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Research Article

Monitoring Water Spread and Aquatic Vegetation using Spectral Indices in Nalsarovar, Gujarat State-India

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Abstract

Nalsarovar Bird Sanctuary, a natural freshwater lake (a relict sea) that is the largest natural wetland in the Thar Desert Biogeographic Province and represents a dynamic environment with salinity and depth varying depending on rainfall. For maintaining ecological balance in coastal and inland environments, wetlands play an important role and the changes in wetland environment can be monitored using satellite remote sensing technique. The present study was carried out using Landsat-7 TM (Feb-2002), Landsat-5 TM (Feb- 2009) and Sentinel-2 multi-spectral data (Feb-2018) covering Nalsarovar area in Ahmedabad district. The study area of Nalsarovar with 10km buffer was extracted from the satellite digital data. Various spectral indices like Normalized difference Vegetation Index (NDVI), Normalized difference Water Index (NDWI) and Normalized difference Turbidity Index (NDTI) were generated for better identification and delineation of water body and aquatic vegetation in the Nalsarovar. The composite images of these indices were also generated to map and monitor changes in water spread and aquatic vegetation in the Nalsarovar. The water spread and aquatic vegetation in the Nalsarovar along with the land use classes were mapped using False Colour Composite (FCC) images of differed years.

The result indicates that the water spread in Nalsarovar has changed from 2002, 2009 and 2018 depending on the monsoon pattern during these years. During drought year of 2002 total precipitation was very less resulting drastic reduction in the water spread in Nalsarovar. The aquatic vegetation has changed from 146.81 ha during 2002 to 510.93 ha during 2018. The land use change indicates that agriculture land, built-up, water body & wetland has increased and barren land, salt affected area has decreased. The aquatic vegetation in Nalsarovar was clearly visible on composite images generated using NDVI, NDWI and NDTI of different years. This study gives clear idea for land use change detection and water spread monitoring using two different techniques using Composite image of NDVI, NDWI and NDTI.

Keywords: Nalsarovar, Change Detection, NDVI, NDWI, NDTI

Introduction

Wetlands are among the most productive ecosystems of the world. The interactions of physical, chemical and biological components of wetlands enable them perform multiple functions like water storage, storm protection and flood mitigation (Mitsch and Gosselink, 2000; Mahdavi et al., 2019). The wetlands like natural lakes, swamps, waterlogged area play very crucial role in avifauna life cycle. Thus, wetland management though requires many parameters, hydrology is the key factor. Wetland ecosystems play a significant role which provides most of the fossil fuel that have been preserved in the swampy environment of past geological era. Wetlands are rated third among the highly productive ecosystem of the world and are generally eutrophic in nature i.e. they are rich in nutrients which support their high growth rates and thus rich in floral and faunal diversity. They perform a variety of ecological, hydrological and social economic functions on the earth. Groundwater.

Nalsarovar is a Bird Sanctuary, spread in the area of 120.82-sq-km, a serene marshland with shallow waters (4-5 ft) which contains 36 small islands. Nalsarovar-Ahmedabad distance is about 60 km located near Sanand Village, in Gujarat. Mainly inhabited by migratory birds as their wintering ground, Nalsarovar is the largest wetland bird sanctuary in Gujarat, and one of the largest in India. Nalsarovar was declared as a RAMSAR site on 24 September 2012, which is the only RAMSAR site in Gujarat state. Nalsarovar is among a few wetlands in the India who made it to internationally recognized 'RAMSAR' site. A RAMSAR site is the wetland recognized by the RAMSAR Convention. RAMSAR Convention is an international treaty for the conservation and sustainable use of wetlands.

