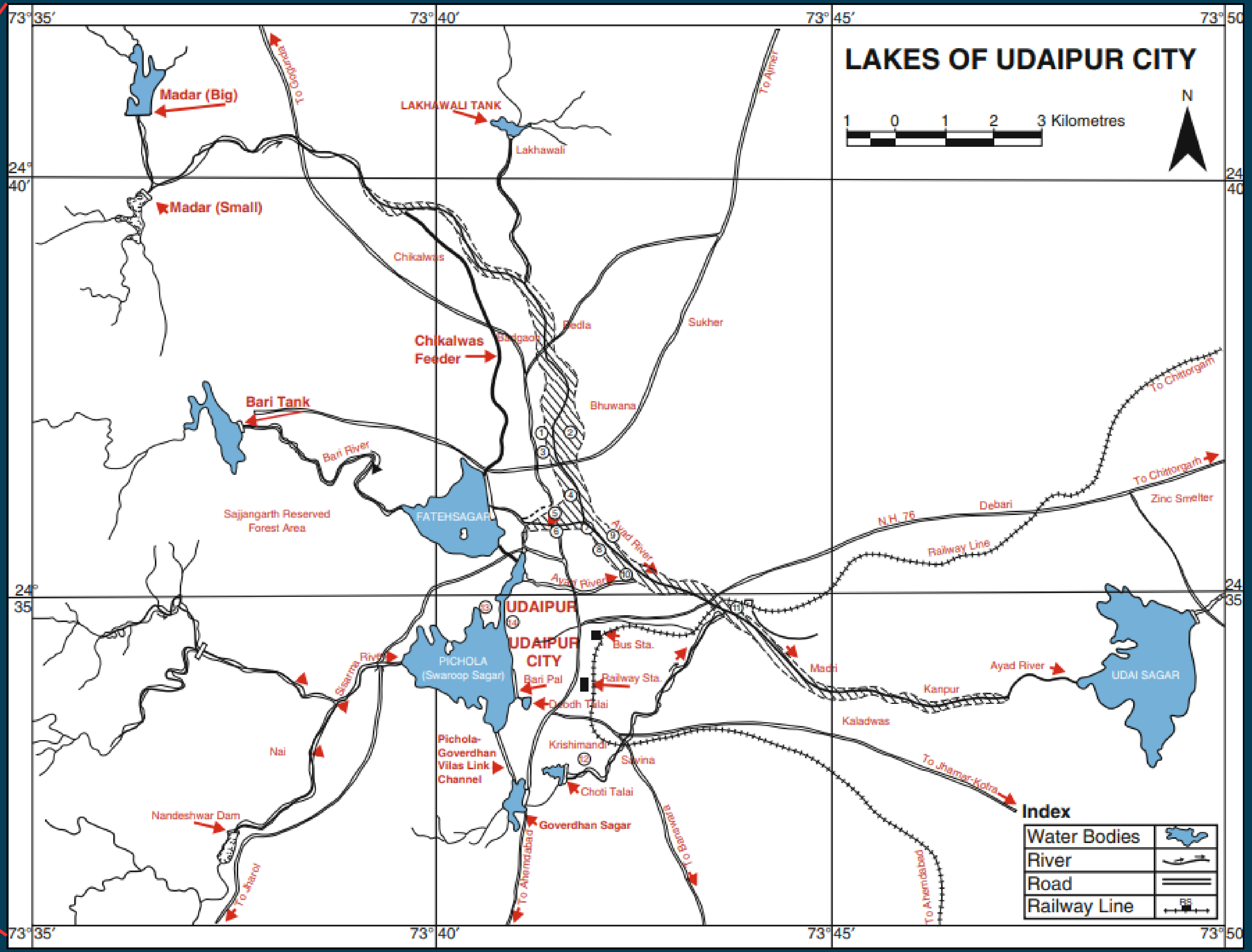
STUDY AREA



INDIA
72°0′0″
80°0′0″
88°0′0″
96°0′0″
40°0′0″
30°0′0″
20°0′0″
10°0′0″
Legend
States of India
Rajasthan
0 250 500 km



UDAIPUR
Administrative Boundaries
70°0′0″
73°30′0″
77°0′0″
32°0′0″
28°0′0″
24°0′0″
20°0′0″
Legend
Udaipur
Districts
0 250 500 km



LAKES OF UDAIPUR CITY
1 0 1 2 3 Kilometres
N
73°35′
73°40′
73°45′
73°50
Madar (Big)
Madar (Small)
LAKHAWALI TANK
Lakhawali
Chikalwas
Chikalwas Feeder
Bari Tank
Bari River
Sajjangarh Reserved Forest Area
FATEHSAGAR
Sukher
Bhuwana
UDAIPUR
UDAIPUR CITY
PICHOLA (Swaroop Sagar)
Bari Pal
Bus Sta.
Railway Sta.
Dudh Talai
Krishimandi
Savina
Choti Talai
Goverdhan Sagar
Pichola-Goverdhan Vilas Link Channel
Nai
Nandeshwar Dam
Ayad River
Madri
Kanpur
Kaladwas
Debari
N.H. 76
Railway Line
To Chittorgarh
Zinc Smelter
UDAI SAGAR
Index
Water Bodies
River
Road
Railway Line

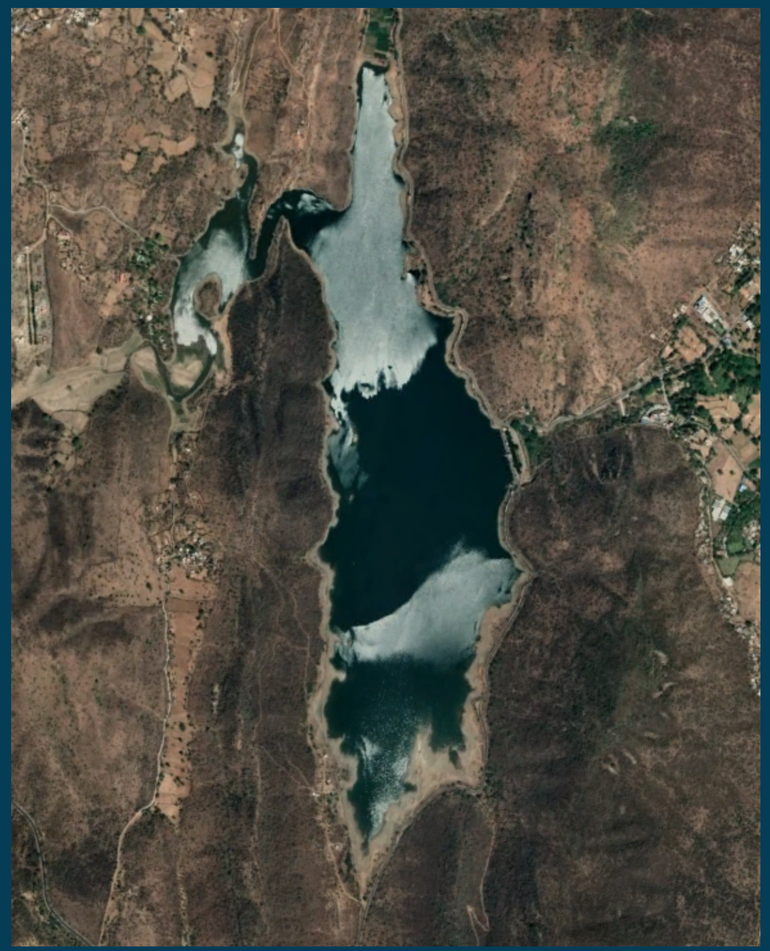
FATEH SAGAR

73.6742° E and 24.6014° N

UDAI SAGAR

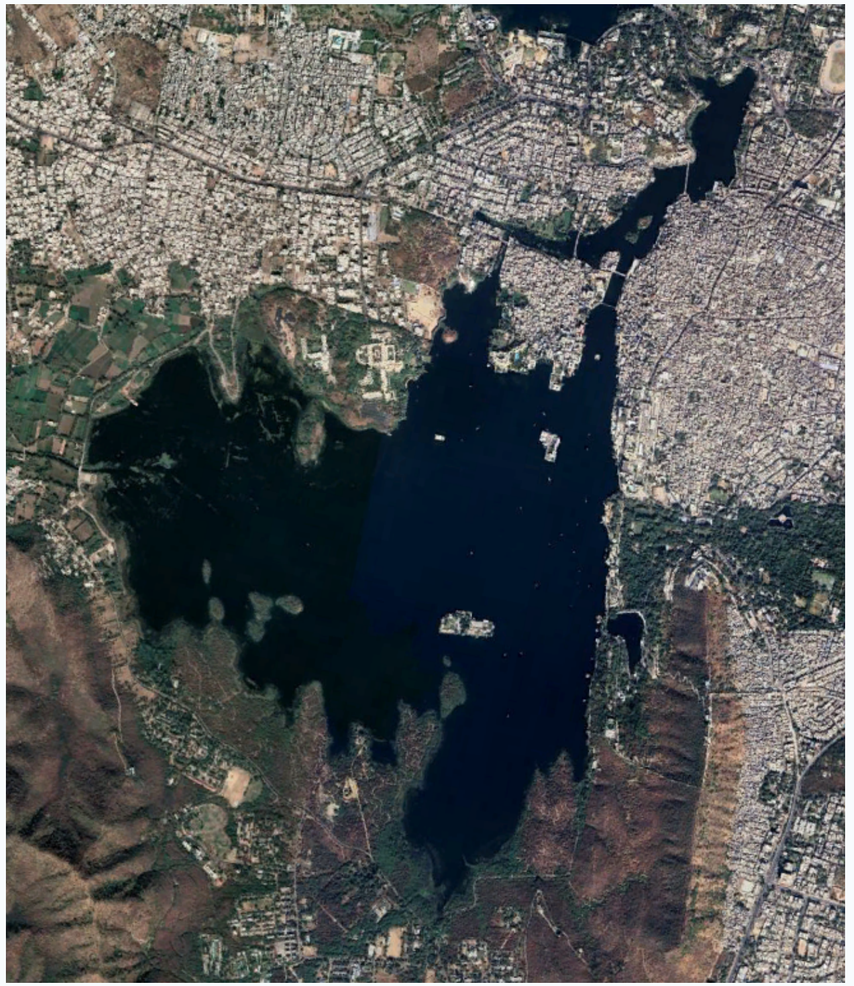
24.5825° N and 73.7186° E

BADI LAKE



24.5589° N and 73.7519° E

PICHOLA LAKE



24.572°N and 73.679°E

PARAMETERS FOR TEMPORAL CHANGES (2009 - 2019)

Temporal Changes in Lake Extend

Land Use and Land Cover Change with Accuracy Assessment

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

Temporal Changes in Water Quality

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

Normalised Difference Chlorophyll Index
NDCI = (MIR - Red) / (MIR + Red)

Surface Algae Bloom Index
SABI = (NIR - Red) / (Green + Blue)

Normalised Difference Salinity Index
SI = (Green – SWIR)/(Green + SWIR)

DATA SET

SENTINEL 2

- **Year:** 2019
- **Source:** https://dataspace.copernicus.eu/

LANDSAT 8

- **Year:** 2014
- **Source:** https://earthexplorer.usgs.gov/

LANDSAT 5

- **Year:** 2009
- **Source:** https://earthexplorer.usgs.gov/

Harmonizing Data

- Sentinel satellites provide high-resolution and frequent coverage, while Landsat satellites offer a longer historical dataset.
- For temporal change analysis resampling of data set is required

Sentinel 2: 10 m
Landsat 8: 30 m and 15 m → 10 m
Landsat 5: 30 m and 15 m → 10 m

METHODOLOGY

LANDSAT 5 - 2009

LANDSAT 8 - 2014

SENTINEL 2 - 2019

→

IMAGE COLLECTION

(Cloud Filtering < 10%)

(Subset to Study Area)

Temporal Changes in

LAKE WATER QUALITY

- Normalized Difference Chlorophyll Index
- Normalized Difference Turbidity Index
- Normalised Difference Salinity Index
- Surface Algal Bloom Index

Temporal Changes in

LAKE WATER SURFACE EXTEND

- Land Use and Land Cover Changes
- Normalized Difference Water Index
- Accuracy Assessment

RESULTS AND DISCUSSIONS

- The intricate interplay between environmental variables and human activities has profound implications for the ecological balance of freshwater ecosystems.
- Udaipur, a city renowned for its picturesque lakes, stands at the intersection of this dynamic relationship, as anthropogenic and natural factors continue to shape the temporal evolution of its water bodies.
- In this context, our research delves into the temporal changes within Udaipur's lakes, employing a comprehensive suite of remote sensing indices and water quality parameters to unravel the complex interactions influencing these aquatic ecosystems.
- Our study harnesses the power of key indices to provide a holistic perspective on the temporal dynamics of Udaipur lakes, capturing variations in quality and quantity of the water as well as the land use and land cover surrounding these lakes.
- In this preliminary results section, we present an overview of our analysis and findings, offering a glimpse into the intricate tapestry of temporal changes within Udaipur lakes through 10 years between 2009 and 2019.
- Through the lens of remote sensing indices and water quality parameters, we unravel the complex story of how these iconic water bodies respond to the influences of time, climate variability, and anthropogenic pressure
- As our study unfolds, it is poised to contribute to the broader discourse on the sustainable management and conservation of freshwater ecosystems in rapidly evolving urban environments.

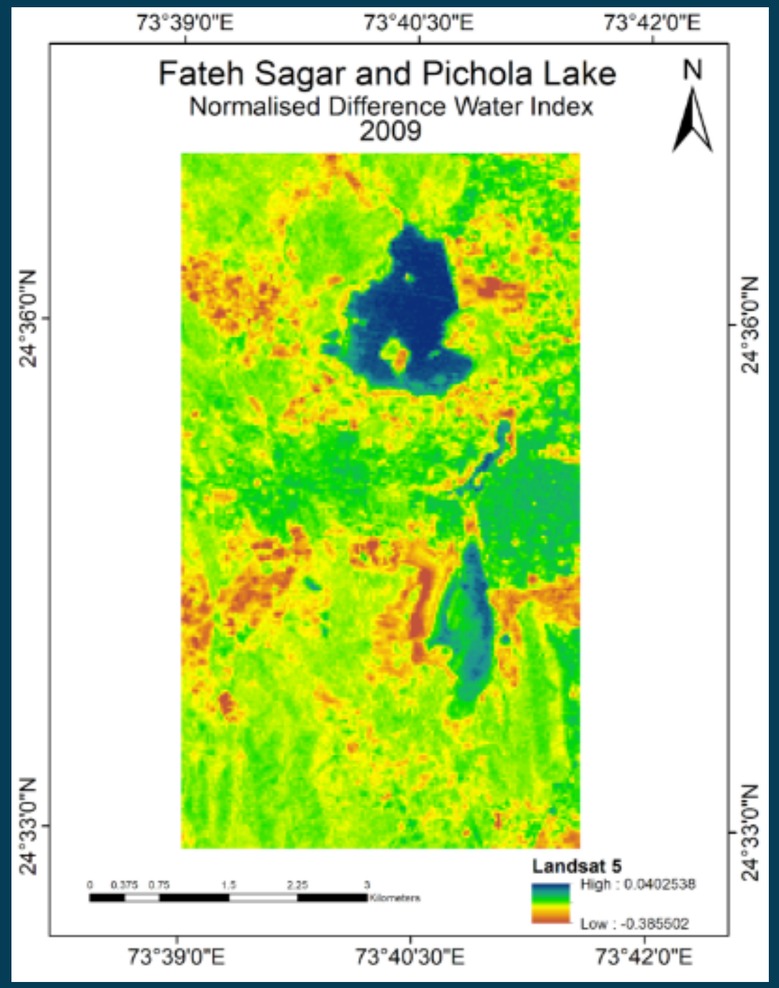
TEMPORAL CHANGES IN LAKE EXTENT

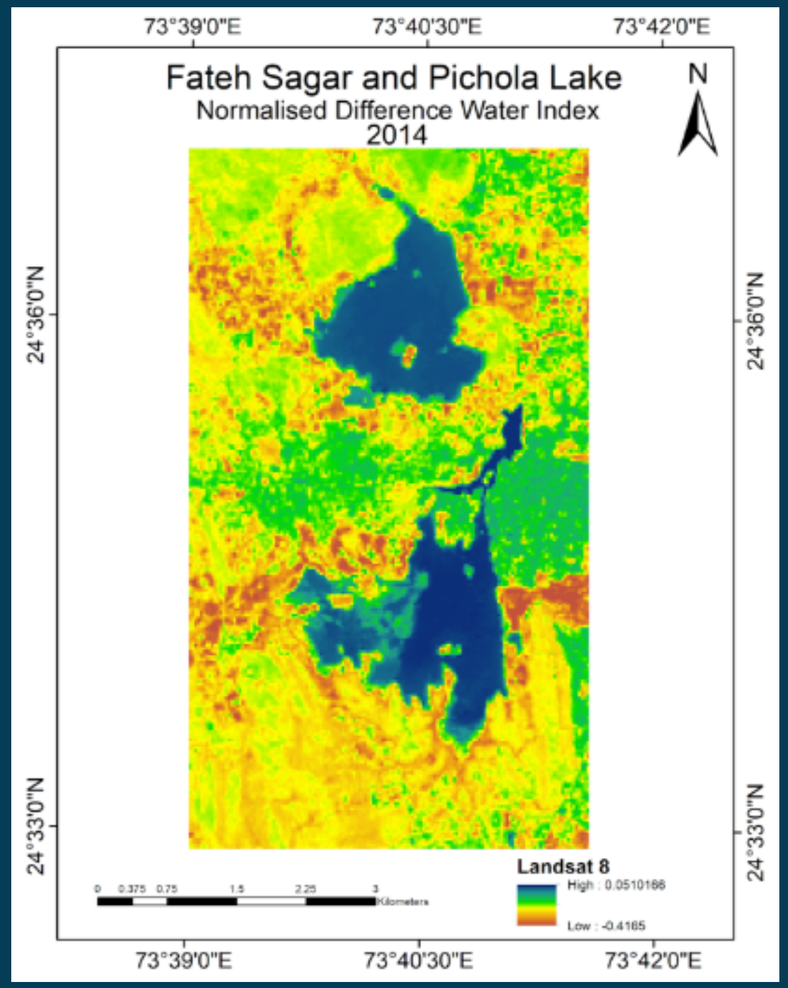
Normalised Difference Water Index

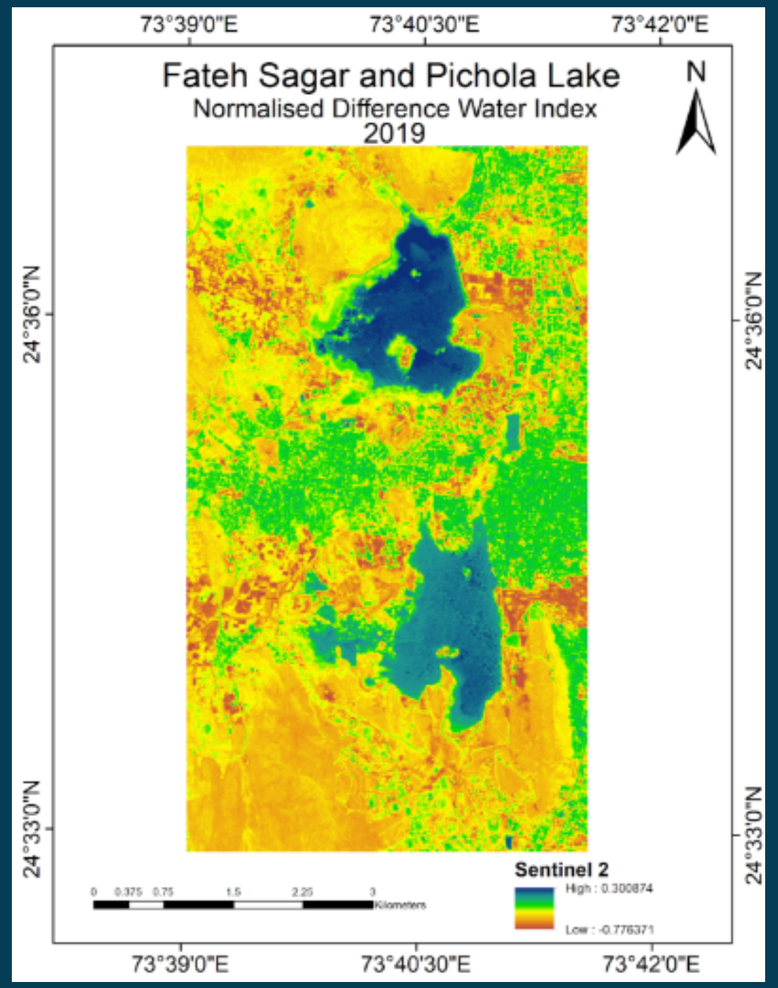
$$NDWI = (Green - NIR) / (Green + NIR)$$

