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Geospatial Assessment of Dal and Nigeen Lakes, Srinagar, India: an impact of anthropogenic activities

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Abstract: **Anthropological activities play a crucial role in physical as well as biological environs of the lake. Discharge of sewage into the lake is a threat to its quality and hygiene. In this study, it is observed that Dal lake is receiving discharges of wastewater from the domestic and tourism industry. Sewage has consisted of nutrients like nitrogen, phosphates that are responsible for the growth of algal bloom/ aquatic vascular plants. That unwanted growth of aquatic plants and sprawling all over the lake is a significant concern about quality deterioration and aesthetic beauty. In this study, an attempt has been made to assess the changes in and around the Dal lake, Srinagar based on satellite images from 1975-2019. Based on this, measures are suggested to control the anthropological discharges as well as in-situ and ex-situ lake treatment since the lake has international importance and source of water supply to the city.**

***Keywords*: Sewage pollution, Aquatic vascular plants/algae, Dal lake, Nigeen lake, Remote Sensing**

I. Introduction

Aquatic environment is a unique ecosystem and it has numerous contributions to the physical environment as well as the social environment. Water is considered as the second most need able resource after air for the existence of the biotic community (Dar et al. 2017). Lakes are distinctive waterbody influenced and regulated by their geology, physiography, vegetation cover and other land use (Mushtaq et al. 2018). Himalayan lakes play a crucial role in their ecological significance, biodiversity, wildlife and environmental sustainability (NWIA, 2011). Water quality is a significant concern to preserve the aquatic ecosystem as well as the terrestrial ecosystem (Saleem et al. 2013). Daily life, agriculture, industry everything is depended on the availability quality and quantity of the freshwater, this freshwater is the key component for sustainable development (Kumar N, 1997). When water is threatened for the biotic community, plant commune, human use and other progressive work it may sound as polluted water (Wani et al. 2014; Denver CO, 1998). Due to haphazard and rapid urbanisation, industrialisation and modern agriculture practices urban waterbodies are going to be polluted day by day (Hunt & Wilson, 1986). Human activities (land and water) in a particular lake basin can change the behaviour of physiochemical properties of waterbody and it harms the catchment area (Saleem et al. 2013). Deterioration of water quality is a threat to environmental safety (Wani et al. 2014) and all over the world facing this serious challenge for a few past decades (Hamnera et al. 2006). The source of water pollution may vary as point and non-point sources. Point sources are the particular, recognisable area for the contamination in water. The sewage treatment plant, manufacturing units, Strom drains may consider as point sources for surface water contamination (Wani et al. 2014). Multiple fields, large area like agricultural runoff, flow of sediment wash, Strom water with nutrients are referred to as a non-point source for the pollution of water (Web-1). Domiciliary wastewater, industrial outflow, agricultural runoff are significant threats for the deterioration of water quality. Nutrients and toxins are carried by the domestic sewage and it may significantly cause of the growth of algal bloom, eutrophication in the lake (Lapointe et al. 2015). Industrial effluent is a mixture of chemicals, heavy metals and other organic and inorganic compounds when it releases into the waterbody disrupts not only water quality but also aquatic life. Pesticides may add to the waterbody through agricultural runoff that may responsible for the ecological disparity in the waterbody (Web-2). Excessive growth of aquatic vascular plants/weeds is a threat to balance in the aquatic ecosystem. The overgrowth of weeds can create a layer on the water surface which can disturb the sunlight (which is needed to several organisms) to penetrate the subsurface of the water. Nutrient pollution can lead to eutrophication that disrupts the microorganism and other living communities in the waterbody (Serediak et al.2014). It leads to the depletion of dissolved oxygen levels (Kibria, 2017) in the water body which directly reflects the water quality degradation.