Nalsarovar bird sanctuary is a natural shallow lake with muddy lagoons. It is one of the largest bird sanctuaries; Nalsarovar harbours one of the highest populations of waterfowl anywhere in India. It supports a variety of other resident bird species and also attracts several migrant varieties. The sanctuary supports more than 300

islets, most of which are located on its western boundary. Geologically, the area is bound in the west by basaltic trap rocks of the Saurashtra peninsula and northwest fringe by the Jurassic and Cretaceous sandstones, while north-east brink is constituted by igneous and metamorphic rocks of Aravalli. Quaternary alluvial plains occupy Cambay basin on its eastern side (Nirmal Kumar, et. al.2007). The lake is situated at the junction of the Saurashtra plateau with the Gujarat Mainland. It is rainfed wetland and serves as a water-catchment area in the monsoons. The lake dries up almost completely in the summer. Reeds and aquatic plants may be found around the lake whereas trees are practically absent. The unique geographical location, climate and topography have endowed Nalsarovar Bird Sanctuary with substantially good floral and faunal diversity (Stanley, 2004; Nirmal Kumar et al., 2006). This natural shallow lake flourishes with 48 species of phytoplankton and 71 flowering plants, including more than 30 species of aquatic macrophytes. The lake fauna includes 76 species of zooplankton, >20 species of fish, 11 species of herpetofauna, 216 species of birds, including 160 species of waterfowl of both resident and migratory species, and 13 mammalian species including the threatened Indian Wild Ass and Blackbuck (Stanley, 2004; Nirmal Kumar et al., 2006).

Remote sensing and GIS

Remote sensing data has been widely used for mapping and monitoring of various structural components of wetland like water spread, aquatic vegetation, water quality etc (Prigent et al, 2001; Ndirima, 2007; Simav et al., 2015; Gazioglu, 2018). Remote sensing has emerged as an important tool for mapping and monitoring habitat types or structural components in wetlands. A number of studies have been carried out world over for wetland inventory and habitat suitability analysis for various waterfowl (Sanjeev Kumar, 2009). The seasonal and inter annual dynamics of water regime in the lake were carried out to derive changes in open-water and vegetation, and also water balance for Nalsarovar Lake, Gujarat using MODIS 8-day composite data for three consecutive years viz 2002/03, 2003/04 and 2004/05 (Murthy and Panigrahi, 2011).

A knowledge-based algorithm has been developed using hierarchical decision tree approach for automated extraction of wetland features such as surface water spread, wet area, turbidity and wet vegetation including aquatic for pre and post monsoon period. The results obtained for Chhattisgarh, India using the automated technique has been found to be satisfactory, when compared with hybrid digital/visual analysis technique (Subramaniam and Saxena, 2011; Wang et al., 2014). Knowledge based hierarchical approach has been implemented for the detection of the wetland vegetation. The required knowledge generation has been carried out with the help of the display of the false colour image (MNDWI – NDPI - NDVI) for the identification. Sentinel-2 data were analyzed to estimate the maximum

chlorophyll index (MCI), nitrogen content, and water turbidity using Green Normalized Difference Vegetation Index (GNDVI) and normalized difference turbidity index (NDTI). Red-edge bands of Sentinel-2 are the keystone feature of the sensor for estimating the addressed water quality parameters in a reliable manner (Esetlili et al., 2018; Mohamed Elhag et al., 2019).

Objectives

The major objectives of study mapping and monitoring water spread and vegetation growth in Nalsarovar are as follows:

- Generation of Composite image of NDVI, NDWI, and NDTI for water spread and monitoring aquatic vegetation over the period of 16 years covering Nalsarovar
- Mapping and monitoring of changes in Nalsarovar land use and vegetation growth using Multi-temporal satellite data of 2002, 2009 and 2018.
- To analyze the effectiveness of composite image of NDVI, NDWI & NDTI for water spread and aquatic vegetation monitoring in Nalsarovar over the period of 17-years

Materials and Methods

Study area

Nalsarovar bird sanctuary is a natural shallow lake, muddy lagoons and dotted by over 300 islets. It is the largest wetland bird sanctuary about 64 km to the West of Ahmedabad in the Gujarat state of India. The lake measures 120.82 km². Nalsarovar Bird Sanctuary is located between 22°78' N to 22° 96' N latitude and 71° 92' E to 72° 64' E longitude, falls in 4B Gujarat-Rajwara biotic province of the semi-arid lands of Central Gujarat, India (Rodgers and Panwar 1988). It receives water from two rivers: Brahmin and Bhogavo. Nalsarovar Bird Sanctuary is only RAMSAR Site in Gujarat State. The UNESCO's RAMSAR Convention, named after the Iranian City where the convention was signed in 1971, seeks to protect wetlands of international importance. The water temperature rises up to 35°C during the month of May and falls below 15°C in January. The average rainfall is about 580mm (Nirmal Kumar *et al.*, 2006). The Nalsarovar being an important bird area receives a large inflow of tourist (approx.75000) each year during the winter season. The location map of the study area is given in Figure-1.