FATEH SAGAR AND PICHOLA LAKE

Normalised Difference Water Index

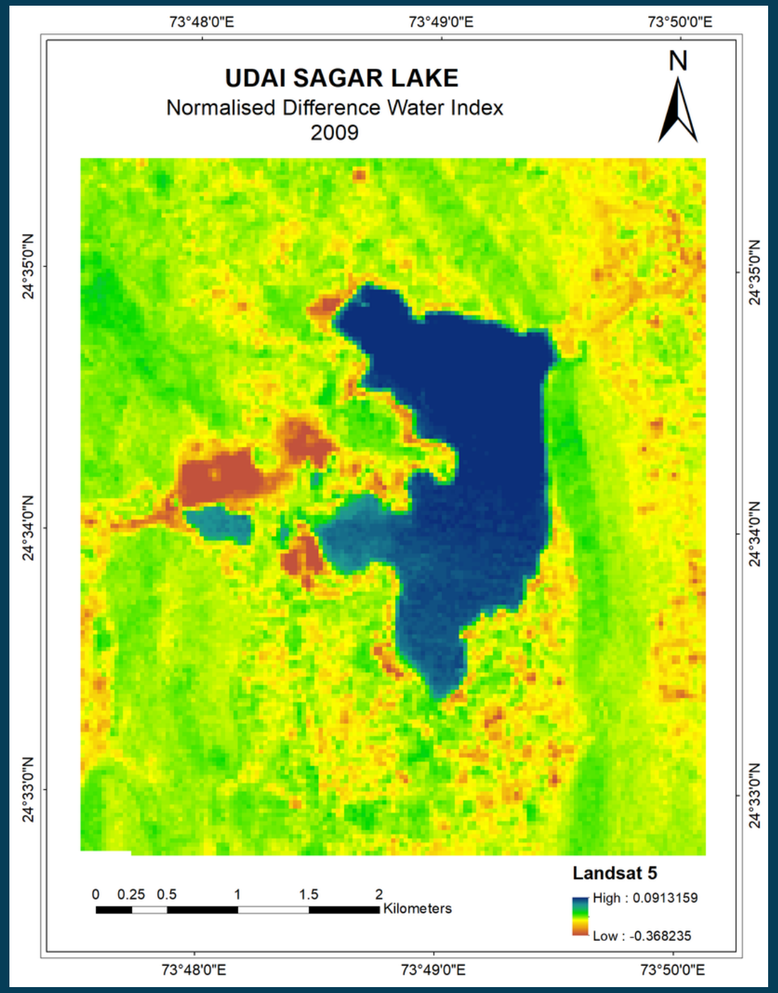


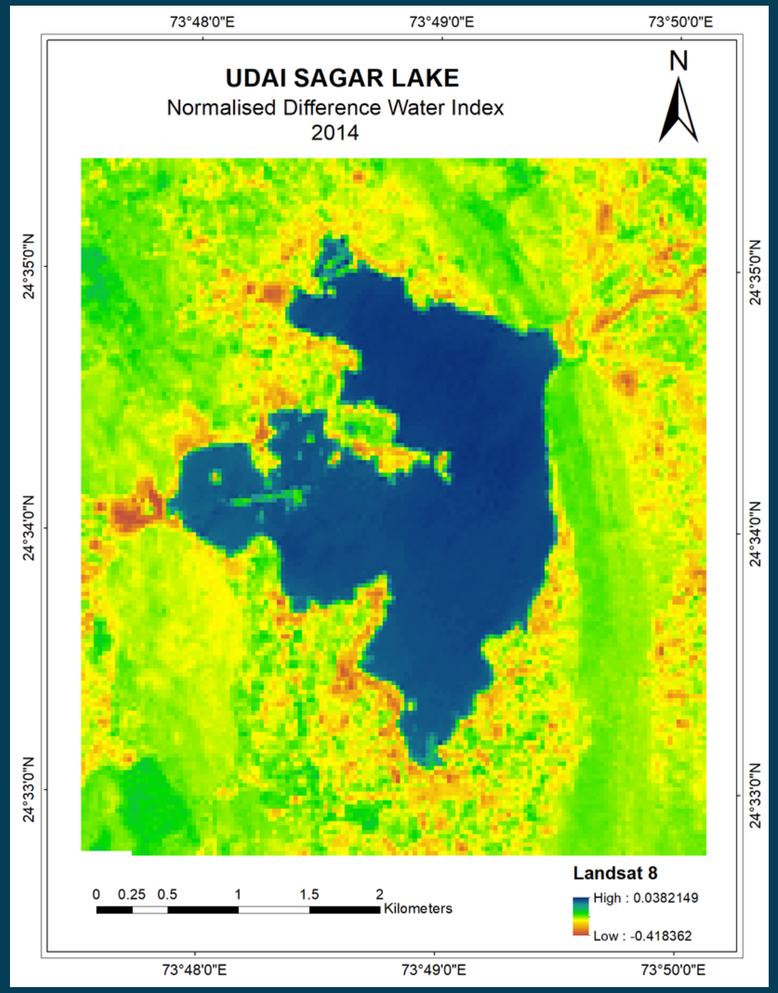


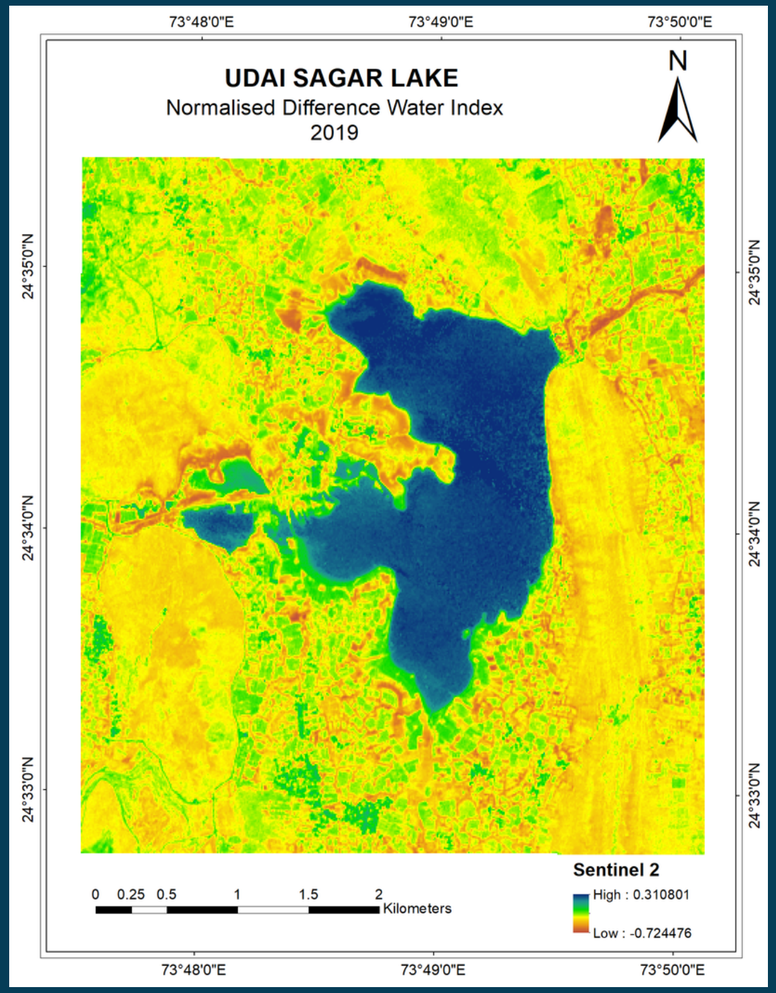


UDAISAGAR LAKE

Normalised Difference Water Index

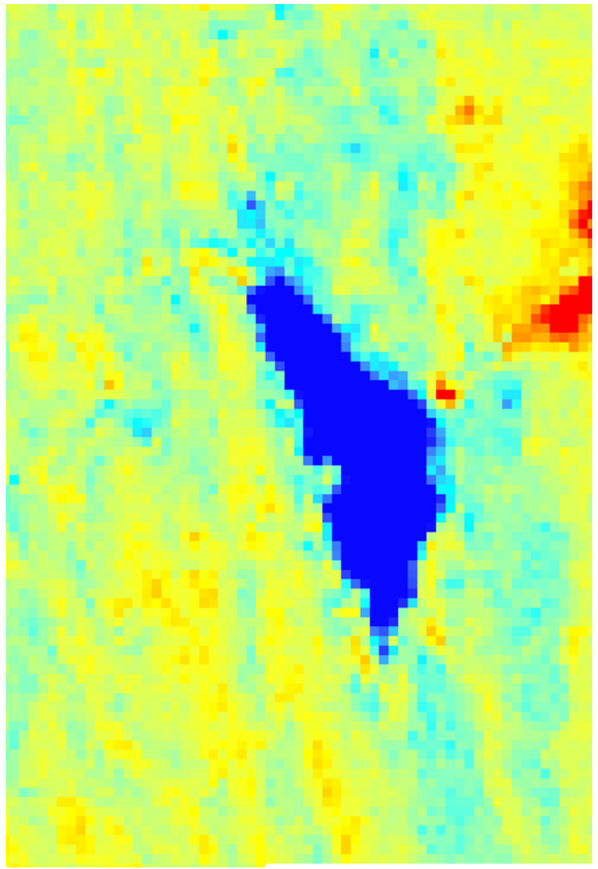






BADI LAKE

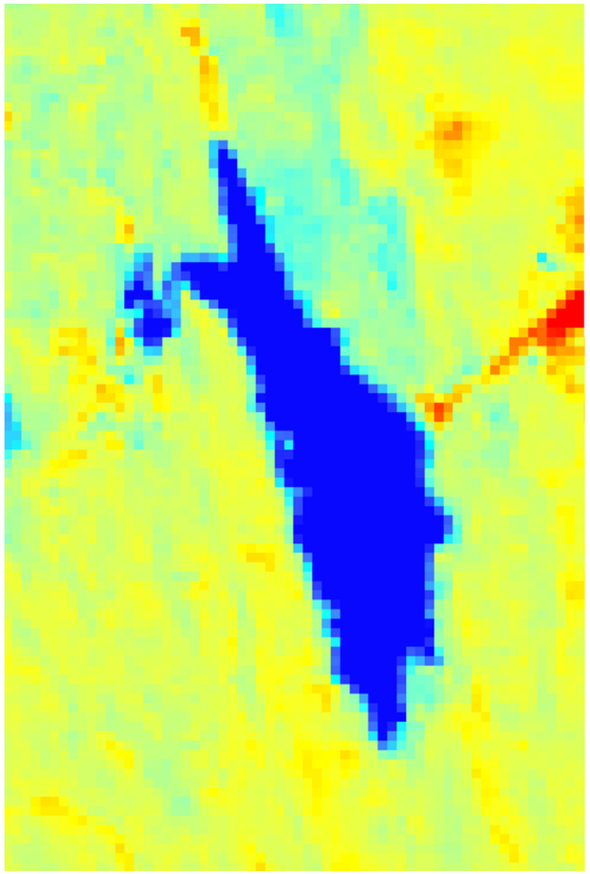
Normalised Difference Water Index



Landsat 5- 2009

High : 0.0216061

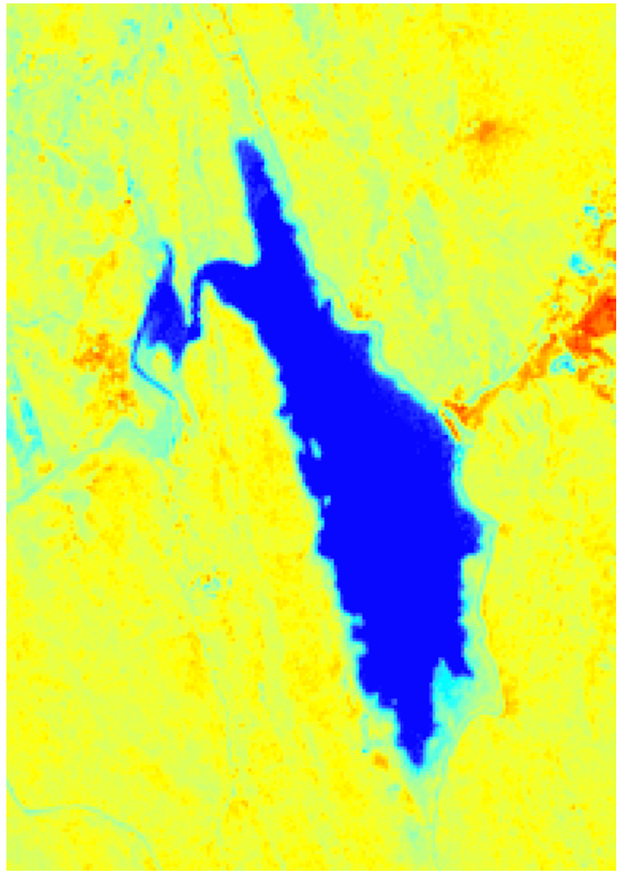
Low : -0.258059



Landsat 8- 2014

High : 0.0165368

Low : -0.368769



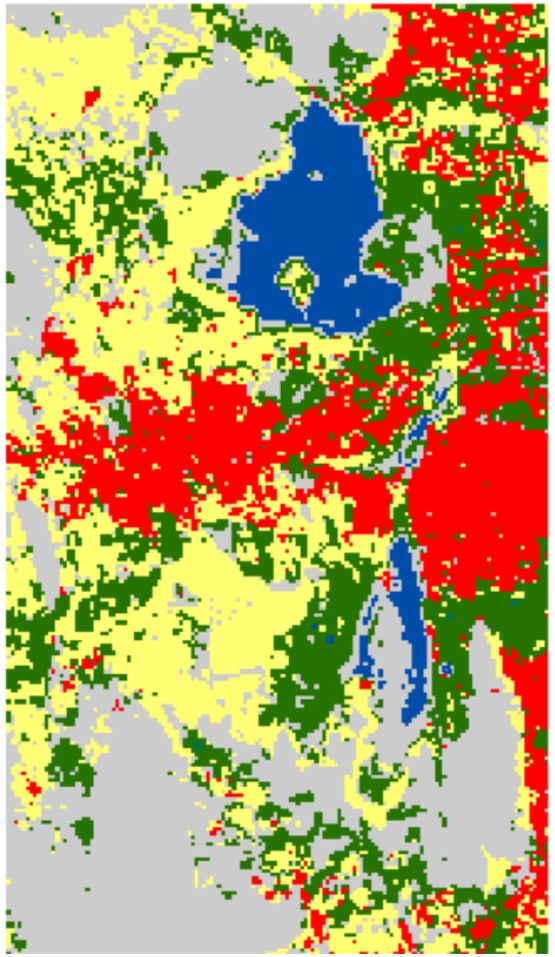
Sentinel 2- 2019

High : 0.325918

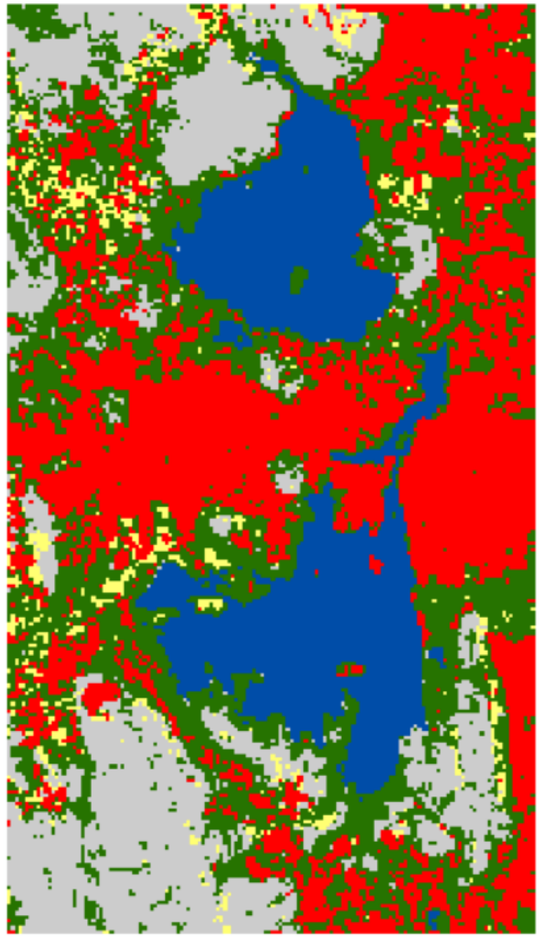
Low : -0.687949

FATEH SAGAR AND PICHOLA LAKE

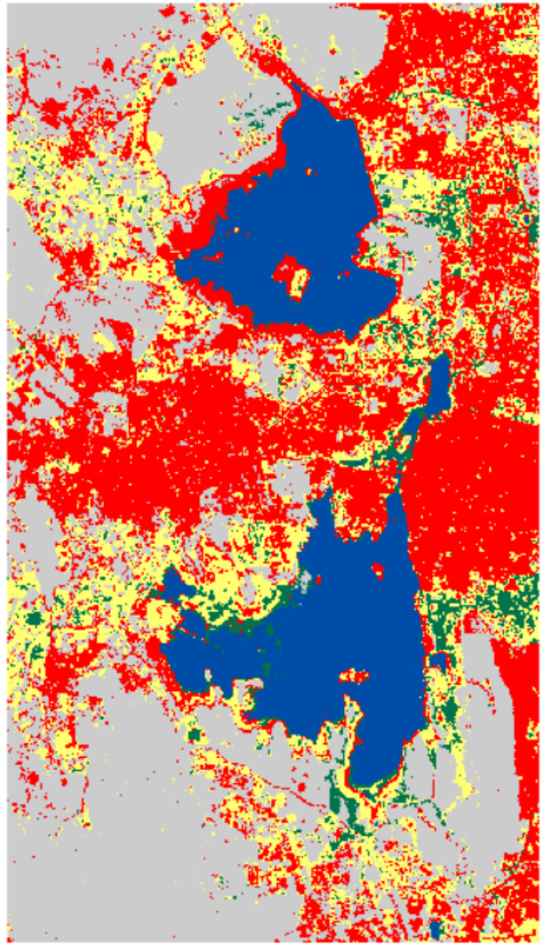
Land Use/ Land Cover Classification



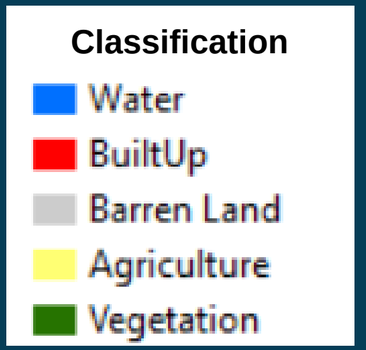
Landsat 5- 2009



Landsat 8- 2014

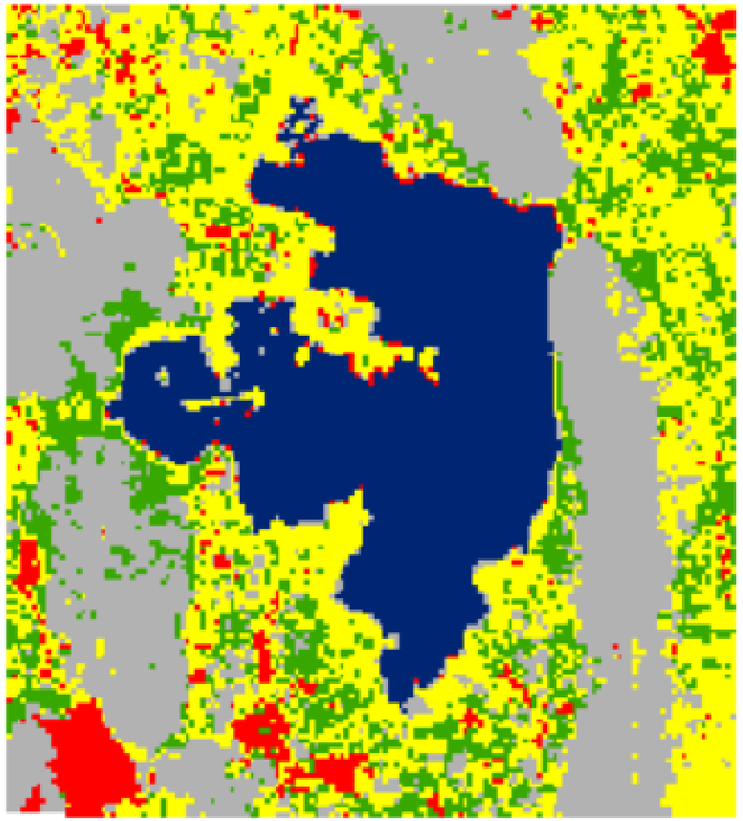


Sentinel 2 - 2019

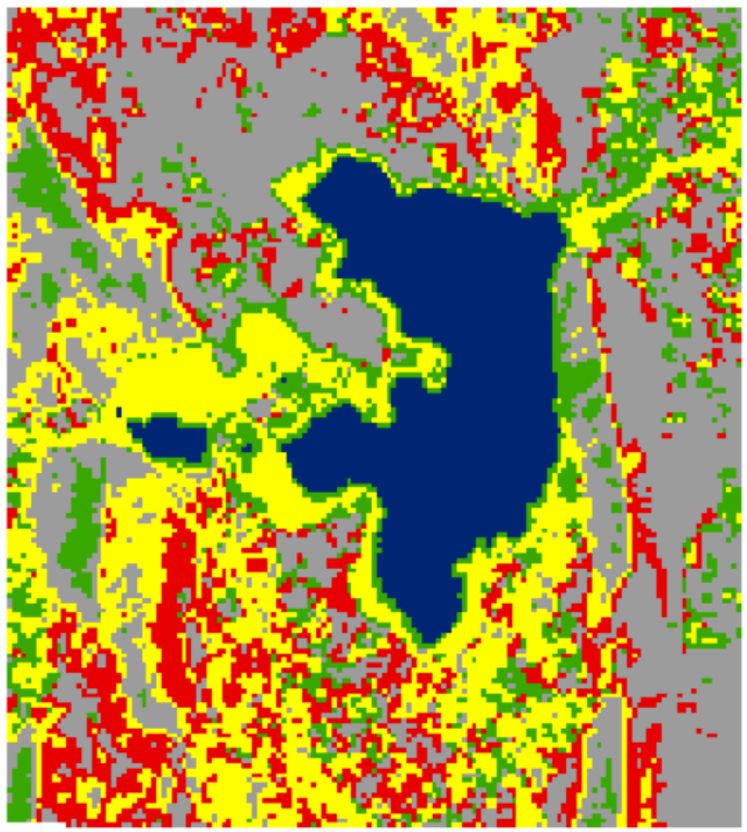


UDAI SAGAR LAKE

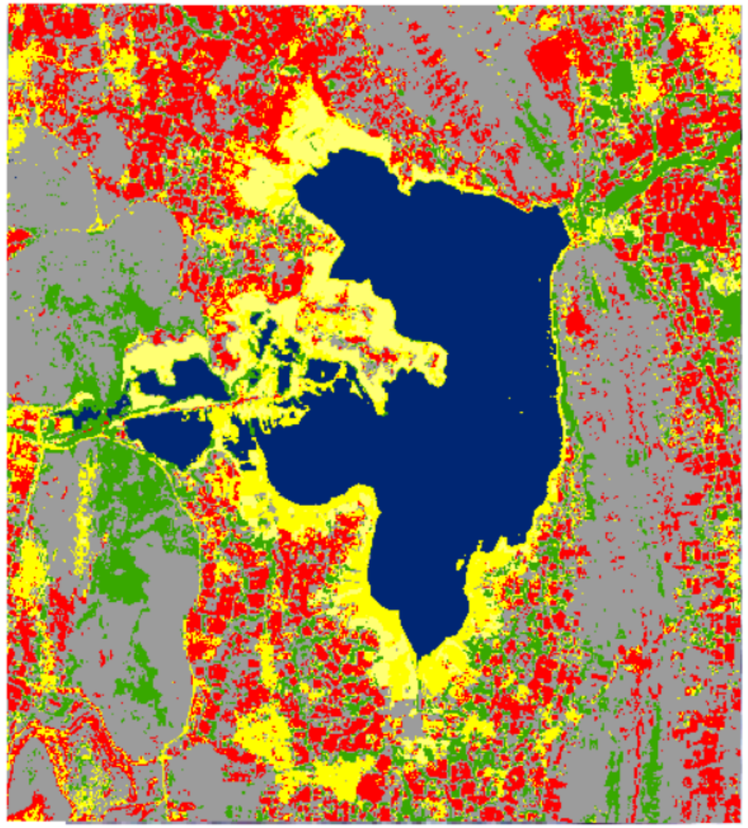
Land Use/ Land Cover Classification



Landsat 5 - 2009



Landsat 8 - 2014



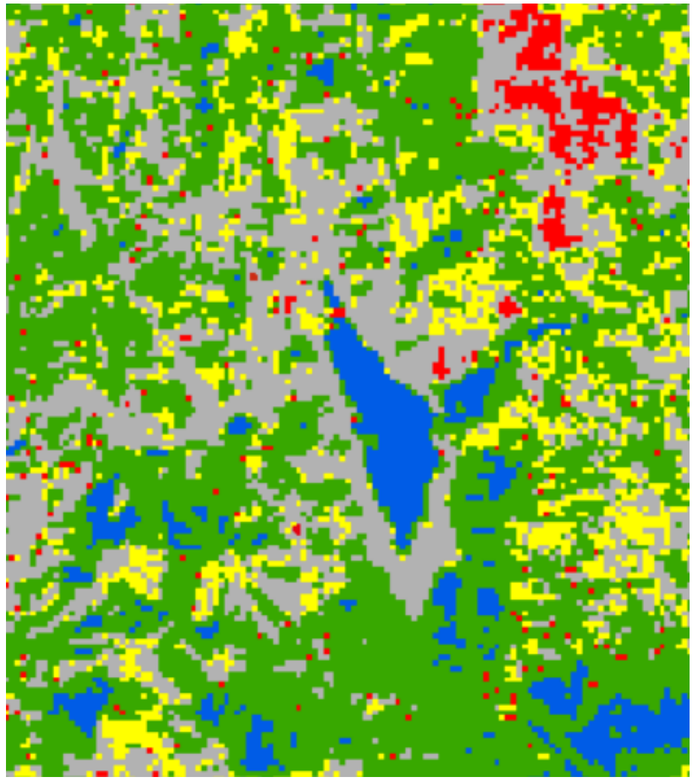
Sentinel 2 - 2019

Classification

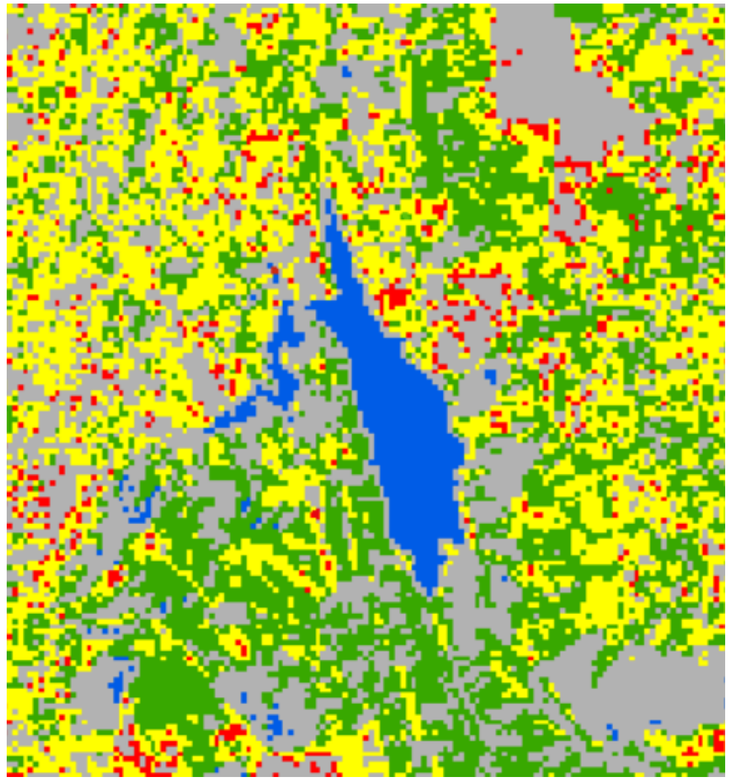
Water | Forest | Agricultural Land | Barren Land | Built Up Area

BADI LAKE

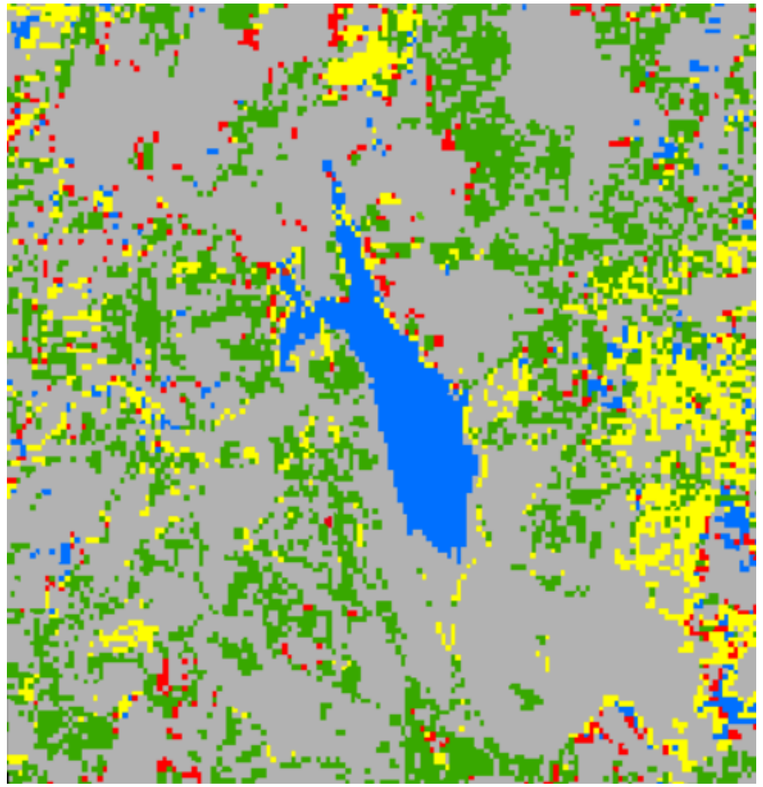
Land Use/ Land Cover Classification



Landsat 5- 2009



Landsat 8- 2014

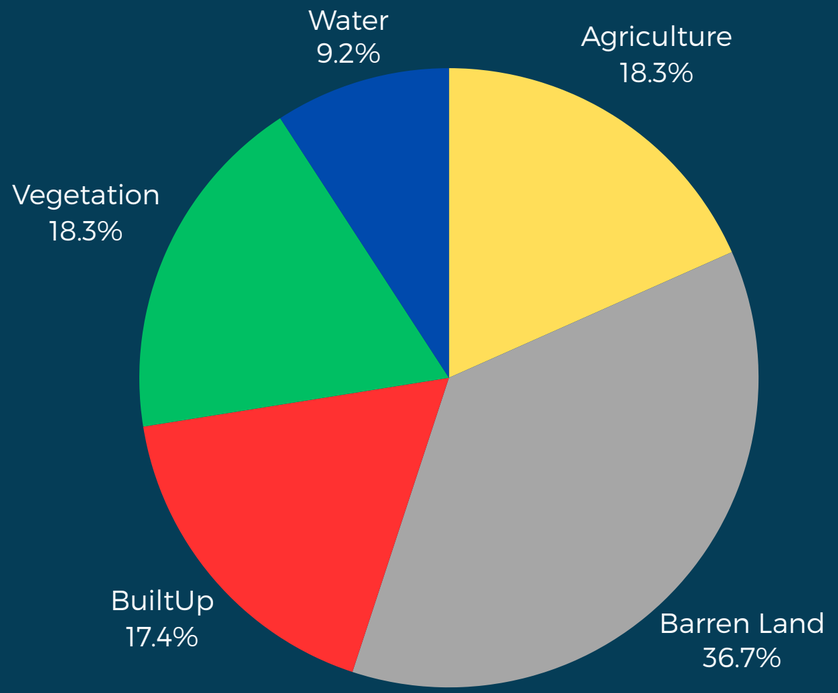


Sentinel 2 - 2019

Classification

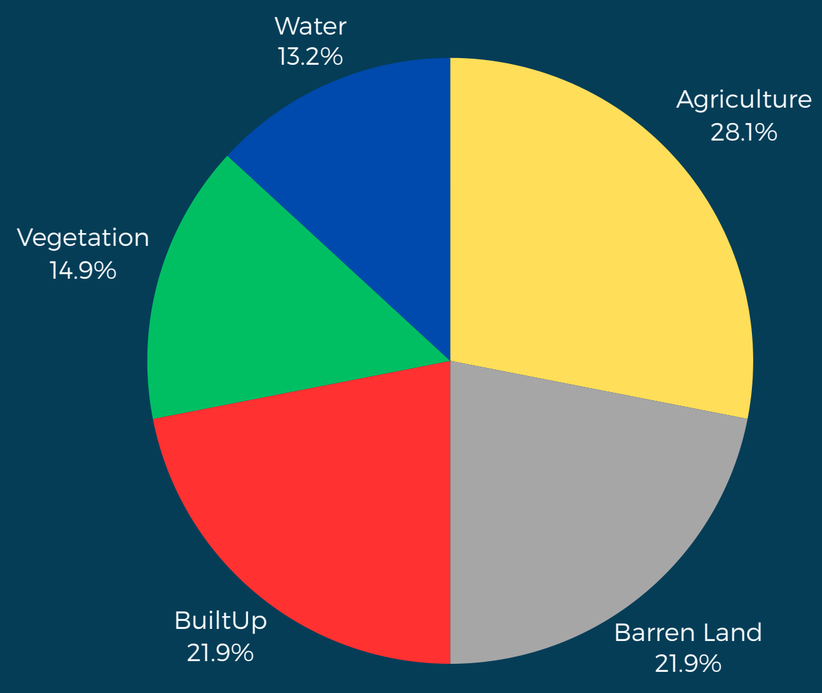
Water | Forest | Agricultural Land | Barren Land | Built Up Area

Overall Temporal Changes in Lake Area



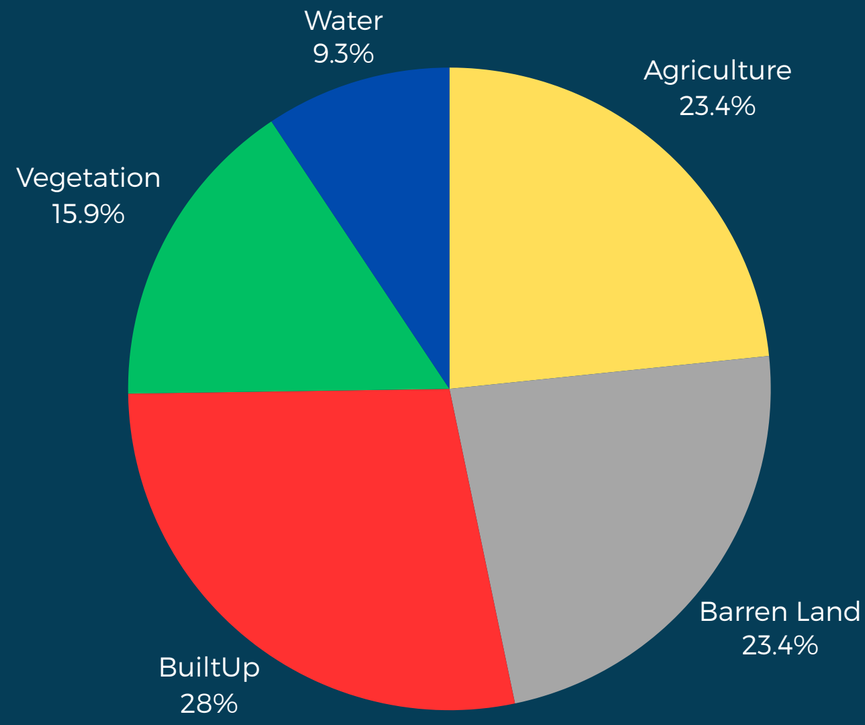
LANDSAT 5