Dal lake is the second-largest freshwater lake of India and it is also trendy for aesthetic presence in the vale of Kashmir. But the picturesque Dal lake is facing a challenge in terms of the growth of aquatic vascular plants from the early 19th century (Web-3). Sewage release in Dal lake is a pitiable reason for contamination. Lakes and Waterways Development Authorities (LWDA, 2017) reported that closely 50 million liters of sewage are released in Dal lake every day and out of that 20 million liters of sewage are untreated. Another lake that is situated in Dal catchment (Web-7) named Nigeen is also facing the same problems (Nissa et al. 2016). Frequent disposal of waste material has harshly reduced the water quality of the lake (Web-8). Growth of algal bloom, decreasing of Dissolve Oxygen (DO), increasing suspended solids and nutrients like phosphorus and nitrogen (Web-4) are now serious provocations to save the water quality of Dal and Nigeen lake.

Geospatial technology is now very efficient and popular to estimate water quality. Water quality depends on the nutrient load and eutrophication due to it. Eutrophication is responsible for clogging of waterbody and deterioration of water quality. The growth of algal bloom/ aquatic vascular plants can effectively assess and monitor through Remote Sensing technology (Ritchie et al. 2003). Remote sensing technology provides temporal data, which is helpful to assess the periodic changes and spatial extent of contamination in waterbaody (Vijay et al. 2015; Jensen 2000; Ellis 1999). Characteristics of waterbody can be measured using reflectance/spectral signature of different components/parameters (Ekercin, 2007). Therefore, the aim of the study is to geospatial assessment of aquatic vascular plants/ algal bloom into Dal and Nigeen lake due to increasing urbanisation and sewage discharges into the lake.

Study Area

The world-famous Dal lake, known as the "jewel in the crown of the Kashmir" (Web-5) is situated in the North-East portion of Srinagar, the capital (Summer) of the Jammu and Kashmir overlooked by the mighty of the Himalayas. Nigeen lake located near the dal lake has also been considered in this study. The geographical settings of the area is 74°46'30" to 74°55'30"E and 34°02'00" to 34°11'30" N. The lake has unique physical settings, three sides of the lake surrounded by mountains (Web-6); eastern side by Zabarwan hill, Shankar-Achariya mountains at Southern side, Kohi-Maran (Hariparbat) at west with an approximate altitude of 1583 m above the mean sea level (Mushtaq et al. 2018). The region is enclosed by the Jhelum basin in the Southern side and the Sindh basin in the north (Sheikh et al. 2008). The diversity and huge expansion added great significance to Dal. The lake covers up nearly 18 sq. km surface area with an average depth of 8.6 ft. (Dar et al. 2017). The study area (Figure 1) is coming under the montane valley climate with a distinct cold winter. The mean temperature is 7.5°C for October to March, 19.8°C for summer. The lowest temperature is -2°C to -3° C in January (Wani et al. 2014). The study area gets significant rainfall by or large all over the year. Western disturbance of the Mediterranean sea materialises the precipitation in the form of snow on the study area during winter (Wani et al. 2012). The yearly mean rainfall is 551mm. Treated sewage from Hazratbal, Habbak and Laam sewage treatment plants (STPs) discharges as well as untreated sewage from various drains namely Botkul, Telbal, Dogi, Pushpav, Meerakshah, Bund channel etc. are also discharging into Dal-Nigeen lakes.