Satellite data:

In this study Remote sensing satellite data of Sentinel-2A (MSI) and Landsat-TM digital data of three different time periods, Feb 2002, Feb-2009 and Feb-2018 was downloaded from the website (USGS). The details of satellite data used are given in Table-1. The Sentinel-2 multi-spectral image covering Ahmedabad district of 22-Feb-2018 and the extracted images covering Nalsarovar area with 10 km buffer are given in Figure-2.

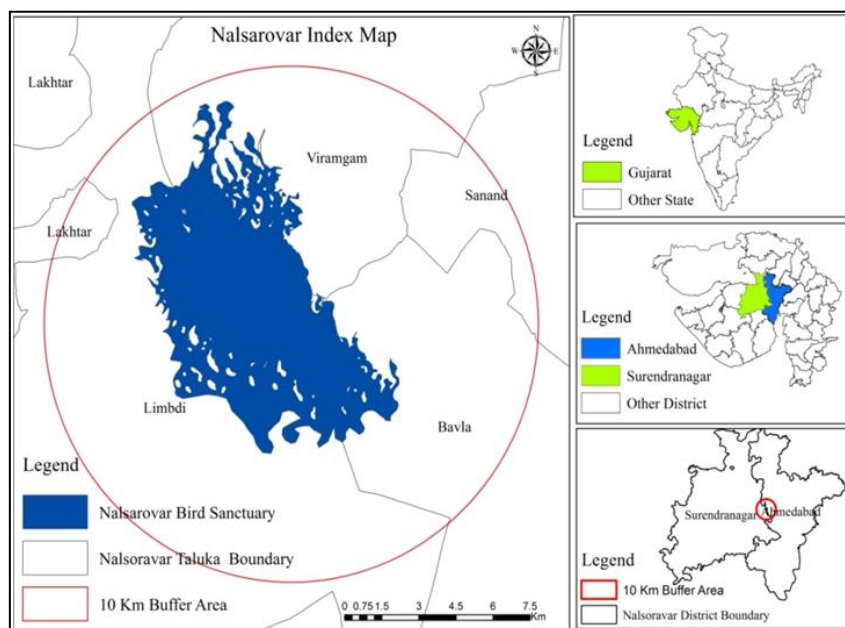


Figure-1: Location Map of Study area in Ahmedabad District, Gujarat State.

Table-1: Details of Satellite Data used

Sr. No.	Satellite	Sensors	Resolution	Date of Pass
1.	Sentinel-2A	MS	10 m	22-Feb-2018
2.	Landsat-5	TM	30 m	16-Feb-2009
3.	Landsat-7	TM	30 m	21-Feb-2002