2009



LANDSAT 8

2014



SENTINEL 2

2019

FINDINGS AND INTERPRETATION

Temporal Changes in Lake Extent

Fateh Sagar and Pichola

- NDWI is sensitive to the amount of water present in the observed area.
- In 2009, Fateh Sagar and Pichola's NDWI values indicated a drought situation where the lake extend was relatively small with reduced inflows, and highlighting the vulnerability of these water bodies to climate-induced variations.
- The surge in NDWI values by 2019 is linked to increased water storage, potentially influenced by the city's water demand, tourism-related activities, or climate-induced variations. The significant expansion aligns with the observations of Gupta et al. (2019), emphasizing the impact of urbanization on water quality and ecological health.

Udaisagar

- NDWI is designed to suppress the influence of vegetation, which also reflects strongly in the near-infrared spectrum.
- The decrease in Udaisagar's NDWI values from 2014 to 2019 suggests a considerable reduction in water extent. Research by Dawadi et al. (2019) underscores the importance of hydrological changes in influencing sediment and nutrient transport in lakes.
- The decline in water extent might be linked to changes in precipitation patterns or anthropogenic activities affecting the lake's hydrological balance.

Badi Lake

- Badi Lake's consistent expansion is noteworthy, and the higher NDWI values indicate its resilience to pollution. Jain et al. (2016) highlight the pristine condition of Badi Lake, attributing its water quality to its isolated location. The expansion may result from the absence of anthropogenic pressures that typically affect lakes in more urbanized areas.