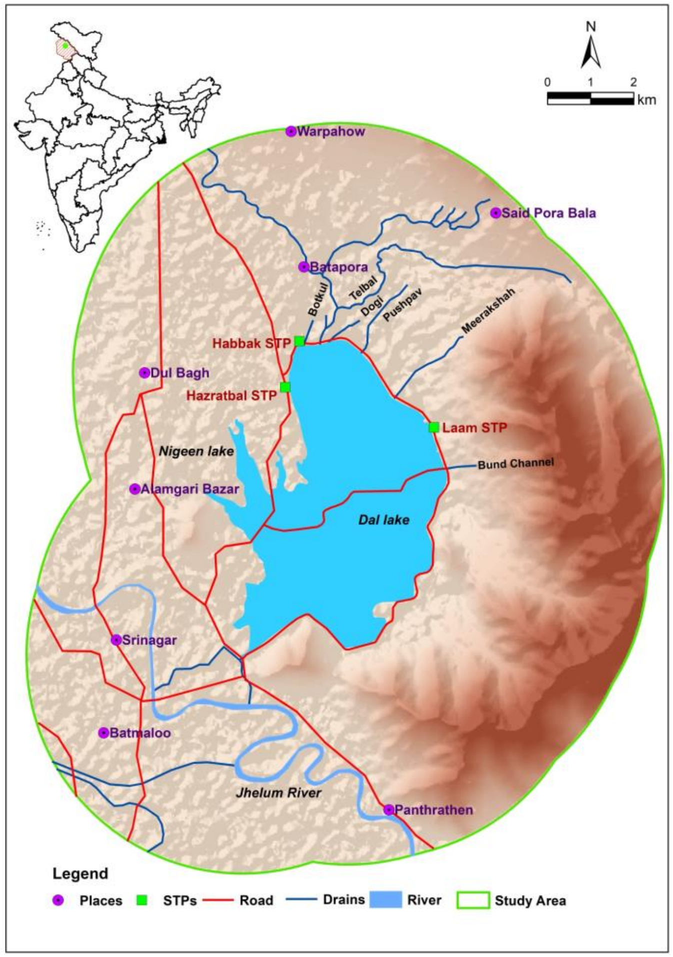


Figure 1: Base map of the study area

II. Material and Methods

To assess the changes in and around the Dal and Nigeen lakes due to urbanisation and various anthropogenic activities data are required to make an analysis and suggestive measures. For qualitative analysis of entire the waterbody and expansion of the built-up area, the colossal data set is required throughout the study span. Geospatial technology has been adopted to avoid the intricacy of field data collection and to get above mention data, spatially and temporally (Carrara et al. 1991, Van Westen 1994). The methodology divides into the following sections:

Section I Acquisition of Data

For Land Use Land Cover (LULC) and lake area coverage, Landsat satellite data of three different years are used. Details about satellite data are described in Table 1

TABLE 1
Details of Satellite Data and its Application

Sr. no	Satellite	Sensor	Resolution	Date of Acquisition	Use
1	Landsat	MSS	30 m	09/04/1975	LULC / Lake area coverage
2	Landsat	TM	30 m	20/04/1991	LULC/ Lake area coverage
3	Landsat	ETM+	15 m	01/04/2019	LULC/ Lake area coverage
4	EOS-Terra	ASTER	30 m	17/08/2011	Slope Analysis

False Color Composites (FCC)

FCCs of the study area for three different years of 1972, 1991, and 2019 are represented in Figure 2. FCCs are a combination of green, red, and NIR bands. NIR band is beneficial to estimate chlorophyll concentration. These FCCs have been used for LULC analysis, estimation of increasing and sprawling of aquatic plants, and accuracy assessment.

Section II Spatial analysis

This section is subdivided into two parts: LULC, slope analysis around the lake and assessment of dynamics of aquatic plants in the lake.

LULC Analysis

LULC analysis was performed to assess the present land use pattern and change detection analysis. In this study, LULC is described in two phases: for the study area and the lake area. Object-Based Image Analysis (OBIA) technique was applied for the LULC analysis for three different years because it generates more consistent results as compared with pixel-based image analysis (Dey et al. 2018; Wuest and Zhang et al. 2009). Nowadays OBIA is a popular and efficient technique for image analysis in the Remote sensing domain (Robson et al. 2015; Blaschke et al. 2014; Hussain et al. 2013). In the OBIA technique satellite image segmented into non-overlaying polygons based on the homogeneity of pixels, called objects (Sherba et al. 2014; Pu and Landry, 2012; Addink et al. 2012; Baatz et al. 2008). Segments/objects are regions that are created by multiple criteria of spectral response about an area. Each segment carried extra information than the single-pixel (Blaschke T. 2014) Classification has been carried out applying these objects or segments. The state of the art software eCognition (9.1 version) developer has been used for OBIA. Under the “edit process” tool several segmentation algorithms are there to create meaningful objects from an image. In this study, a multiresolution segmentation algorithm has been applied to create the segments for the basic classification of an image. Multiresolution segmentation is a significant method for meaningful object extraction from an image. Using different band indices like Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI) LULC generate for the study area. Different indices are expressed as

$$NDVI = \frac{NIR - Red}{NIR + Red} \ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$NDWI = \frac{Green - NIR}{Green + NIR} \ldots\ldots\ldots\ldots\ldots \text{(3)}$$