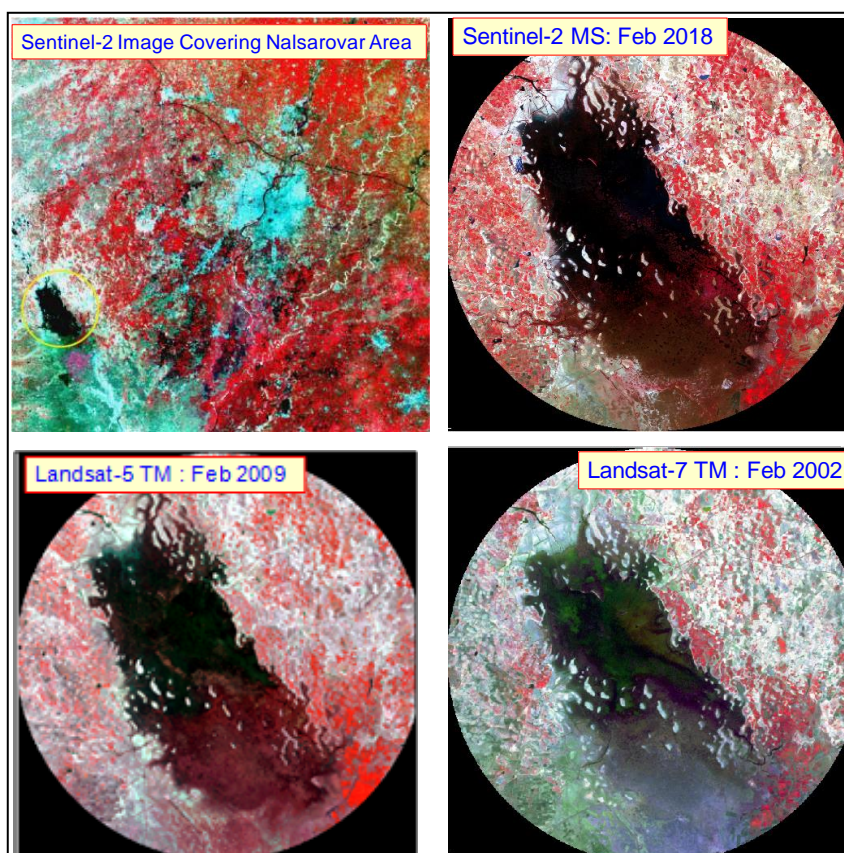


Figure-2: Sentinel-2 multi-spectral image covering Ahmedabad Area and extracted images covering Nalsarovar area with 10 km buffer.

Multi-spectral, multi-temporal data of Landsat-5, Landsat-7 TM and Sentinel-2 MS for the years 2002, 2009 and 2018 has been analysed for mapping water spread and wetland vegetation in and around the Nalsarovar. These datasets were geo-referenced with defined parameters of TM Projection and WGS 84 datum. The geo-referenced images of Post Monsoon month of February of each year which represent the maximum water spread and wet-land vegetation development were used for the analysis of wetlands. The Sentinel-2 and Landsat-5 & 7 TM data was analysed using QGIS open source software consisting of following steps;

i) Layer stacking of selected bands from Sentinel-2 and Landsat TM data

- ii) Extraction of Area of interest covering study area with 10 km buffer
- iii) Generation of spectral indices like: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) & Normalized Difference Turbidity Index (NDTI) and generation of composite images of these indices
- iv) Digitization of different Land Use Classes, Aquatic vegetation and water spread
- v) Area estimation of Land use, aquatic vegetation and water spread and change monitoring.

The methodology flow-chart of data analysis is given in Figure-3.