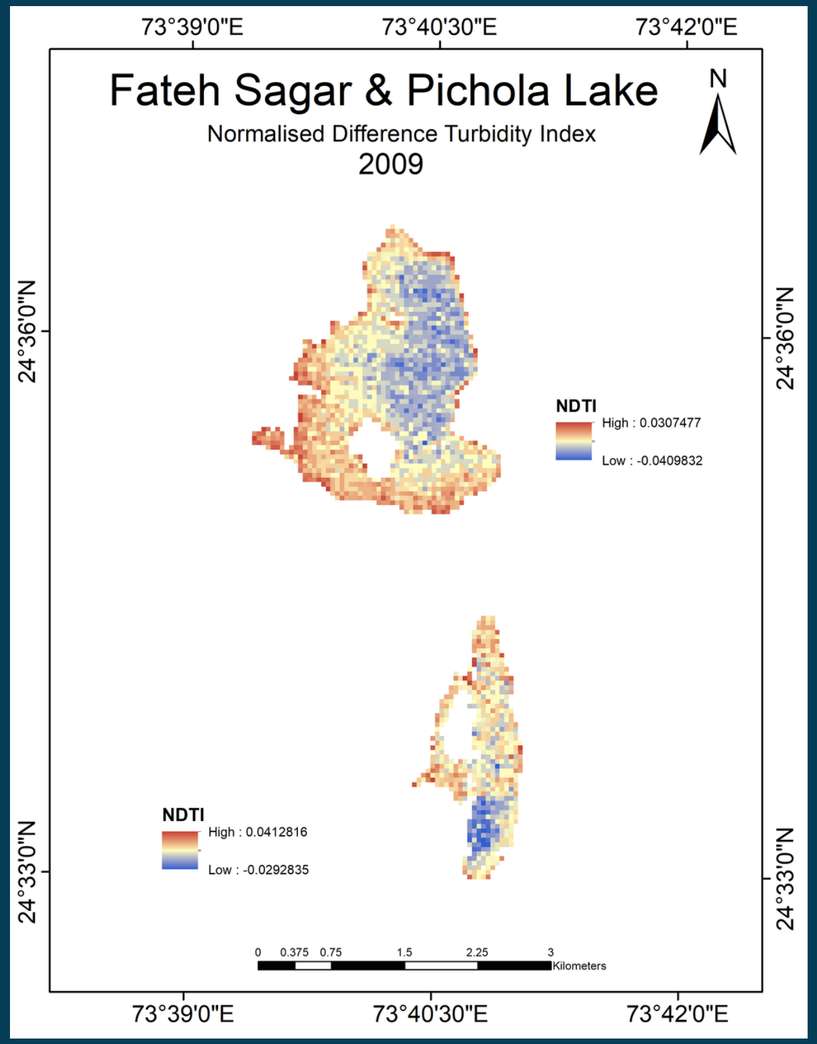
TEMPORAL CHANGES IN WATER QUALITY

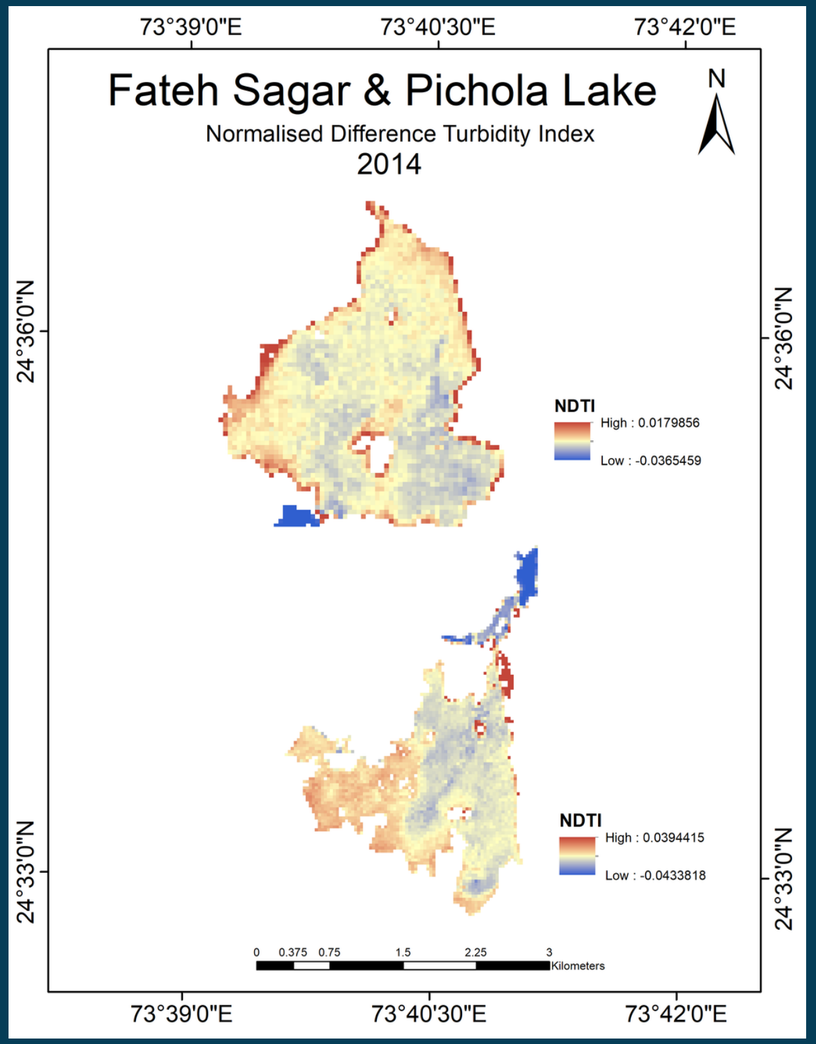
Normalised Difference Turbidity Index

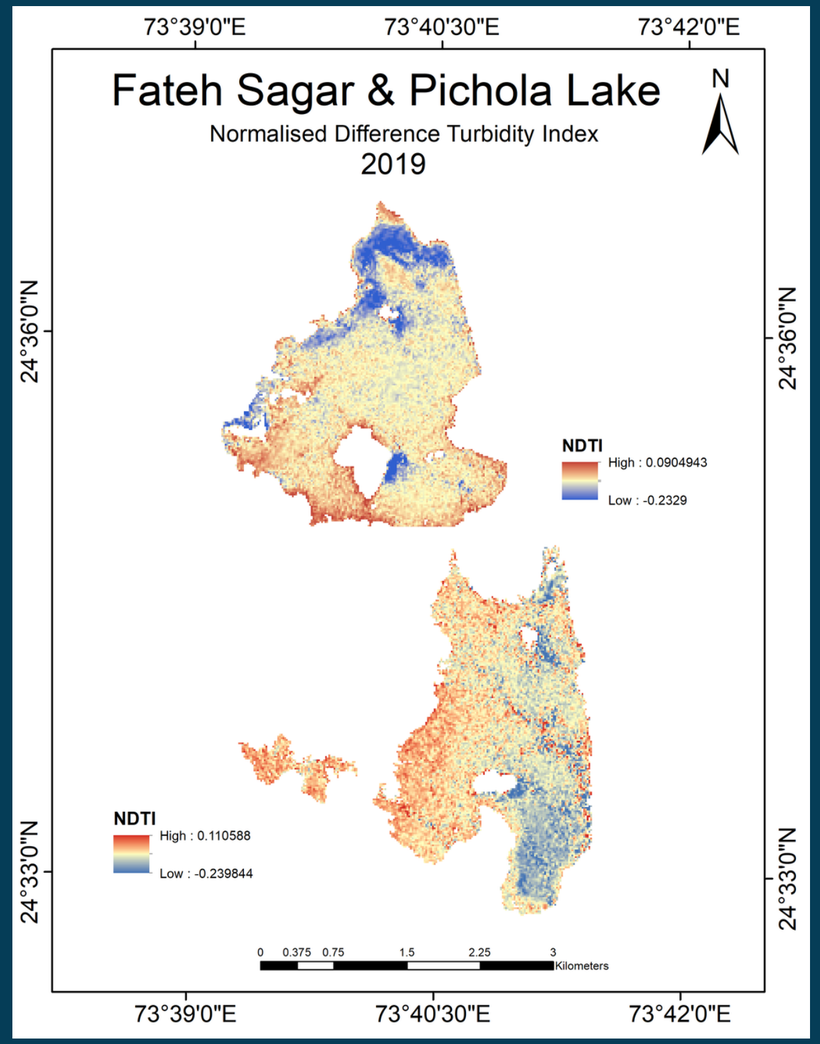
$$NDTI = (Red-Green) / (Red+Green)$$

FATEH SAGAR AND PICHOLA LAKE

Normalised Difference Turbidity Index

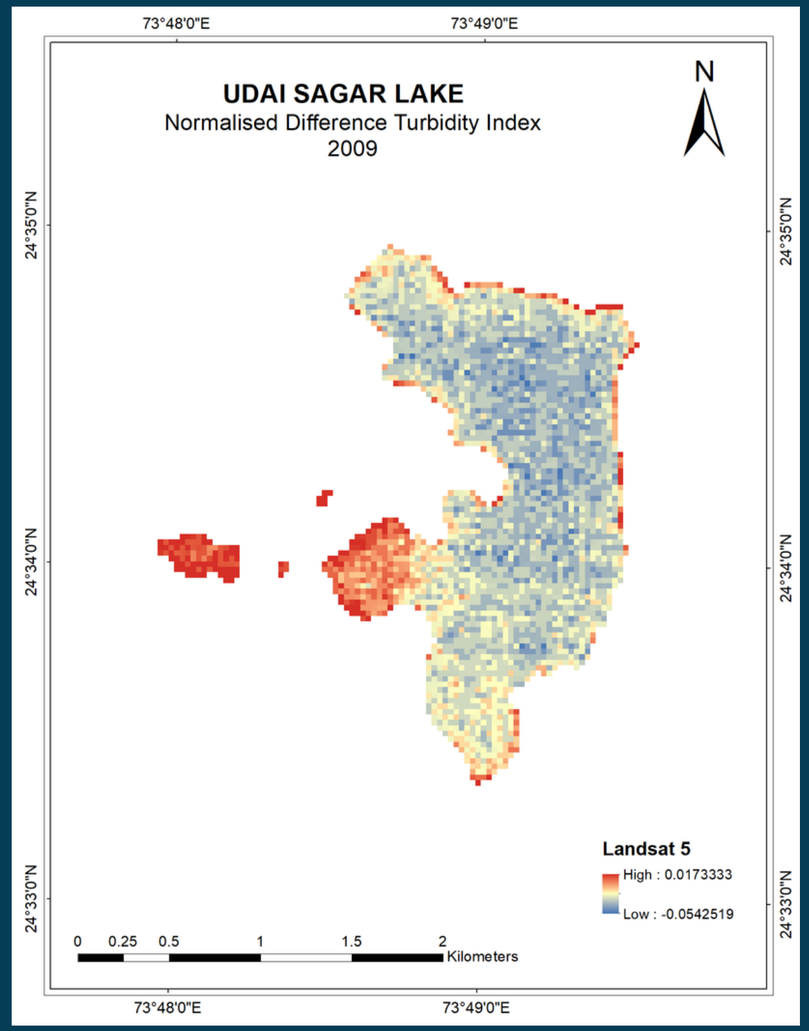


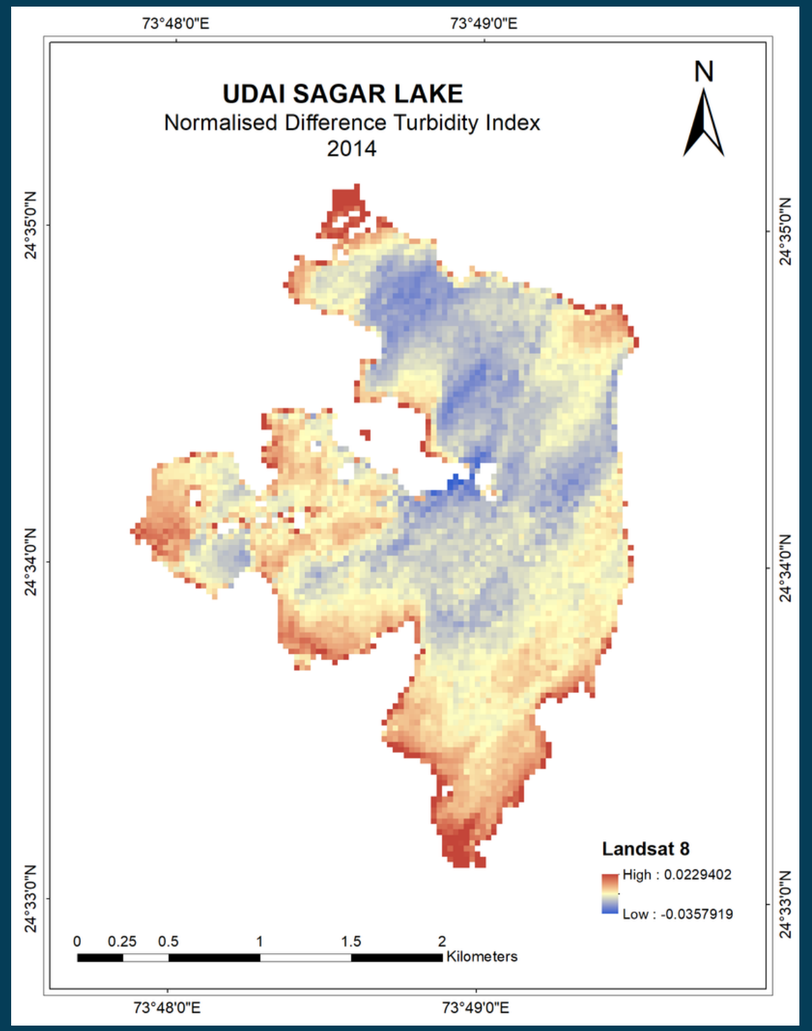


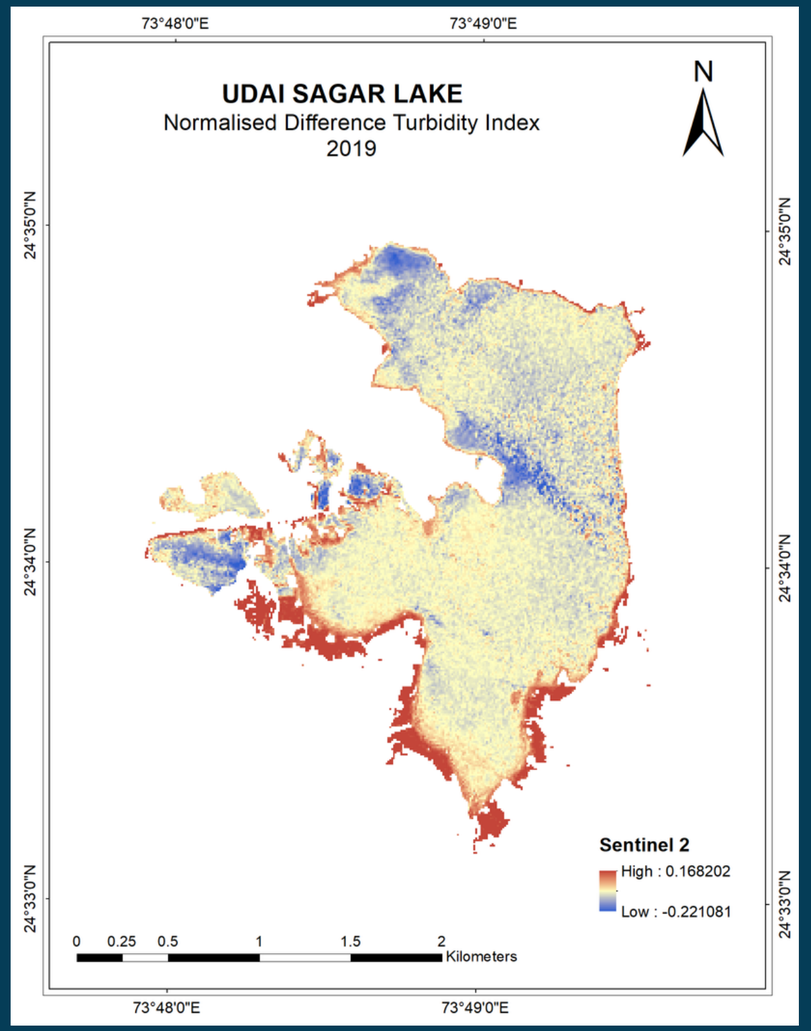


UDAISAGAR LAKE

Normalised Difference Turbidity Index

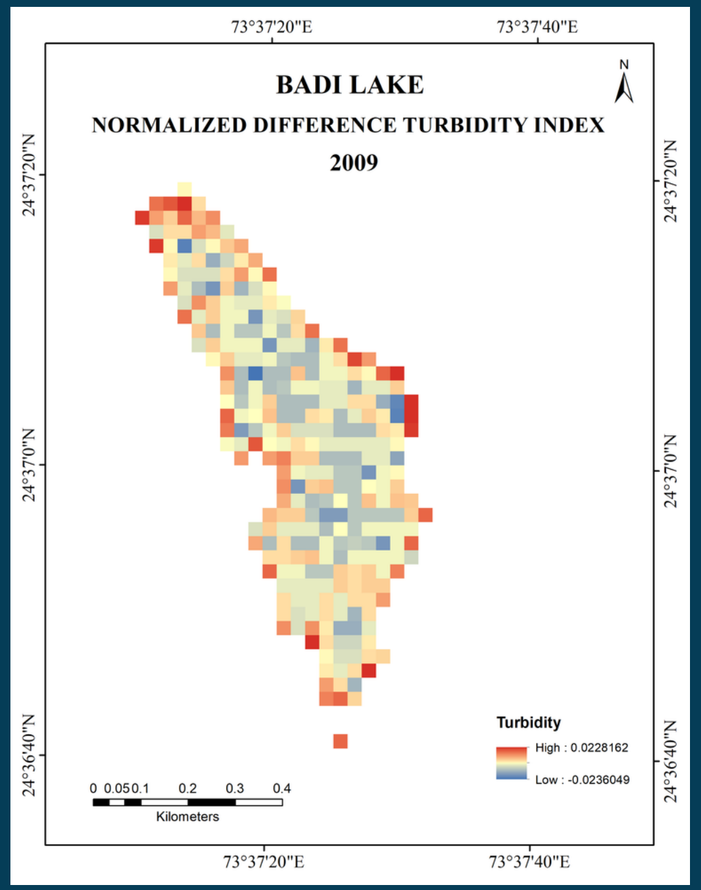


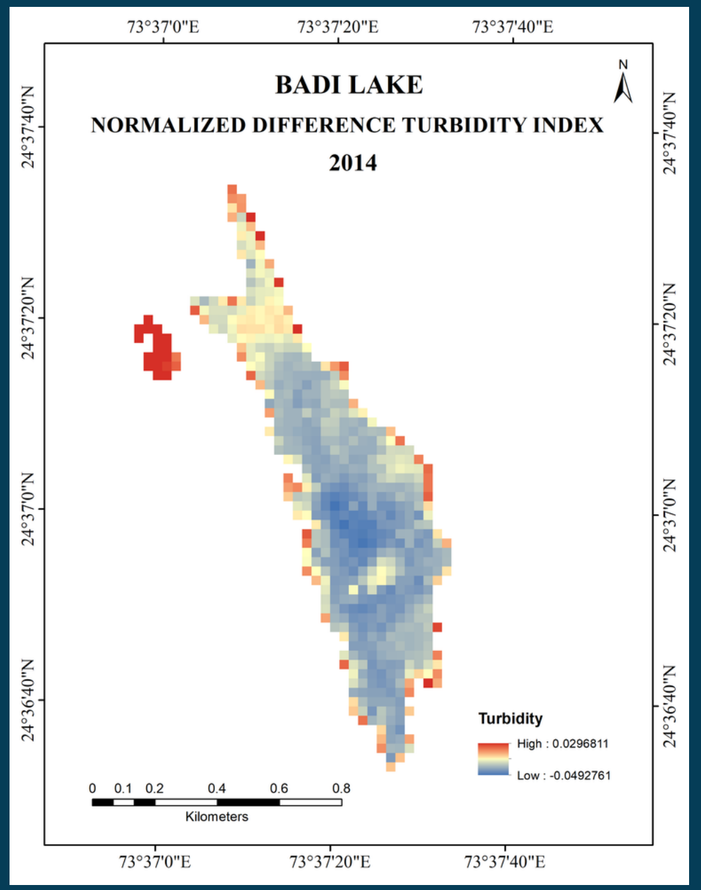


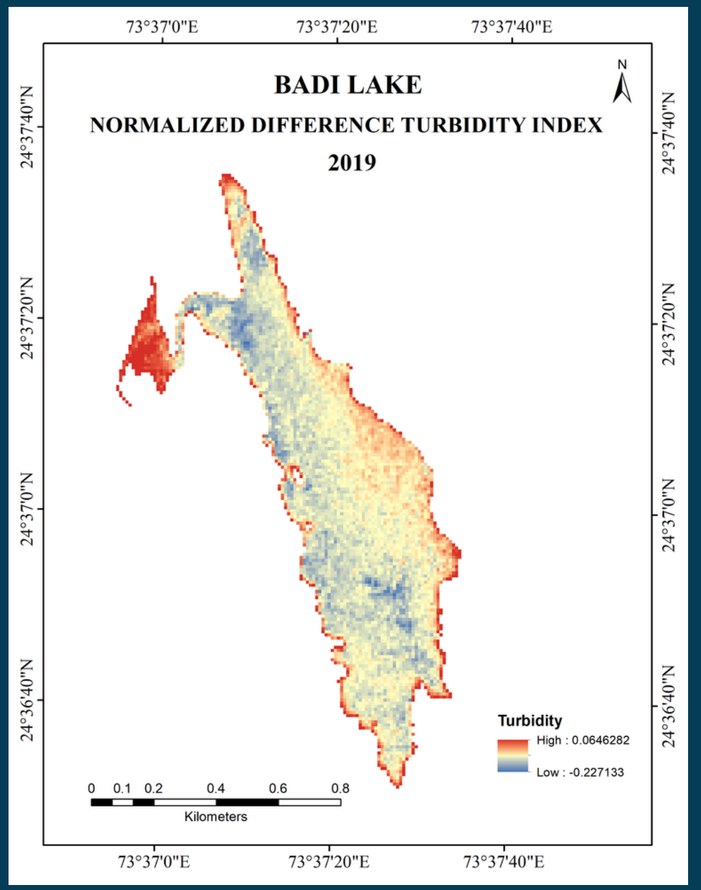


BADI LAKE

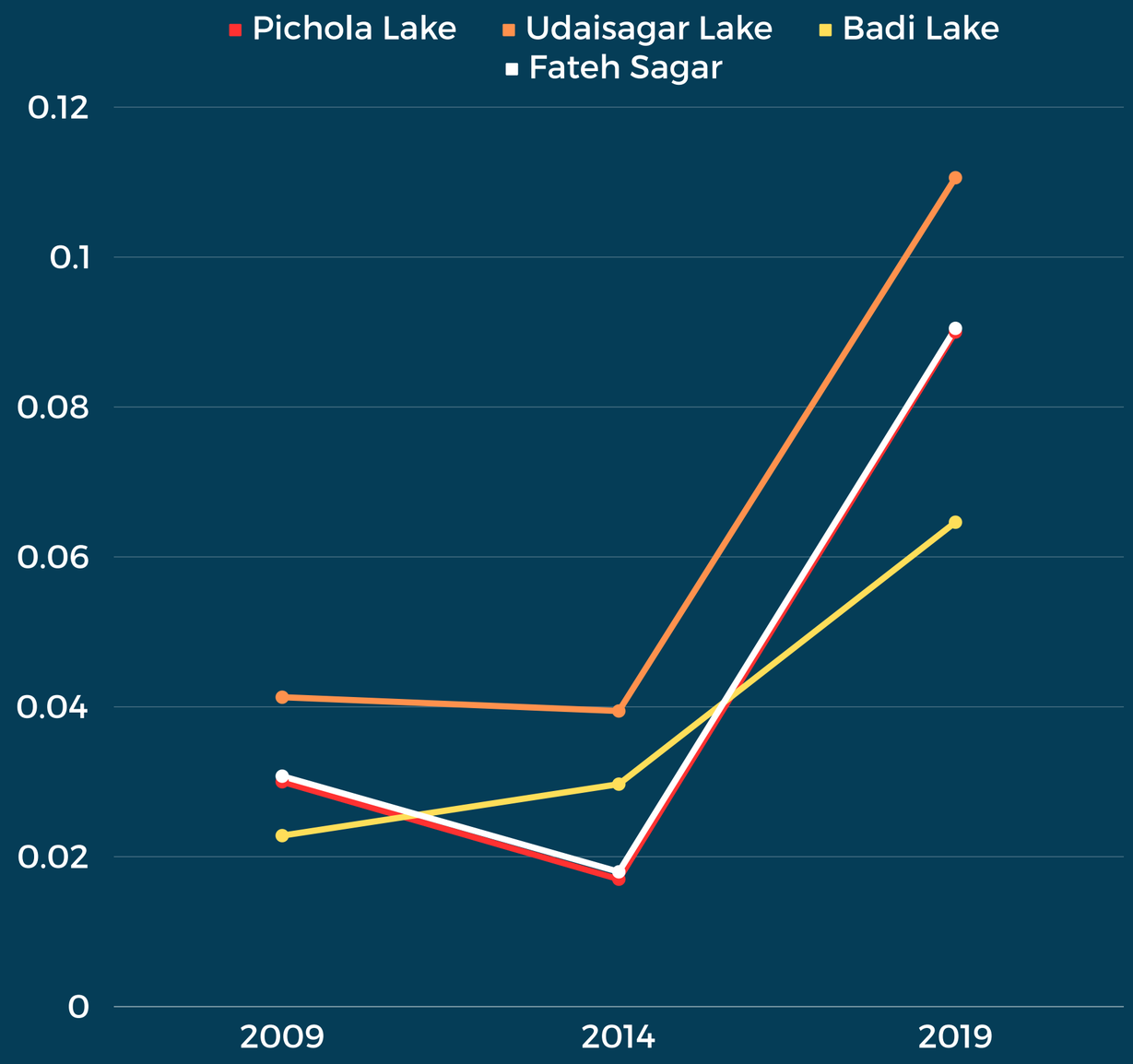
Normalised Difference Turbidity Index







Normalised Difference Turbidity Index



Fatehsagar and Pichola Lakes

- Similar NDTI Patterns: Proximity led to similar trends.
- 2019 Turbidity Surge: Increased urbanization and tourism escalated turbidity from 0.01 in 2009 to 0.09 in 2019, signifying heightened pollutant levels.

Udaisagar Lake:

- Consistent Turbidity: Stable values in 2009 and 2014.
- 2019 Rise: Expansion of nearby farmlands contributed to fertilizer discharge, elevating turbidity levels.