LULC has been carried out into 9 classes such as agriculture, aquatic vegetation, built-up, forest, marshy, pasture land, plantation, vegetation and waterbody. The dynamic range of different spectral band and band ratio for OBI analysis:

Slope Analysis

The slope map is generated to understand the direction of sewage flow, runoff, and other discharges (house, hotels etc.) in this study area. Using EOS-Terra digital elevation model popularly known as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) having 30m spatial resolution has been used to derive the slope map. The slope map is categorised as gentle, moderate, strong, steep, and very steep as prescribed by NRC, 1998.

Assessment of growth of aquatic plants/ algal bloom in the lake

To evaluate the dynamics of aquatic vascular plants in Dal-Nigeen lake, a special emphasised has given for Lake periphery. This part is very crucial to observe the shrinkage of the spatial extent of the lake and the unwanted growth of aquatic vascular plants. It should be more significant to display the periodical changes in and around Dal lake. Lake water is facing a considerable amount of nutrients load as a threat due to rapid urbanisation and others development activities (Bhat et al. 2017) Concentration of pollutants (Nitrogen, Phosphorus) load is increasing due to releasing of untreated sewage into the lake.

Due to nutrient load in lake water algal bloom/ aquatic vascular plants are increasing day by day and it is directly related to eutrophication in the lake. Algal blooms are directly responsible for eutrophication in the lake, so estimation of algal growth is one of the critical parameters for water quality assessment. The reflectance of chlorophyll can quickly assess through Remote sensing technology. Normalised Difference Vegetation Index (NDVI) is used to measure the chlorophyll content through remote sensing. NDVI indices can generate using Near Infrared (NIR) band and red band.

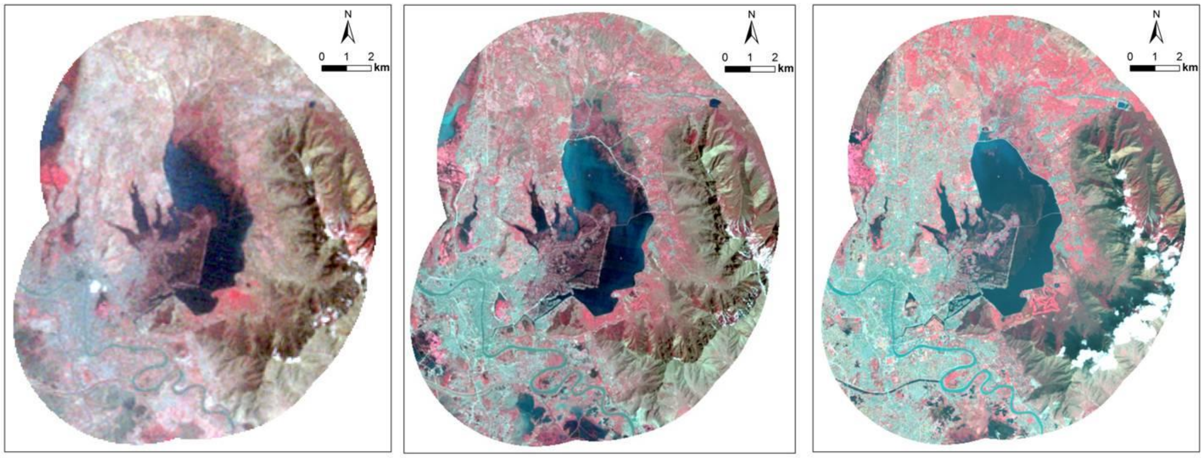


Figure 2: FCC of the study area (a-9/4/1975, b-20/4/1991, c-1/4/2019)