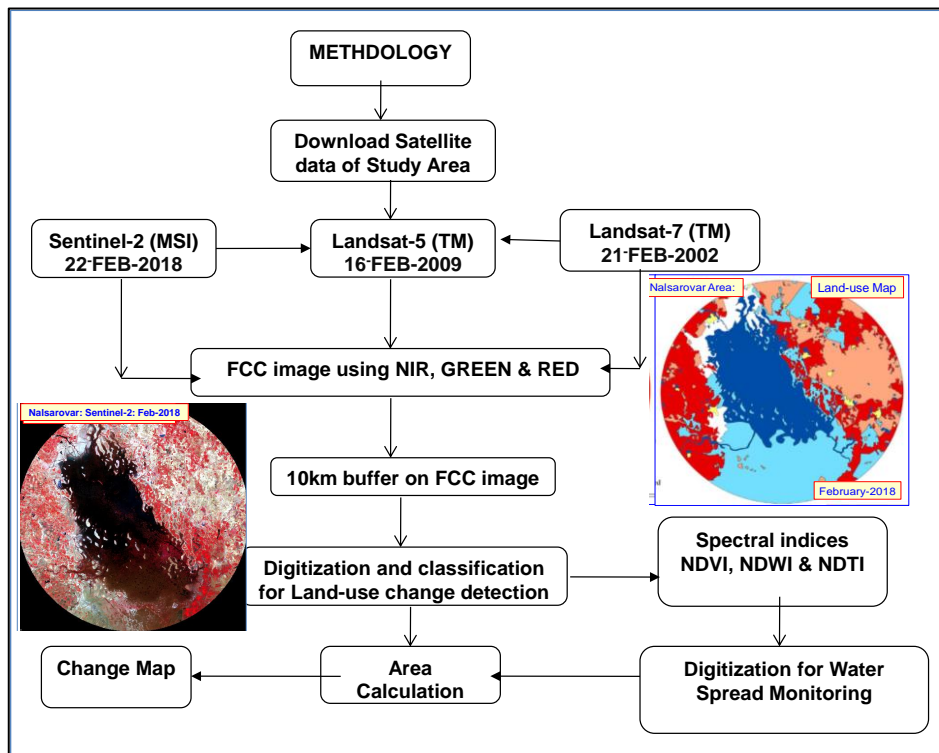


Figure-3: Methodology flow-chart of data analysis

Generation of Spectral Indices

Each index is principally a definite mixture of the sensor-measured reflectance properties at 2 or more wavelengths that reveals specific characteristics of vegetation (Çelik and Gazioglu, 2020). In this study different types of spectral indices were generated for mapping and monitoring the changes in water spread and aquatic vegetation in the Nalsarovar using Landsat TM and Sentinel-2 multi-spectral data. The various types of spectral indices generated are Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI) & Normalized Difference Turbidity Index (NDTI).

Normalized Difference Vegetation Index (NDVI)

Vegetation indices derived from satellite imagery provide an estimate of the health and vigour of

vegetation. One of the most widely used vegetation indices is the Normalized Difference Vegetation Index

(NDVI) defined by Rouse et al. (1974). The Normalized Difference Vegetation Index (NDVI) images of Feb-2002, Feb-2009 and Feb-2018 covering Nalsarovar Lake are with 10 km buffer were generated. This index is based on the difference between the maximum absorption of radiation in the red due to the chlorophyll pigments and the maximum reflection of radiation in the NIR due to the leaf cellular structure. NDVI provides a measure of vegetation health and vigour. The NDVI values range between -1 and +1. The NDVI images were generated using the following formula:

$$NDVI = (NIR - R) / (NIR + R)$$

Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) was first proposed by McFeeters in 1996 to detect surface waters in wetland environments and to allow for the measurement of surface water extent and values of NDWI greater than zero are assumed to represent water surfaces, while values less than, or equal, to zero are assumed to be non-water surfaces. Although the index was created for use with Landsat Multispectral Scanner (MSS) image data, it has been successfully used with other sensor systems in applications where the measurement of the extent of open water is needed

(Chowdary et al., 2008). Normalized Difference Water Index (NDWI), is used to differentiate water from the dry land or rather most suitable for water body mapping. Water bodies have a low radiation and strong absorbability in the visible infrared wavelengths range. NDWI uses near Infra-red and green bands of remote sensing images and the NDWI is calculated using following equation:

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

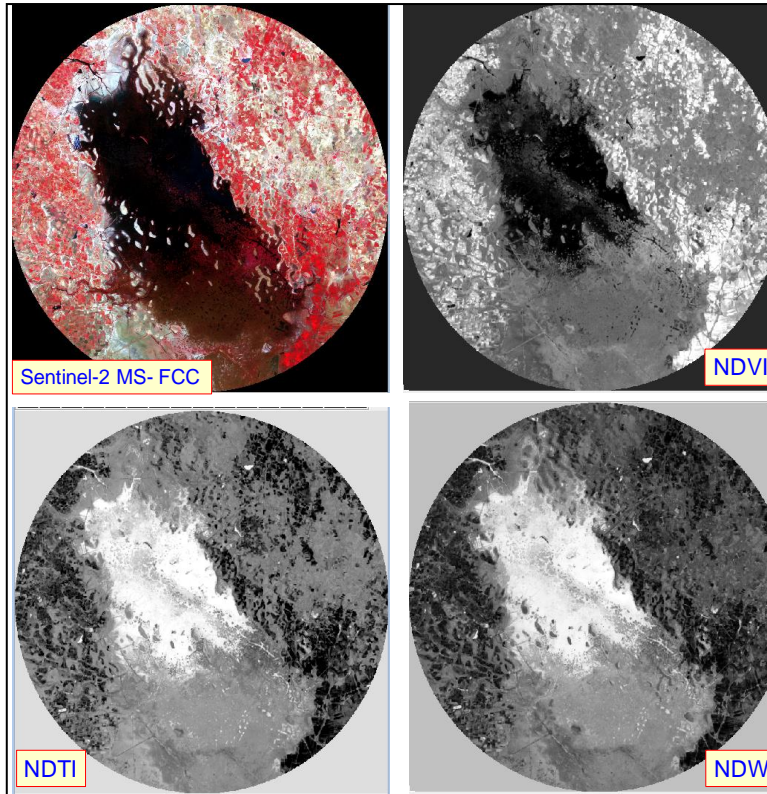


Figure-4: NDVI, NDWI and NDTI generated using Sentinel-2 multi-spectral data along with FCC covering Nalsarovar area.