Badi Lake

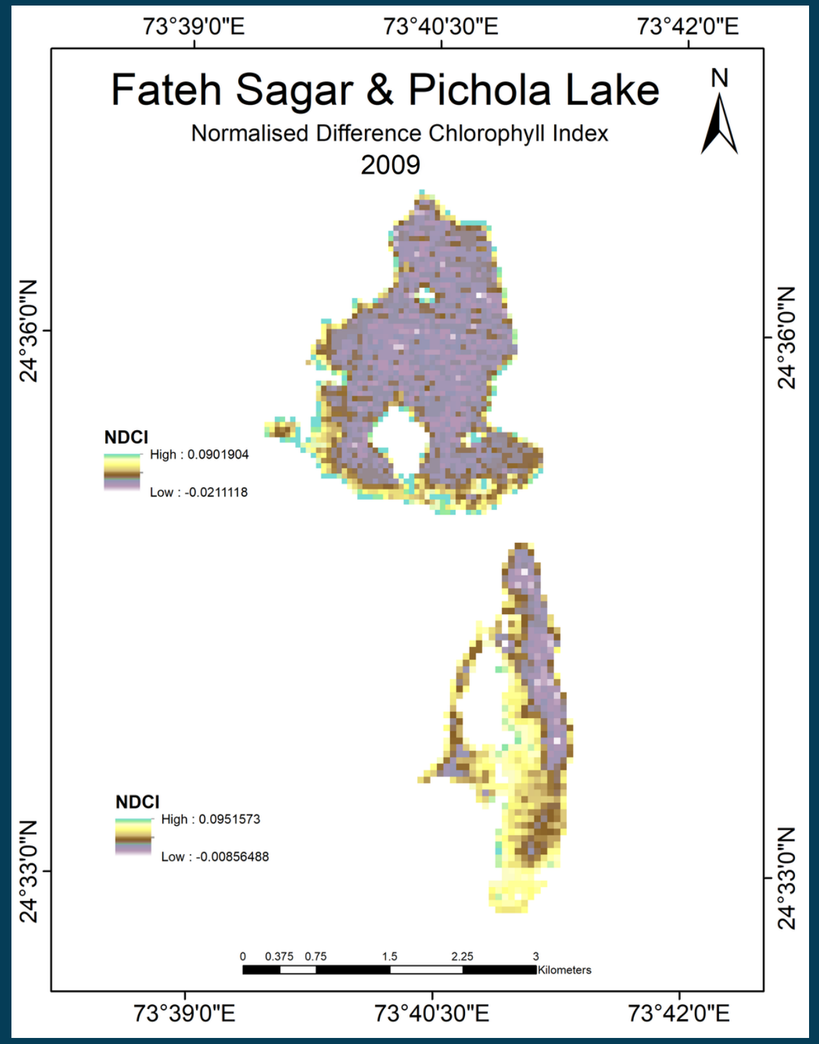
- Minimal Turbidity: Geographically secluded, surrounded by hills and barren lands.
- 2019 Peak: Recorded its highest value at 0.06, indicating a relative increase potentially influenced by external factors.