TABLE 2
Range of Spectral Bands for OBIA

LULC Class	1975		1991		2019	
	Spectral index	Range	Spectral index	Range	Spectral index	Range
Agriculture	NIR	0.01-0.07	NIR	0.0-0.13	NIR	0.1-0.18
Aquatic-Vegetation	NDVI	0.01-0.04	NDVI	0.03-0.05	NDVI	0.02-0.07
Built-up	NDBI	0.17-0.7	NDBI	0.11-0.82	NDBI	0.1-0.78
Forest	NDVI	0.2-0.6	NDVI	0.14-0.77	NDVI	0.2-0.71
Pastureland	Brightness	57-64	Brightness	52-56	Brightness	50-54
Plantation	Green	41-56	Green	27-44	Green	37-64
Vegetation	NIR	60-82.5	NIR	28-47	NIR	56-88
Marshy Land	MIR	64-74.4	MIR	41-87.5	MIR	33-68.45
Waterbody	NDWI	0.12-0.53	NDWI	0-0.9	NDWI	0-0.43

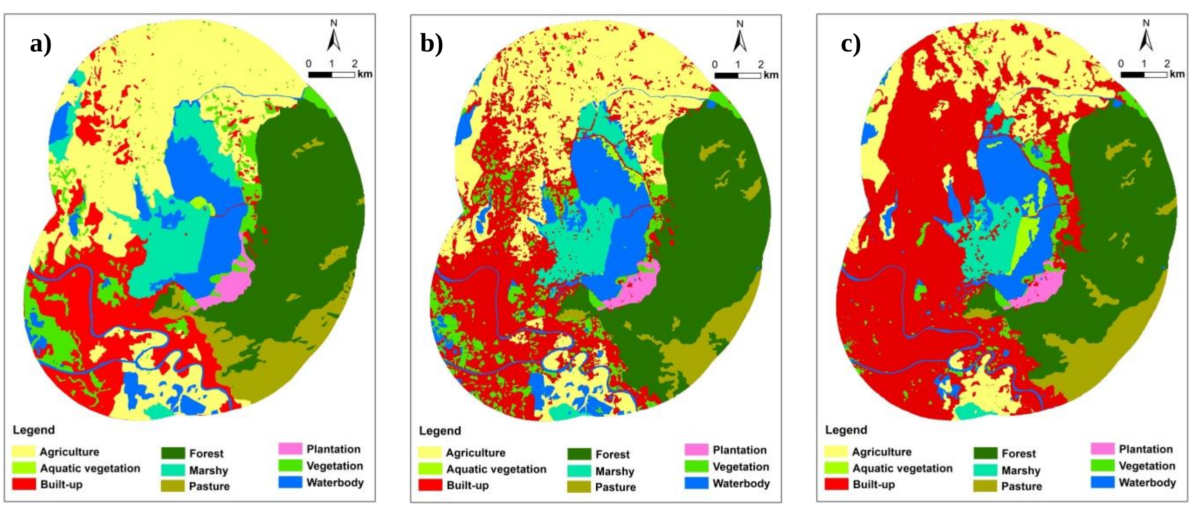


Figure 3: LULC of the study area (a-9/4/1975, b-20/4/1991, c-1/4/2019)

III. RESULTS AND DISCUSSION

This section discusses the results of the research work carried out in the present study. LULC, analysis and dynamics of aquatic vascular plants over the year have been explained in the following section.

LULC in the study area

LULC analysis (Figure 3) has been done by OBIA and the inventory of LULC has been discussed in two parts. Depending on the LULC analysis of the study area, it is observed that there is a considerable change in spatial extent for different LULC categories (Figure 4). The entire study area is considered as 201 km^2.