Normalized Difference Turbidity Index (NDTI)

Lacaux et al., 2007 developed an algorithm to estimate the water turbidity using remote sensing data specifically for ponds and inland waters, and it is calculated using following equation:

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

As turbidity level of water increases due the increase in the suspended particles in the water, the reflectance of the red band more than that of the green band (Monirul Islam et.al. 2006). This spectral characteristic of the turbid water can be used for the detection of turbid water pixels and has been captured in the Normalized Difference Turbidity Index defined by Lacaux, et al, 1986. The variation in the turbidity levels of different water bodies has been found that the NDTI values vary from -0.2 to 0.0 in the case of clear water and from 0.0 to 0.2 for the moderately turbid water bodies. The various indices like NDVI, NDWI and NDTI generated using

Sentinel-2 MS data of Feb. 2018 along with False Colour Composite (FCC) are given in Figure-4.

Generation of Composite Images of Different Indices

The major objective of this study was to monitor changes in water level and aquatic vegetation in Nalsarovar over the period of 17-years from 2002 to 2018 using the multi-spectral and multi-temporal Remote Sensing data. Therefore, to highlight the wetland boundary, open-water spread and aquatic vegetation composite images were generated using NDVI, NDWI and NDTI. The wetland boundary, open-water spread and aquatic vegetation could be delineated using combinations of indices images. The Sentinel-2 FCC of the Nalsarovar Lake area along with composite FCC of indices highlighting accurate detection of open water and aquatic vegetation areas are given in Figure-5(i) and Figure-5 (ii). These two images indicate the two different combinations for generating composite images using NDVI, NDWI and NDTI. These composite images

are very useful in delineating water spread and aquatic vegetation in the Nalsarovar.

The composite images were created using NDVI, NDWI & NDTI spectral indices in different color assignments so as to clearly identify water spread and aquatic vegetation in the Nalsarovar. Generally, NDVI index useful for clearly identifying the healthy and unhealthy

vegetation but in this case NDVI is useful for distinguishing aquatic vegetation and grasses in the deep and shallow waters of Nalsarovar. The NDWI and NDTI both spectral indices are very useful for water body analysis. In this case NDWI is useful for identifying deep and shallow water and NDTI is useful for analysis of turbidity in the Nalsarovar.

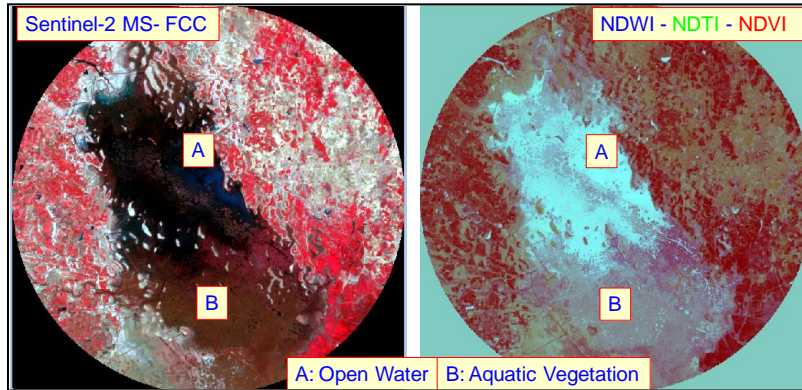


Figure-5 (i): Sentinel-2 FCC of the Nalsarovar Lake area along with composite FCC of indices highlighting open water and aquatic vegetation