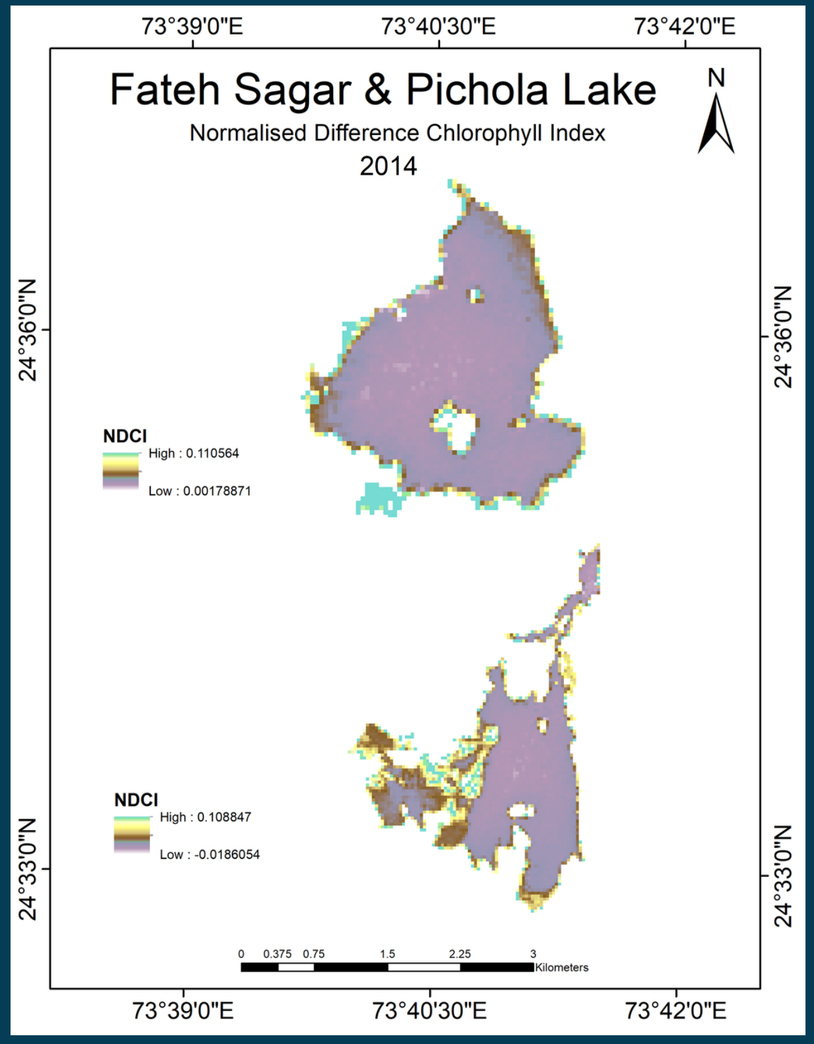
Normalised Difference Chlorophyll Index

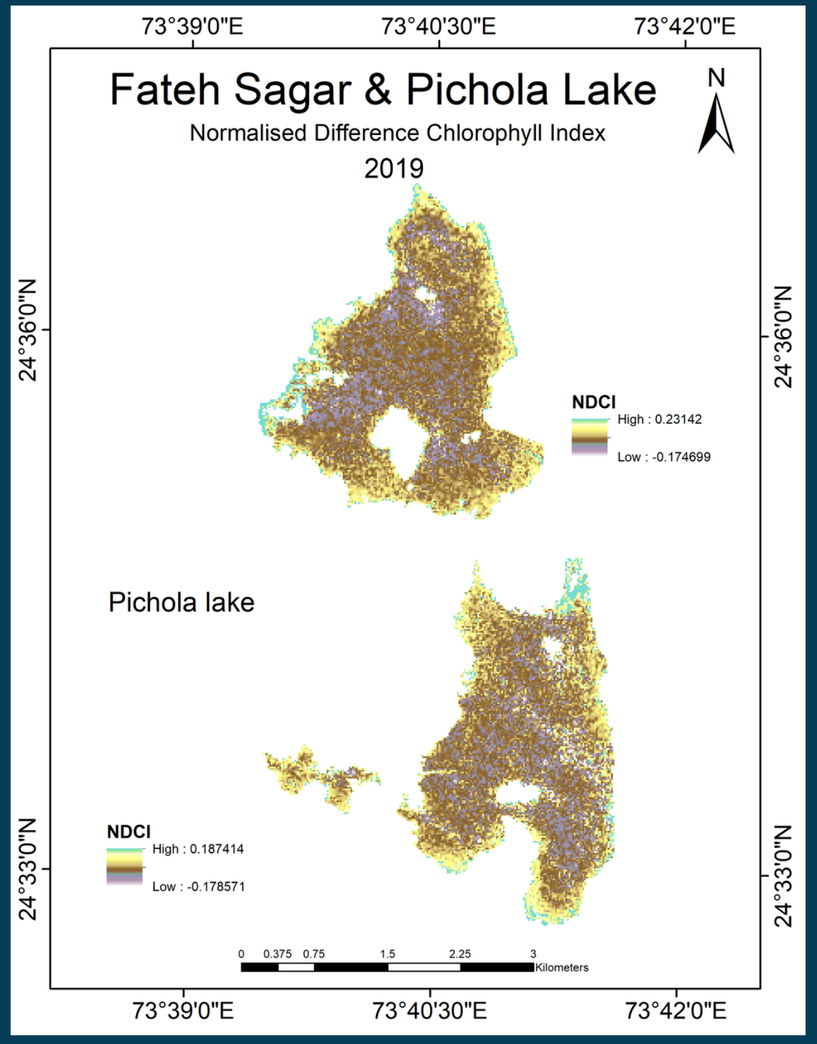
$$NDCI = (MIR-Red) / (MIR+Red)$$

FATEH SAGAR AND PICHOLA LAKE

Normalised Difference Chlorophyll Index

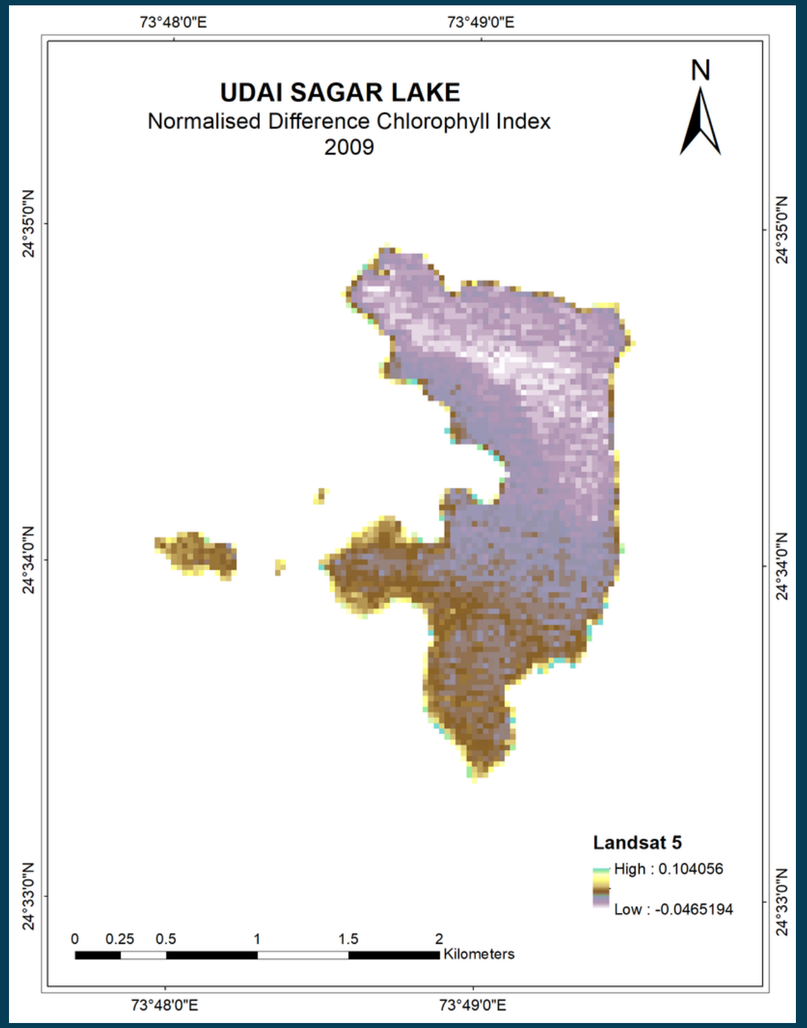


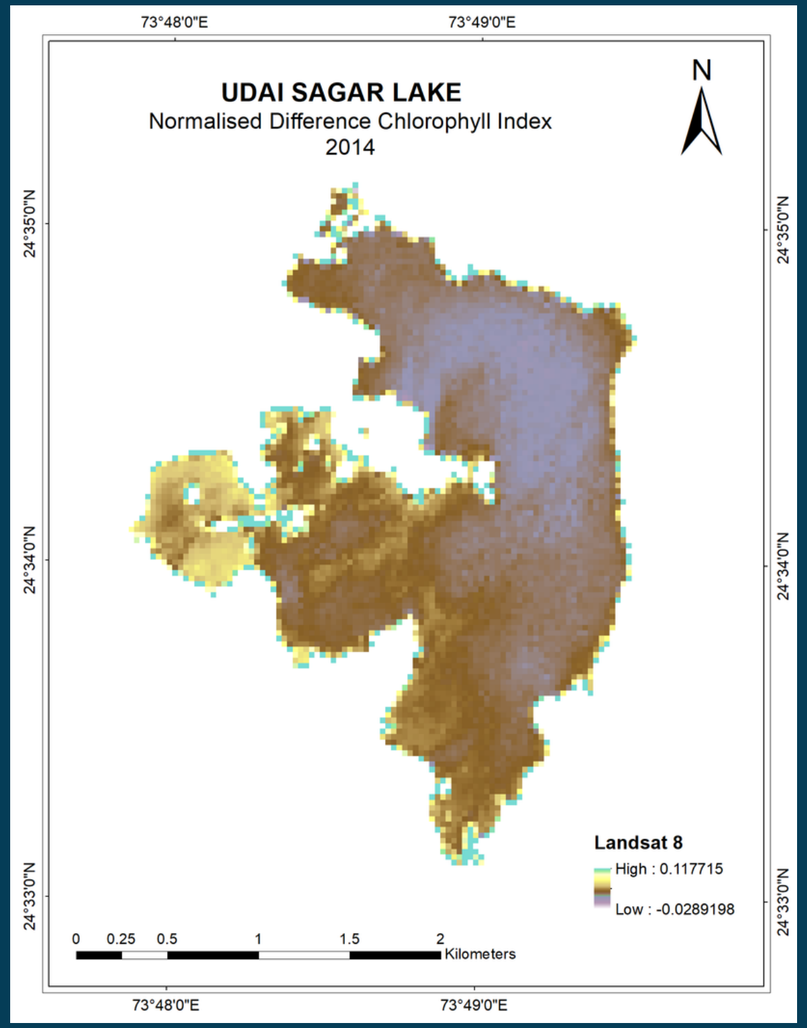


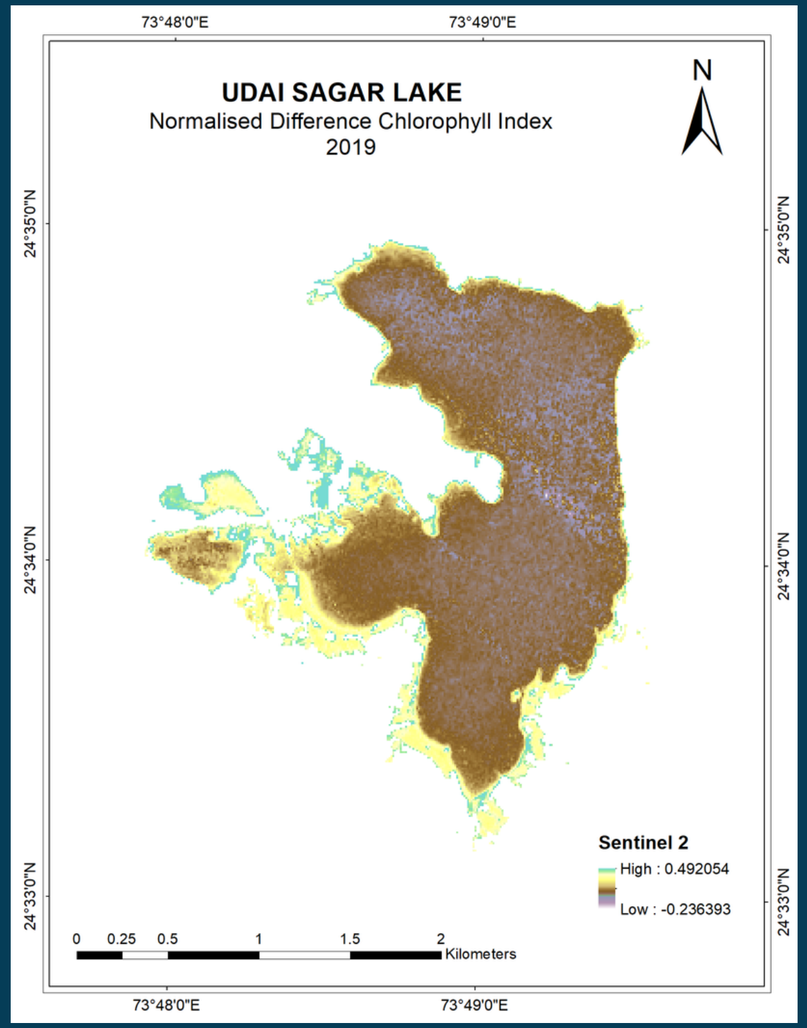


UDAI SAGAR LAKE

Normalised Difference Chlorophyll Index

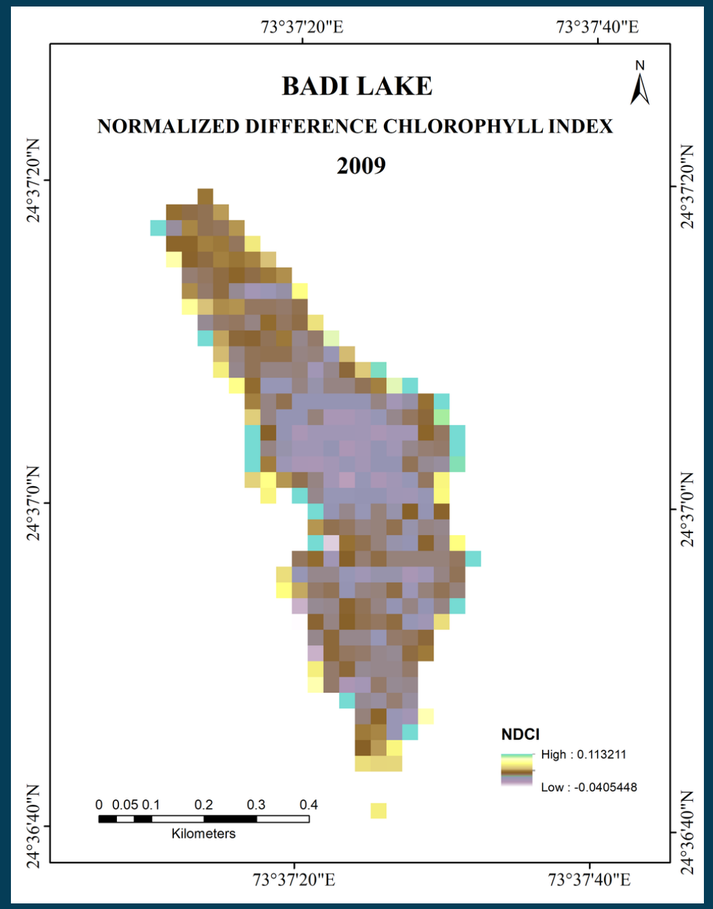


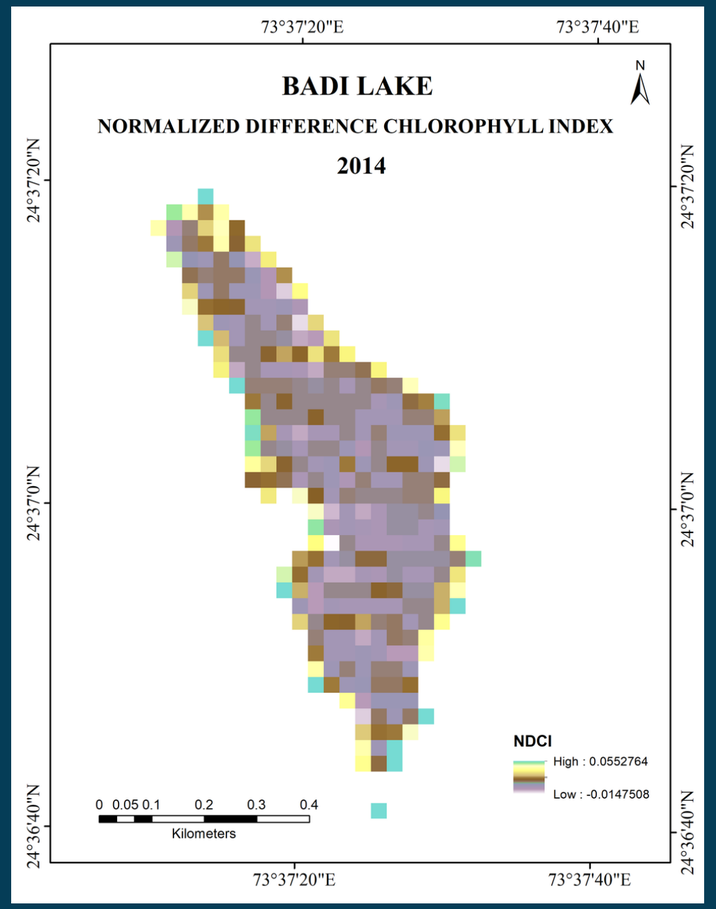


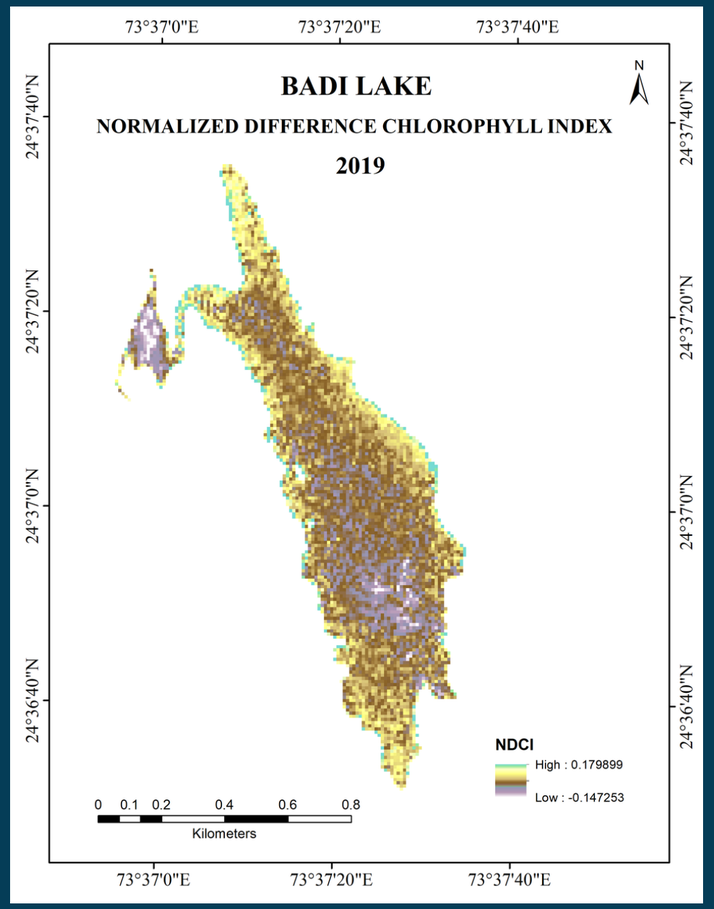


BADI LAKE

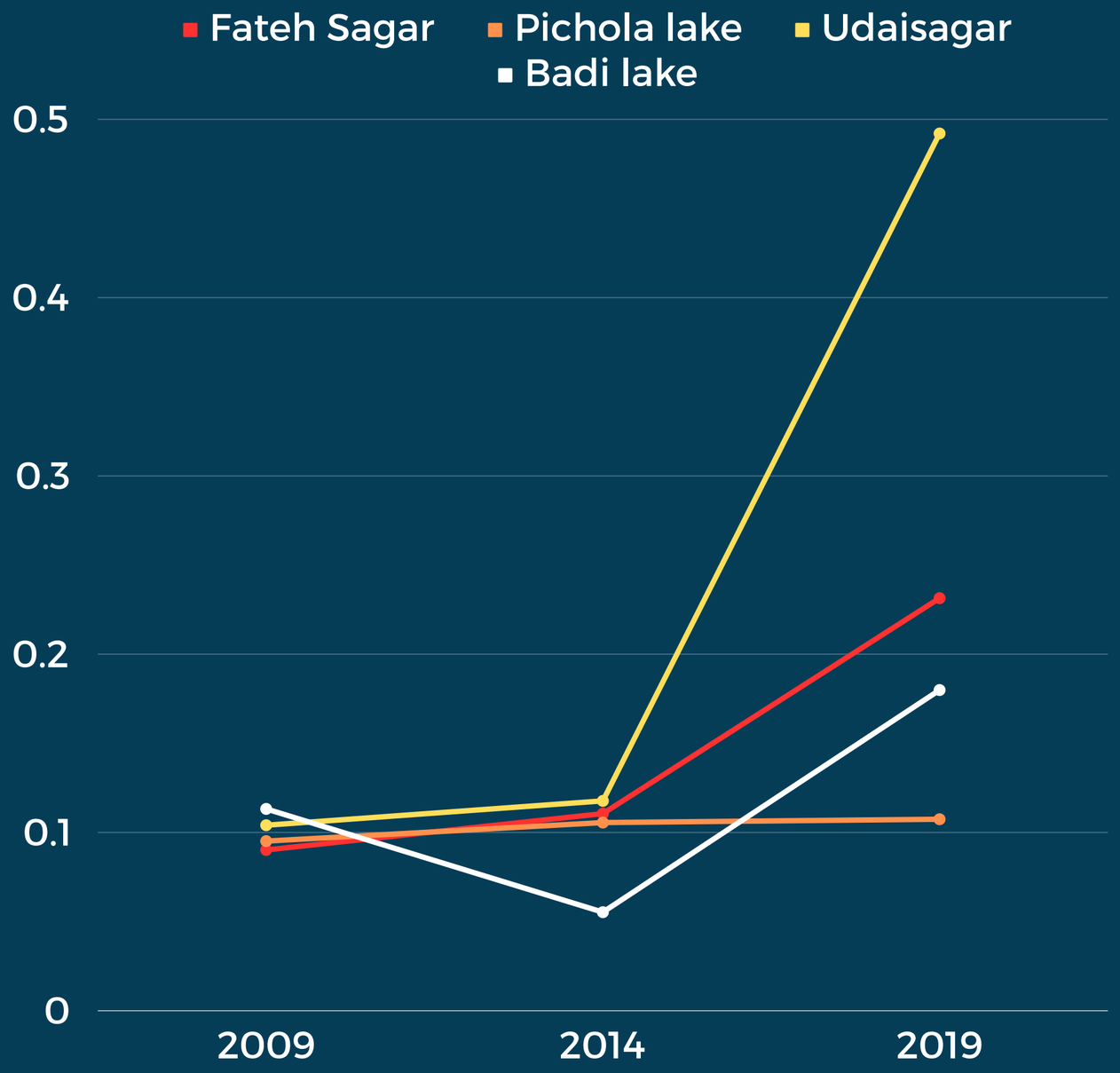
Normalised Difference Chlorophyll Index







Normalised Difference Chlorophyll Index



Udaisagar Lake and Fatehsagar Lake

- NDCI remained steady around 0.1 in 2009 and 2014.
- 2019 Spike: Increased farmland and runoff caused a sudden rise due to agricultural drainage into these lakes.

Badi Lake

- 2009 Chlorophyll Index: 0.113
- 2014 Dip: Influenced by shifting weather patterns affecting aquatic plant growth and metabolism.
- 2019 : Subsequent increase attributed to the changes in temperature and weather conditions.

Pichola Lake:

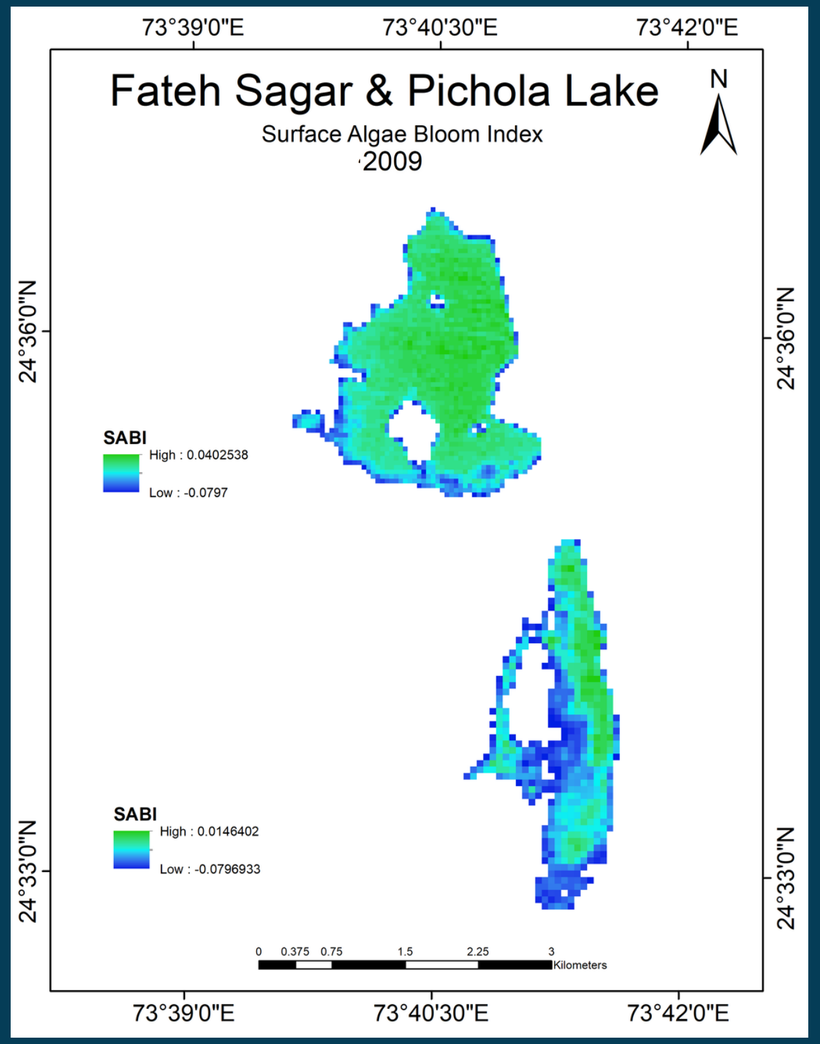
- Maintained stability in chlorophyll levels consistently over the years.
- Attributed to effective conservation and management practices implemented by the local government.