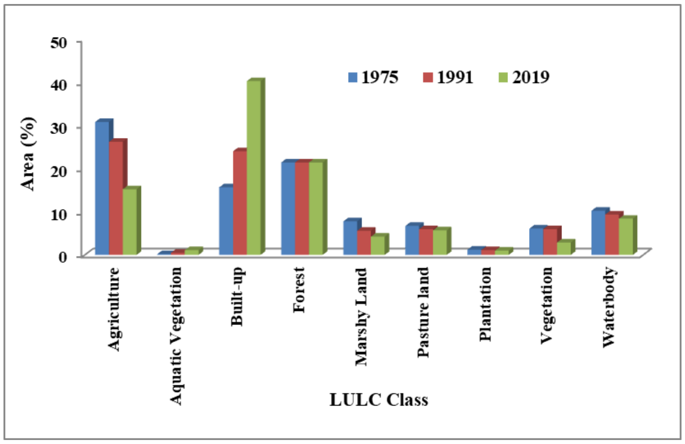


Figure 4: LULC Inventory in and around the Dal-Nigeen lake

Pasture land is decreasing from 6.7%, 6% and 5.7% in the year of 1975, 1991and 2019 respectively. Similarly, Vegetation cover is also reducing over the year 6.1%, 6% and 2.9% in the year of 1975, 1991and 2019 respectively. The spatial extent of Plantation is decreased from 1.2 to 1.1% from 1975 to 1991 and 1.1 to 1% from 1991 to 2019. Agriculture is reduced from 30.8 to 26.2% from 1975 to 1991 and 26.8 to 15.2% from 1991 to 2019. Nengroo et al. (2017) also reported that the agricultural land is drastically reducing and converting into the other land use category. Area cover of marshy land is decreased from 7.8 to 5.6% from 1975 to 1991 and 5.6 to 4.2% from 1991 to 2019. There is no change in spatial extent in forest area because most of the forest area is comes under protected forest.

The spatial extent for some of the LULC classes is increasing over the year. Built-up area is increased from 15.6% to 24% from 1975 to 1991 and increased from 24% to 40.2% from 1991 to 2019. It is the most significant reason for the areal decreasing in the agricultural area and another LULC category. The aquatic vascular plant is increasing by areal coverage and sprawling here and there into the lake.

Accuracy assessment of the LULC with reference to Ground Control Points (GCP) and real-world information is necessary to validate the analysis work (Anderson 1976). In this study, 40 random points were collected using a handheld GPS receiver (Trimble Juno 3B) to assess the accuracy of the computer-generated classified maps. Details of ground-truthing are summerised in Table 3. are taken as ground truth data and overall accuracy and kappa coefficient are calculated as 80% and 0.71 respectively. An error matrix or confusion matrix is prepared by comparing agreement and disagreement between satellite-based information and filed data on a class-by-class basis. Overall accuracy along with producer accuracy for each class is described in Table 4.

Change assessment in Lake

For environmental safety and security, waterbody is a major concern and it was found that spatial coverage of the waterbody is decreasing over the year. To estimate the changes in the lake (Figure 5) periphery including the submerged area the total area has been considered as 27.2 km^2. A graphical representation of the inventory of LULC for the lake area is shown in Figure 6. During 1975-1991 it is reduced by 1.0% and by 3.8% during 1991-2019 with the overall decreasing of 4.8% through the whole study span. Similarly, marshy land is also found at a decreasing rate. It is decreased by 8.1% during 1975-1991 and again it decreased by 8.9% during 1991-2019 with an overall reduction of 17%. Built-up area is significantly increasing in this region. Inventory of LULC is revealing that the built-up has increased by 4.8% during 1975-1991 and 4.7% during 1991-2019, which reflects increasing human interference in this area. In 1975 and 1991, there was no agriculture activity inside the lake boundary but in 2019 2.3% of the area comes under the agriculture. The terrestiral vegetation cover also appeared in 1991 as 2.1% area cover and increased by 1.6% during 1991-2019. Aquatic vegetation/vascular plants increased by 1.1% during 1975-1991 and rapidly expanded by 5.1% during 1991-2019.

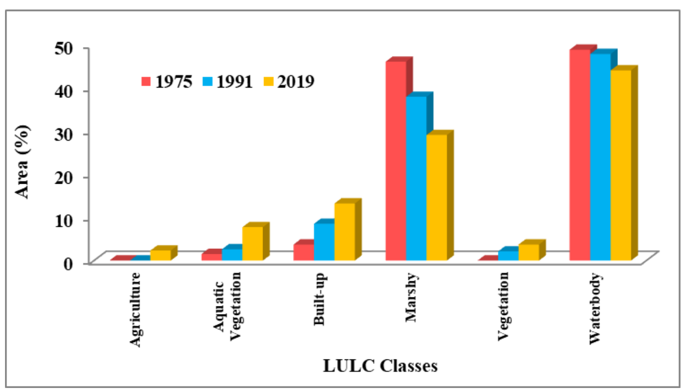


Figure 6: Inventory of changes in the lake area

From this analysis, it is observed that waterbody, marshy land are replaced by built-up, agriculture etc. anthropogenic activities. Aquatic vascular plants are taking place on the clear water and sprawling haphazardly all over the lake.