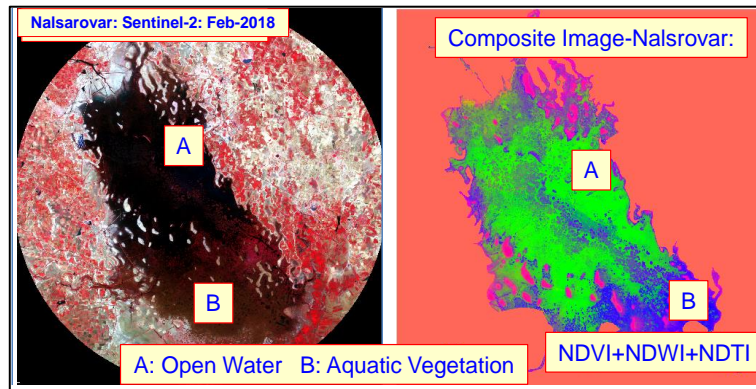


Figure-5 (ii): Sentinel-2 FCC of the Nalsarovar Lake area along with composite FCC of indices highlighting open water and aquatic vegetation.

Result and Discussion

Land Use/Land Cover Mapping

The land-use mapping of Nalsarovar area was carried out using Landsat and Sentinel-2 digital data in open-source QGIS software. The satellite digital data of Feb. 2002 (drought year), Feb-2009 (normal monsoon) and Feb

2018 (sub-normal monsoon) covering Nalsarovar area was used for on-screen digitization of different land-use categories for land use mapping using visual interpretation technique. The Land use maps of Feb-2009 and Feb 2018 covering Nalsarovar area are given in Figure-6. The area under each category was also computed and given in Table-2.

Table-2: Area under different land use classes in Nalsarovar area from 2002 to 2018

Area (ha) under Land-use Classes during 2002, 2009 & 2018			
Category	Year 2002	Year 2009	Year 2018
Agriculture	6931.9	7067.2	8932.3
Barren Land	9379.7	7527.7	6544.3
Built up	61.6	181.6	274.8
Salt affected	1722.9	1299.2	1700.4
Water body	6426.4	9575.0	6489.5
Wetland	6935.5	5807.3	7516.7
Total Area (ha)	31458.0	31458.0	31458.0

Monitoring Changes Land Use and Water spread in Nalsarovar

The changes in land use categories were computed as Relative Deviations in percentage (RD %) as:

$$RD (\%) = (\text{Current area} - \text{Previous area}) / \text{Current area} * 100$$

The changes in land use were calculated from 2002 to 2009, 2009 to 2018 and over all changes during study

Table-3: Changes in different land use classes in Nalsarovar area from 2002 to 2018

Changes(Per cent) in Different Land use classes during 2002, 2009 & 2018

Category	Year 2002-2009	Year 2009-2018	Year 2002-2018
Agriculture	1.91	20.88	22.40
Barren Land	-24.60	-15.03	-43.33
Built up	66.28	33.55	77.59
Salt affected	-32.62	23.60	-1.32
Water body	32.88	-47.55	0.97
Wetland	-19.43	22.74	7.73
Category	1.91	20.88	22.40

Conclusions

The study on water spread monitoring in Nalsarovar was carried out using Multi-temporal Satellite data from Landsat and Sentinel-2. Landsat digital data of 2002 and 2009 and Sentinel-2 MSI data of 2018 was analysed for mapping and monitoring changes in Land use and water spread in Nalsarovar area. The Various spectral indices like Normalized difference Vegetation Index (NDVI), Normalized difference Water Index (NDWI) and Normalized difference Turbidity Index (NDTI) were generated for better identification and delineation of water body and aquatic vegetation in the Nalsarovar. The major conclusions of this study were as followed:

- ❖ The results of present study indicated that composite images generated from different spectral were very helpful for mapping open-water, aquatic vegetation and wetlands along the Nalsarovar.
- ❖ The land use change monitoring indicated the significant changes in the area under agriculture, barren land and water spread area. The year 2009 was a normal monsoon season showing maximum water spread area in Nalsarovar as compared 2002 (drought year) and 2018 (semi-normal monsoon).
- ❖ Agricultural area shows increase during the study period mainly because converting barren land into agriculture due to better monsoon after drought of 2002.

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period of 2002 and 2018 (Table-3). The results from Table-3 indicate that area under agriculture, barren land and water spread area shows maximum changes. As indicated 2009 was a normal monsoon season showing maximum water spread area in Nalsarovar as compared 2002 (drought year) and 2018 (semi-normal monsoon). Agricultural area shows increase during the study period mainly because converting barren land into agriculture due to better monsoon after drought of 2002.

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