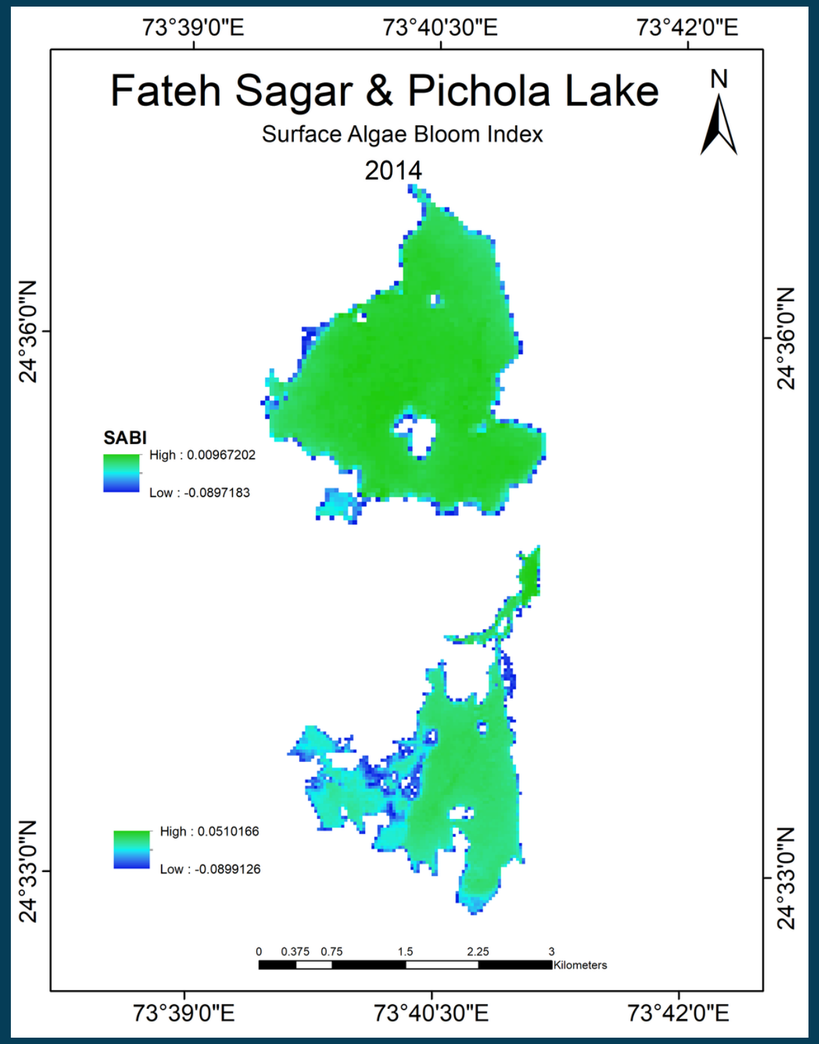
Surface Algae Bloom Index

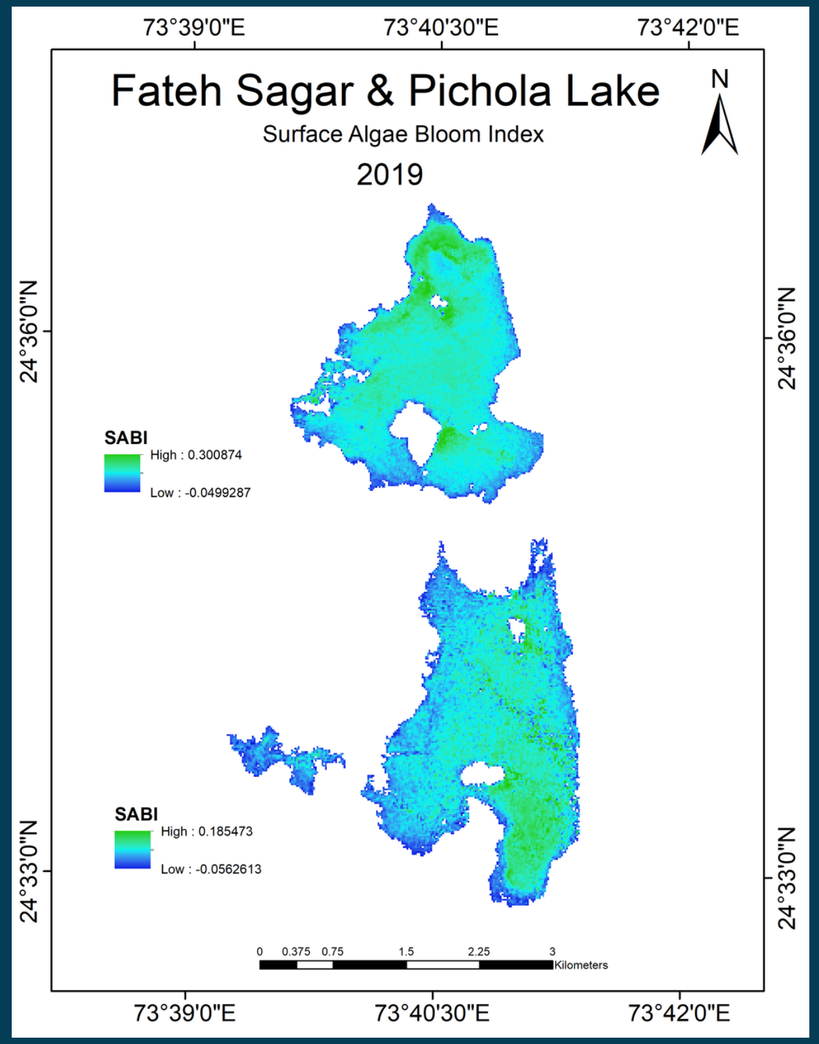
$$SABI = (NIR - Red) / (Green + Blue)$$

FATEH SAGAR AND PICHOLA LAKE

Surface Algae Bloom Index

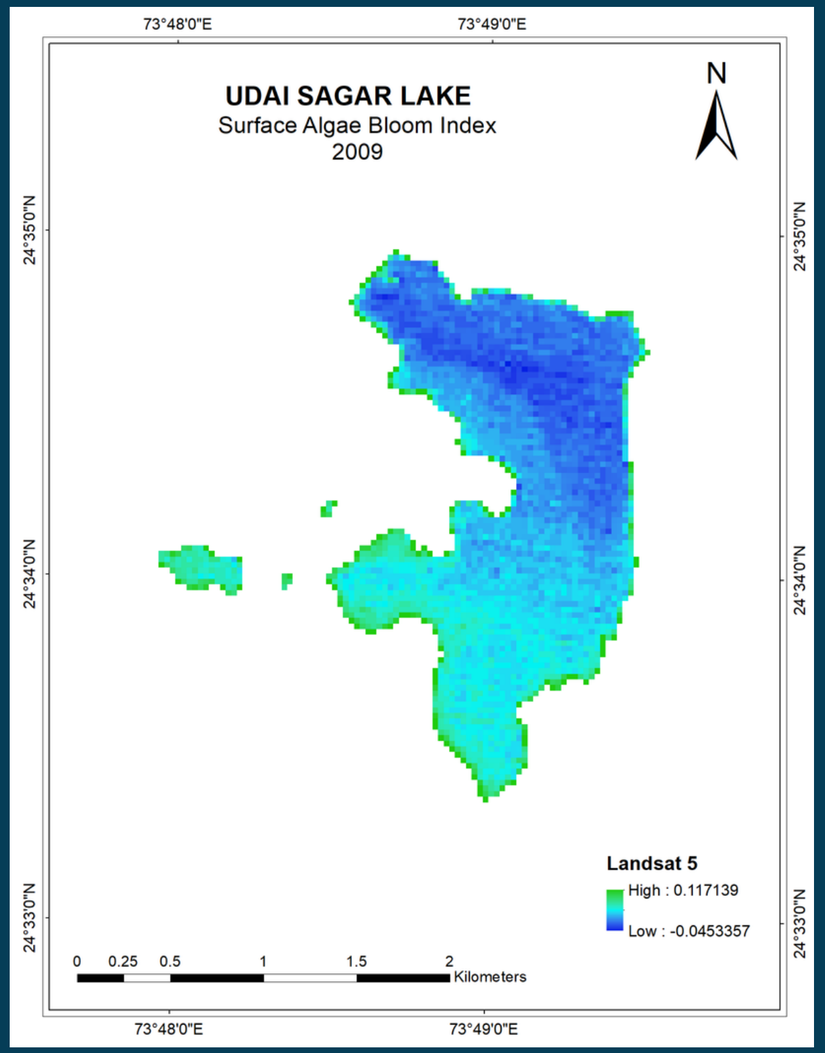


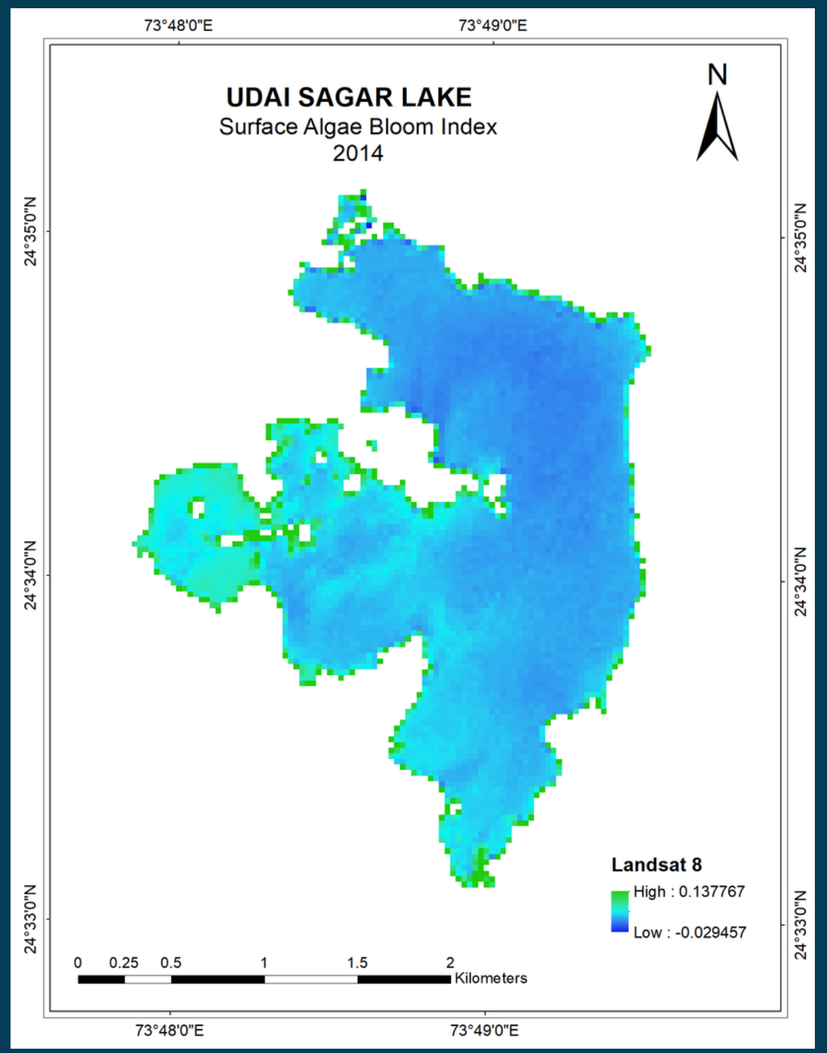


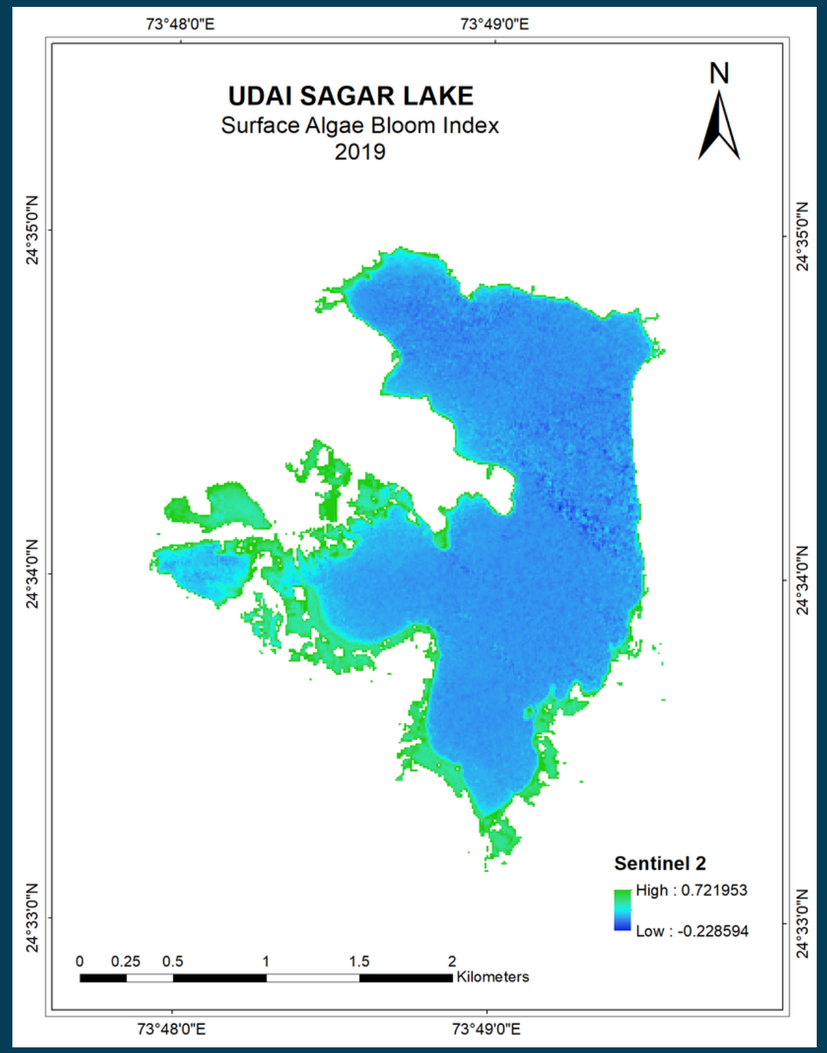


UDAI SAGAR LAKE

Surface Algae Bloom Index

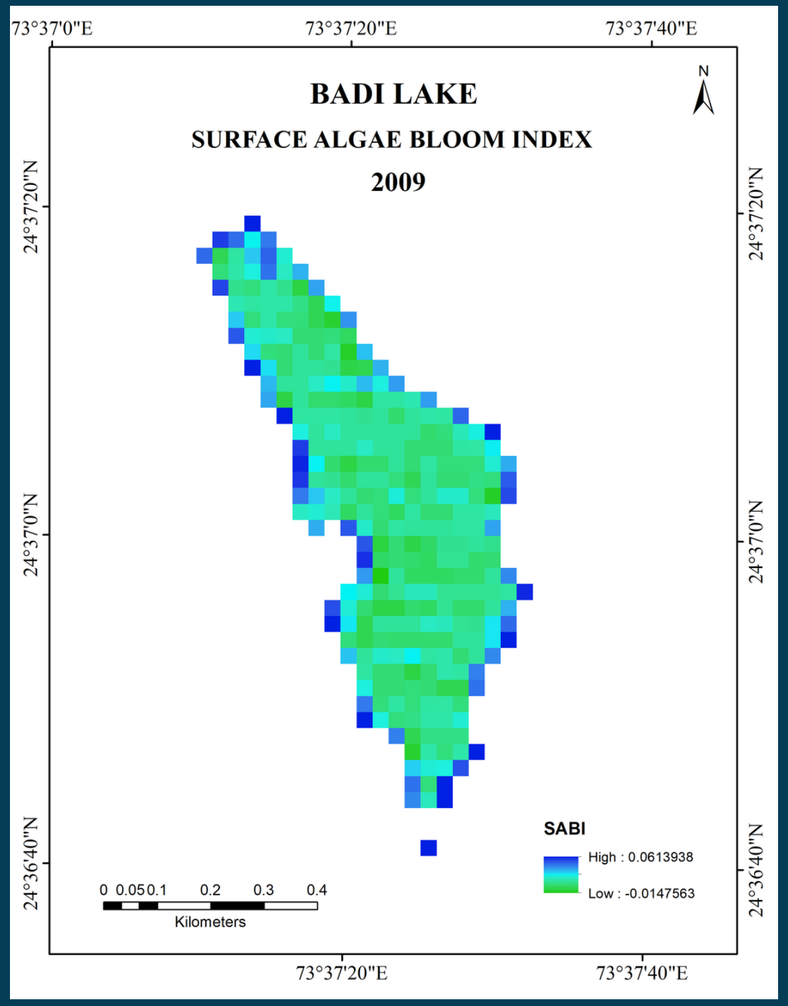


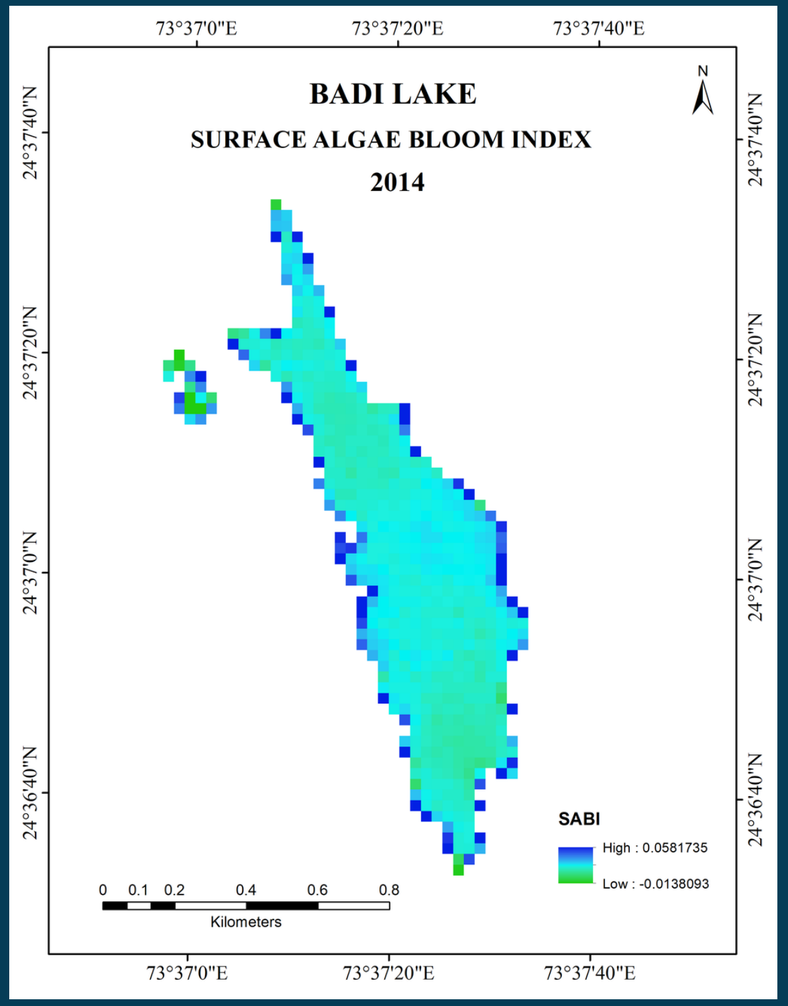


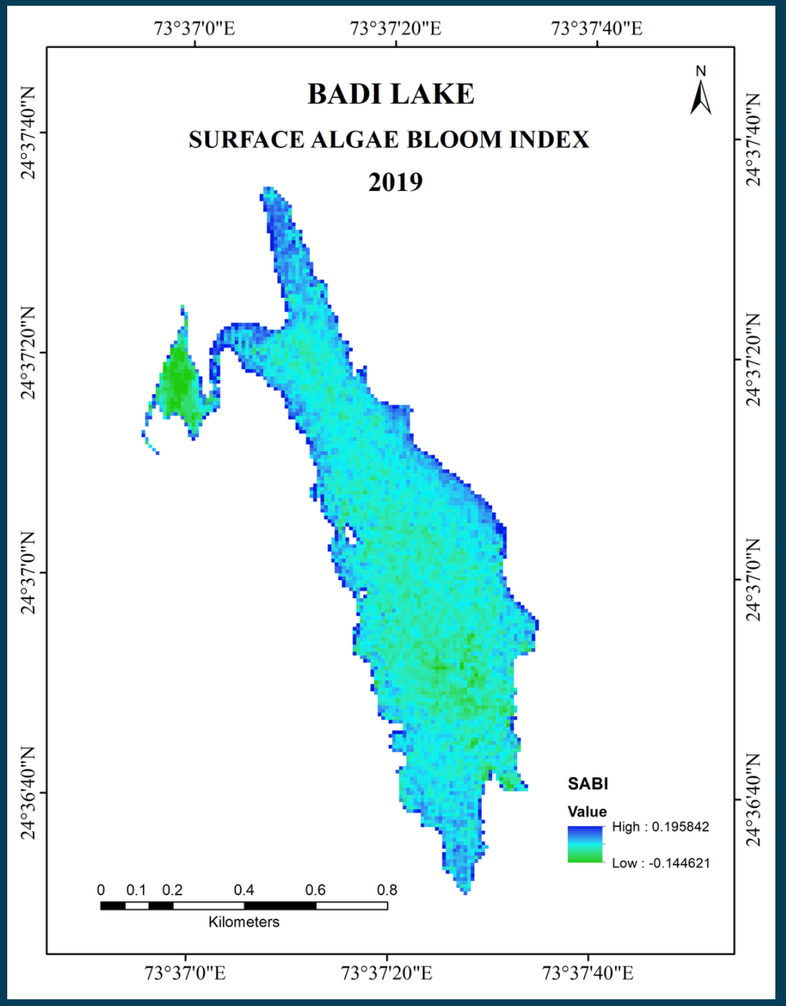


BADI LAKE

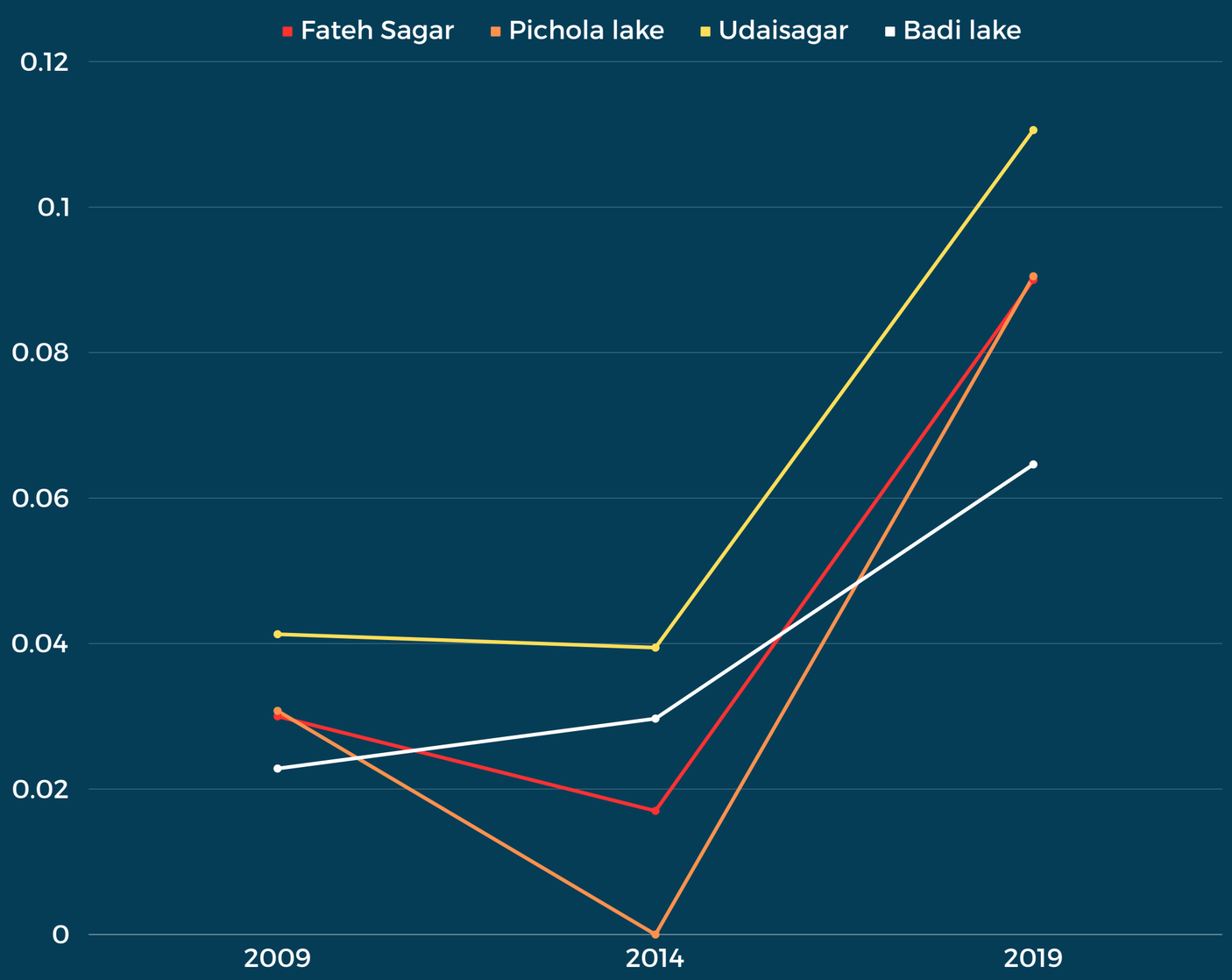
Surface Algae Bloom Index







Surface Algae Bloom Index



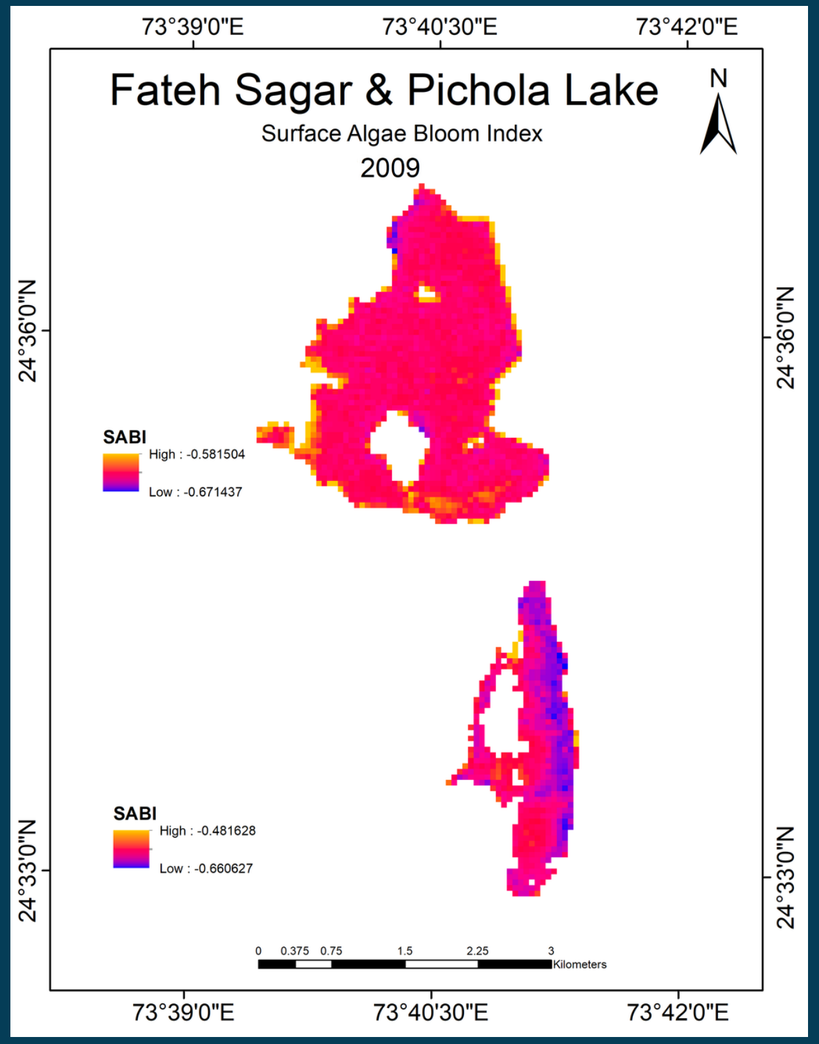
- The presence of algae in water indicates an increase in nutrient content, signaling poor water quality.
- **2009**: Fateh Sagar, Pichola, Badi Lake, and Udai Sagar showed SABI values from 0.03 to 0.3, indicating moderate to high surface algae.
- **2014**: SABI values ranged from 0.02 to 0.17, showing variability and potential reduction compared to 2009.
- **2019**: SABI values ranged between 0.06 and 0.1, indicating a potential stabilization or minor reduction in algae intensity compared to 2009.
- **Causes**: Human activities like agricultural and industrial runoff likely contributed to increased algae growth, impacting water quality and ecosystems.
- **Persistent Concerns:** Moderate SABI values in 2019 highlight continued worries about algae's effect on water quality.