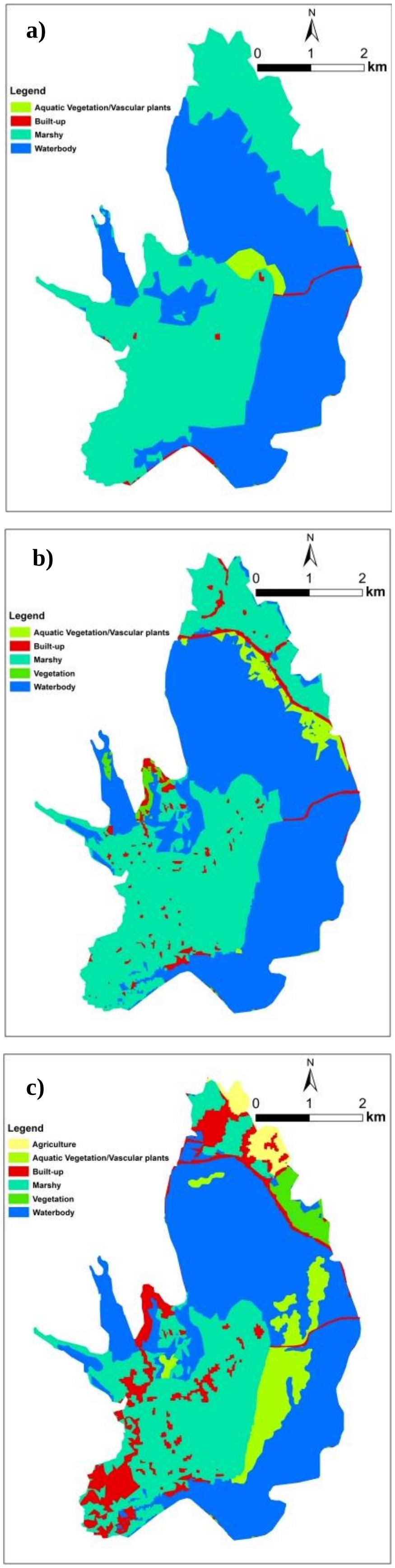


Figure 5: Changes in Dal-Nigeen lakes (a-9/4/1975, b-20/4/1991, c-1/4/2019)