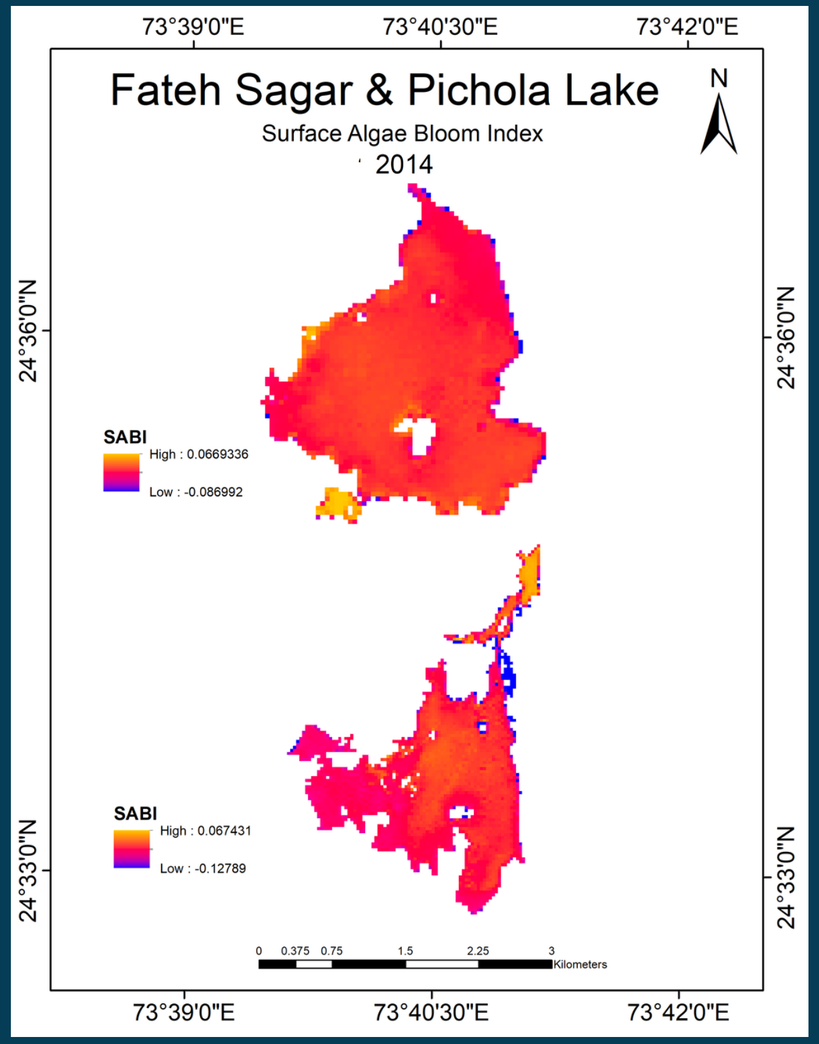
Normalised Difference Salinity Index

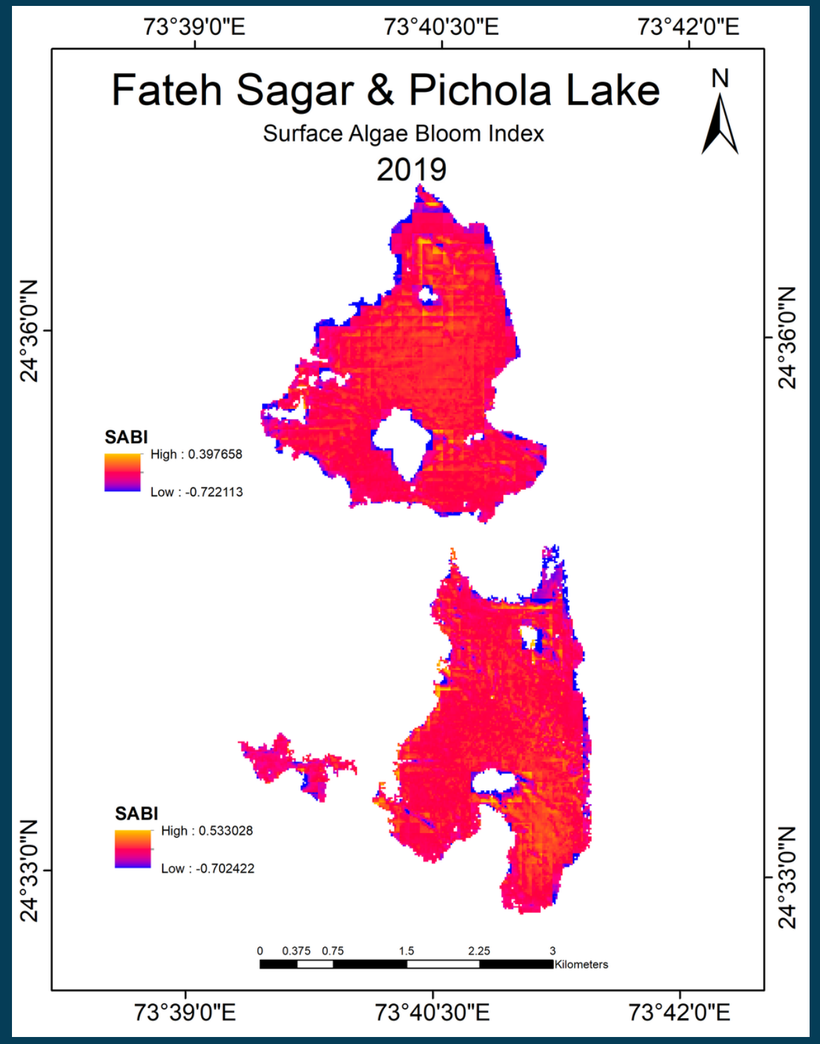
SI = (Blue x Red) / Green

FATEH SAGAR AND PICHOLA LAKE

Salinity Index

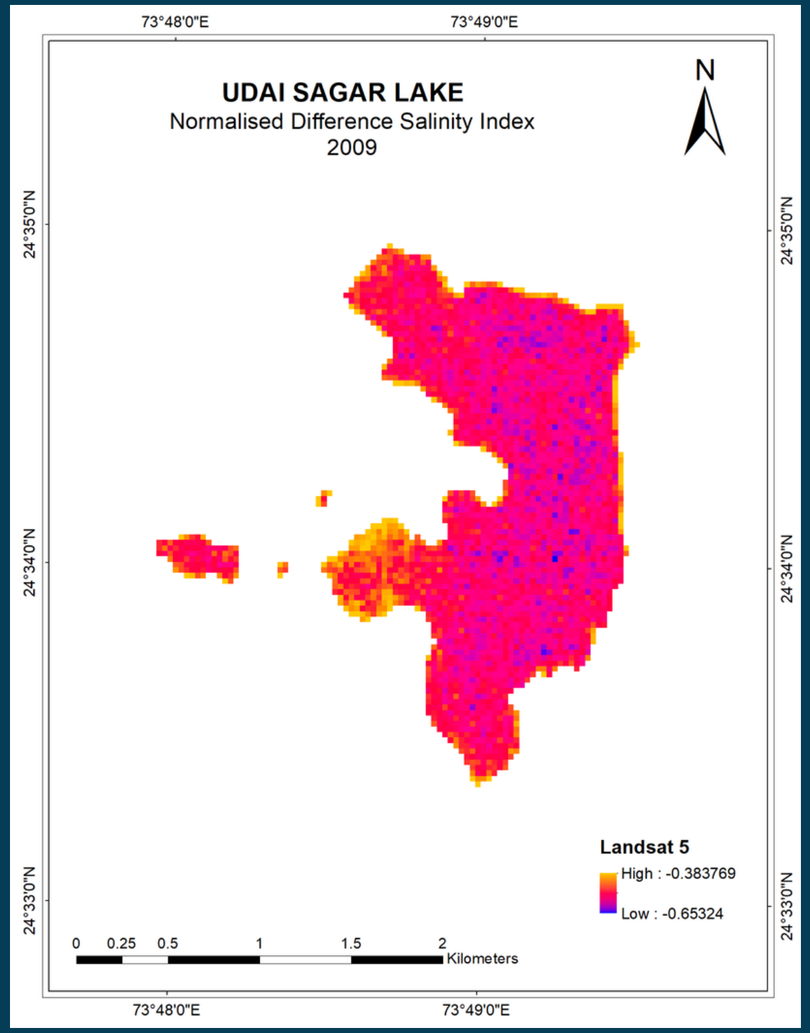


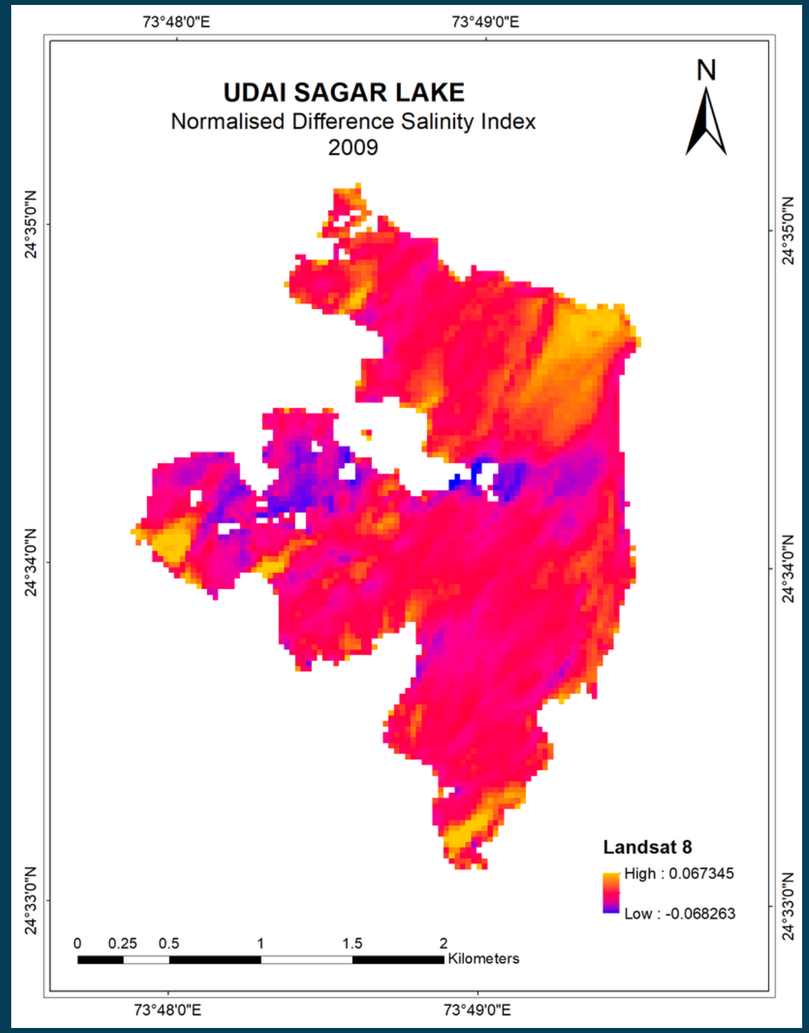


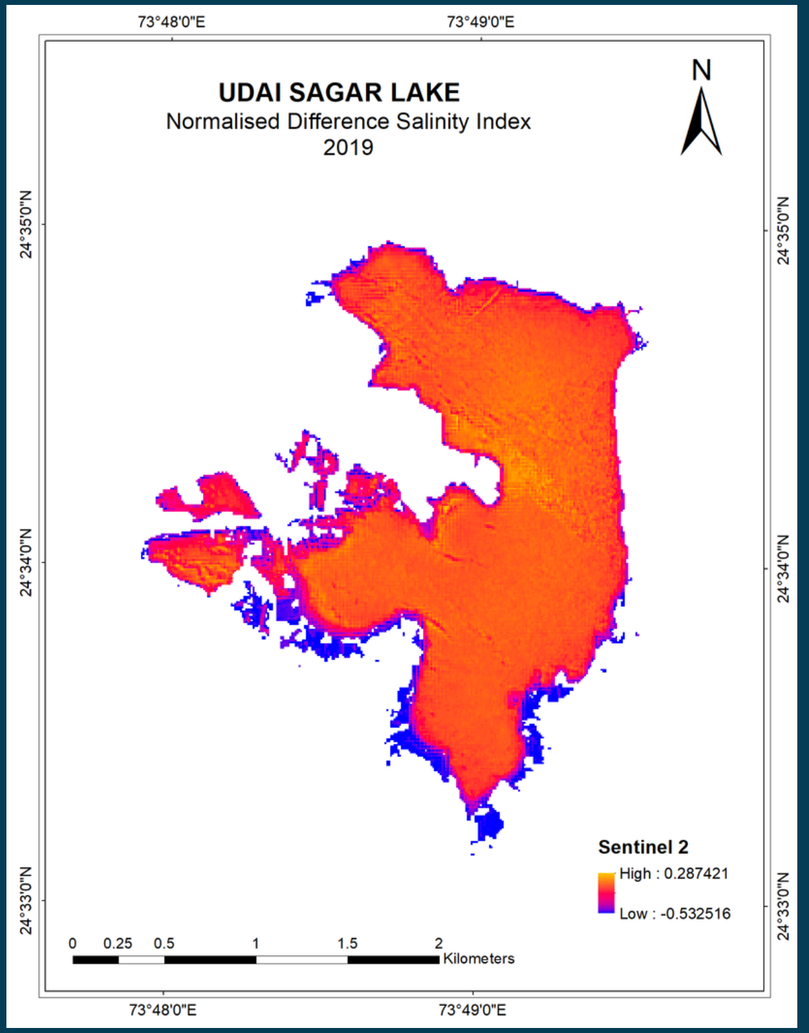


UDAI SAGAR LAKE

Salinity Index

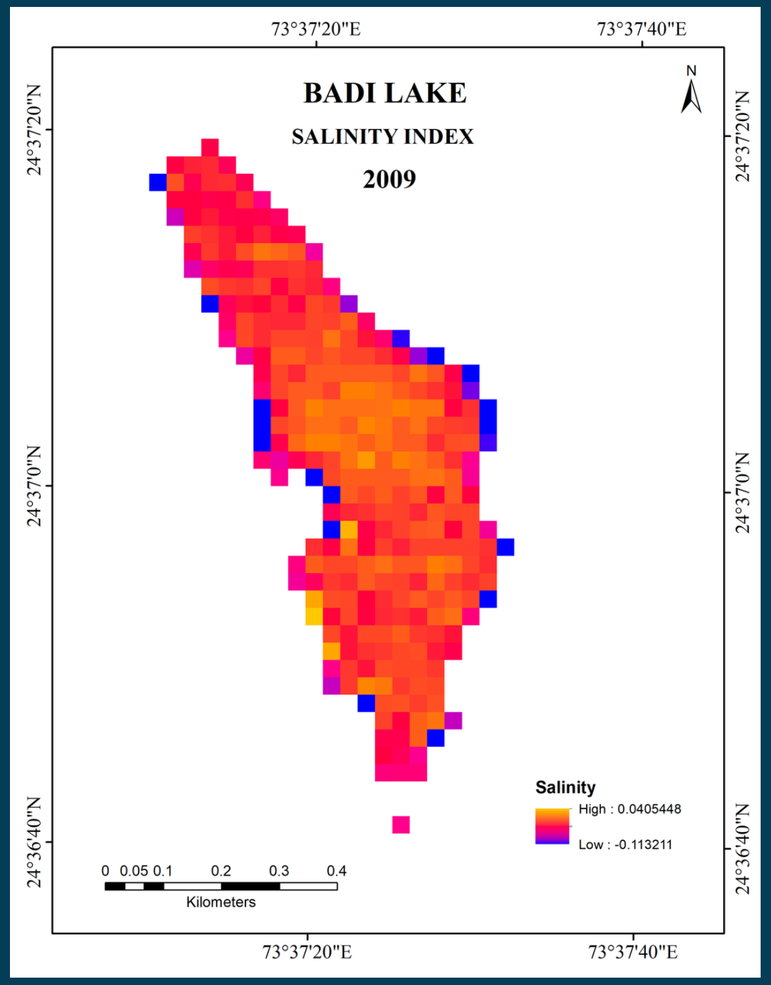


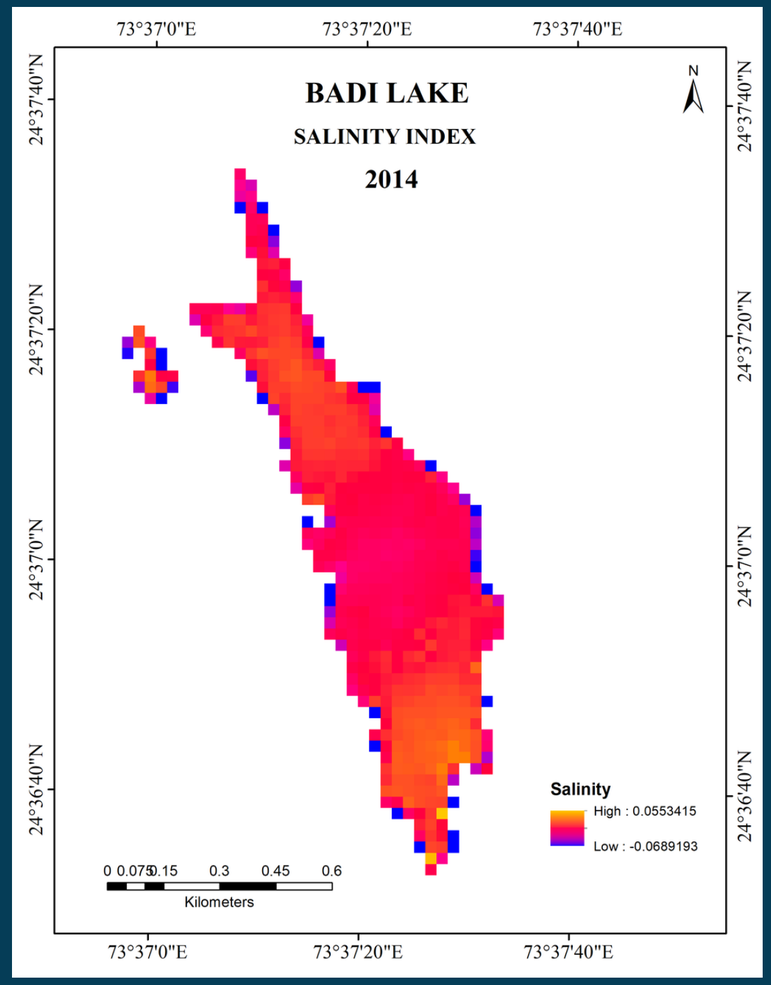


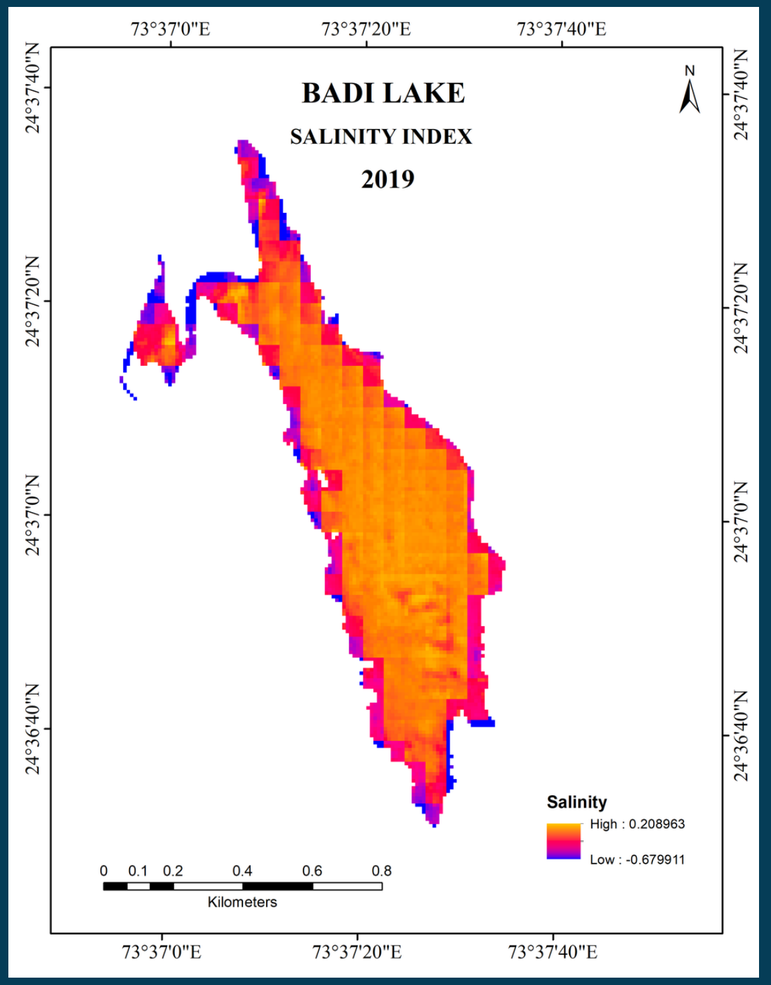


BADI LAKE

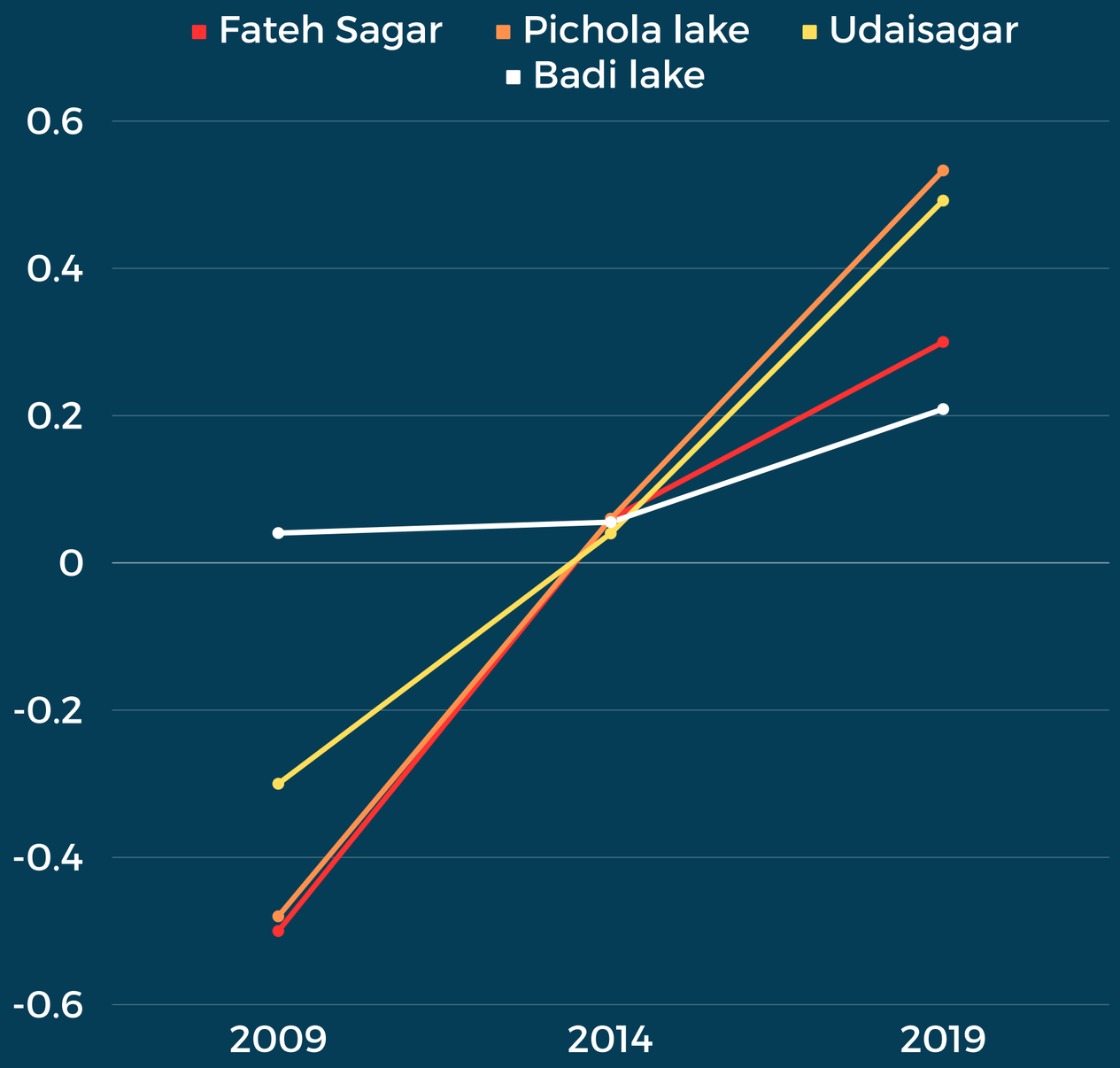
Salinity Index







Normalised Difference Salinity Index



2009 - Lower Salinity

- Range: -0.05 to 0.5 ppt, typical of freshwater or slightly brackish conditions.
- Occurrence: Mix of freshwater and seawater, common in estuarine areas.

2014: Moderate salinity

- All lakes show similar values.

2019 - Higher Salinity

- Increase to 0.3 to 0.5 ppt, indicating elevated salinity levels.
- Likely Causes: agricultural runoff, industrial discharge, urbanization and other anthropogenic activities contribute to alterations in the lakes' salinity.

Impact on Ecosystem

- Disruption to aquatic life adapted to lower salinity.
- Concerns: Water quality for human use, agriculture, and recreation; potential harmful algae growth.

Conclusion

- Industrial discharge likely led to the rise in salinity, impacting the lakes' ecosystems.
- Urgent measures needed to mitigate the adverse effects and preserve ecological balance.

COMPARATIVE ANALYSIS

2019

	Spatial Extent	Chlorophyll	Turbidity	Salinity	Algae Bloom
Highest	Fatesagar	Udaisagar	Udaisagar	Pichola	Udaisagar
Lowest	Badi	Pichola	Badi	Badi	Badi

Chlorophyll & Algae Bloom:

- Direct association due to chlorophyll presence in algae and photosynthetic organisms.
- Chlorophyll aids photosynthesis, leading to increased algal growth during blooms.

Turbidity Impact:

- Elevated chlorophyll levels contribute to increased turbidity.
- Algae and phytoplankton cells scatter light, causing water to appear cloudy.

Salinity Influence:

- Varied effect on algal growth.
- Moderate salinity supports chlorophyll-containing organisms; extreme levels limit growth, reducing chlorophyll.
- Chlorophyll and algae exhibit a direct link, impacting turbidity, while salinity's influence on chlorophyll levels varies based on environmental conditions.

RECOMMENDATION AND SCOPE

- The exploration into the spatio-temporal changes in Udaipur's lakes unravels a myriad of questions, beckoning further research avenues
- Calculating the **Land Surface Temperature (LST)** can help understand its influence on evaporation rates, affecting water levels and quality which can provide insights into the thermal dynamics of the lakes and their correlation with water quantity fluctuations.
- Conduct **hydrological modeling** to analyze the water flow dynamics within and around the lakes can elucidate the pathways of water inflow and outflow, aiding in the identification of critical areas for conservation efforts
- Extend the analysis to assess the influence of various **climatic variables on lake dynamics** to involve studying the correlation between precipitation patterns, temperature fluctuations, and lake water levels can help understand the climatic drivers of lake changes is crucial for predicting future trends and implementing effective adaptive management strategies
- Assessing **inflow and outflow patterns**, along with the impact of climatic variables, will contribute to a holistic understanding of hydrological regimes.
- Continuous **monitoring and adaptive management of lakes** to mitigate environmental impacts.
- Collaboration between **stakeholders for sustainable agricultural practices** to reduce runoff into lakes.

CONCLUSION

- The findings encapsulate a multifaceted narrative, encompassing alterations in water quality, lake extent, land use, and ecological dynamics over the pivotal decade from 2009 to 2019.
- This study substantially contributes to the existing body of knowledge in the domain of lake ecosystems and urban ecology.
- The spatio-temporal analyses offer nuanced insights into the evolving dynamics of Udaipur's lakes, bridging critical gaps in understanding serving as a benchmark for future investigations into urbanized lake ecosystems.
- The intricate interplay of variables, from water quality to land-use changes, underscores the need for a holistic approach in addressing the challenges posed by urbanization.
- As the lakes continue to evolve, this study not only enriches our understanding of Udaipur's unique aquatic landscapes but also lays the groundwork for future research endeavors in the broader realm of urban ecology and water resource management.
- In conclusion, the spatio-temporal analysis of Udaipur's lakes provides a robust foundation for informed decision-making and sustainable management of water resources.


THANK YOU !