TABLE 3
Details about ground trothing and ground control points

Sr. No.	Latitude (N)	Longitude (E)	Class Name
1	34° 10' 36.5"	74° 52' 24.8"	Agriculture
2	34° 8' 6.7"	74° 47' 35.1"	Agriculture
3	34° 7' 2.3"	74° 51' 37.5"	Built-up
4	34° 6' 27.1"	74° 52' 46.8"	Built-up
5	34° 9' 15.6"	74° 51' 3.3"	Built-up
6	34° 5' 13.2"	74° 50' 48.1"	Forest
7	34° 4' 49.4"	74° 50' 40.2"	Forest
8	34° 4' 43.2"	74° 52' 18.2"	Forest
9	34° 4' 48.1"	74° 52' 43.3"	Forest
10	34° 8' 15.1"	74° 53' 4.3"	Forest
11	34° 4' 4.8"	74° 52' 36.4"	Pasture land
12	34° 7' 27.4"	74° 53' 23.4"	Pasture land
13	34° 4' 59.8"	74° 51' 10.6"	Plantation
14	34° 5' 40.8"	74° 52' 44.5"	Plantation
15	34° 10' 44.6"	74° 50' 31.8"	Agriculture
16	34° 2' 47.7"	74° 50' 52.1"	Agriculture
17	34° 5' 16.3"	74° 50' 52.1"	Vegetation
18	34° 5' 10.8"	74° 51' 1.1"	Vegetation
19	34° 4' 50.1"	74° 51' 37.2"	Vegetation
20	34° 8' 12.7"	74° 50' 23.8"	Vegetation
21	34° 4' 26.7"	74° 50' 55.8"	Vegetation
22	34° 2' 47.8"	74° 51' 58.7"	Vegetation
23	34° 11' 22.8"	74° 51' 55.6"	Vegetation
24	34° 4' 13.8"	74° 49' 49.8"	Waterbody
25	34° 5' 56.5"	74° 52' 33.9"	Waterbody
26	34° 6' 38.8"	74° 51' 2.7"	Marshy
27	34° 6' 53.9"	74° 51' 45.2"	Marshy
28	34° 6' 57.6"	74° 50' 10.3"	Marshy
29	34° 7' 16.9"	74° 50' 22.6"	Marshy
30	34° 6' 51.9"	74° 49' 11.3"	Marshy
31	34° 5' 8.6"	74° 53' 2.6"	Forest
32	34° 5' 25.8"	74° 51' 44.8"	Aquatic Vegetation
33	34° 7' 46.6"	74° 52' 29.9"	Aquatic Vegetation
34	34° 5' 38.6"	74° 51' 27.2"	Aquatic Vegetation
35	34° 5' 57.1"	74° 51' 45.7"	Aquatic Vegetation
36	34° 6' 10.2"	74° 52' 2.6"	Aquatic Vegetation
37	34° 6' 32.1"	74° 51' 56.7"	Aquatic Vegetation
38	34° 7' 39.8"	74° 52' 13.9"	Aquatic Vegetation
39	34° 7' 24.4"	74° 51' 24.2"	Aquatic Vegetation
40	34° 6' 49.6"	74° 52' 16.4"	Aquatic Vegetation

Slope Mapping

Slope analysis (Figure 7) for this region revealed that the majority of the study area is covered by the gentle slope (72.1%) followed by strong (10.3%), moderate (8.3%), steep (7.9%), and very steep (1.4%). Slopy terrain mostly exists on the eastern side of the lake that addresses the surface runoff, domestic sewage, from the hilly urban area. The natural drains from the hill, city sewage drains might be disposing the nutrients into the lake, which is leading for eutrophic conditions over this place. There are several Sewage Treatment Plants (STPs) along the Dal lake (mentioned on the slope map), which are supposed to treat city sewage before discharging into the lake.

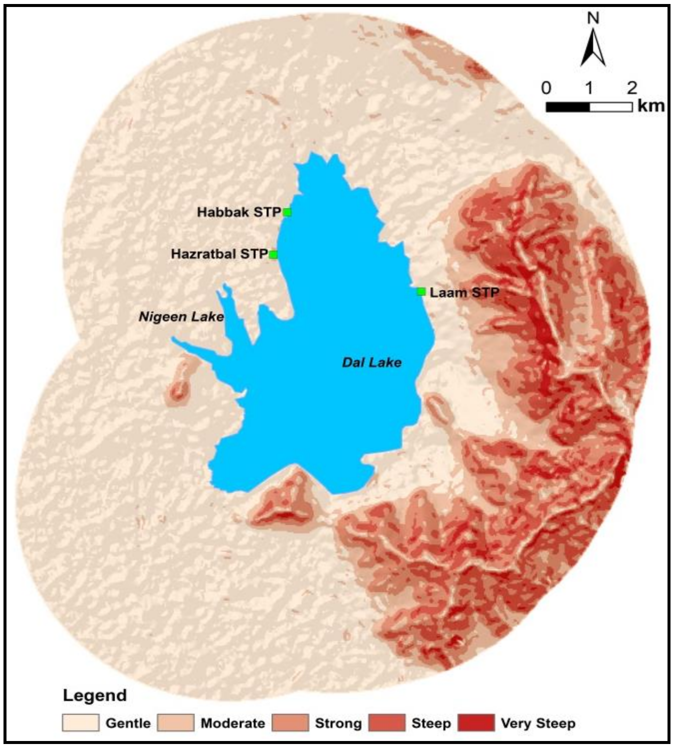


Figure 7: Slope map along with STPs around the lake

Assessment of aquatic vascular plants/algal bloom

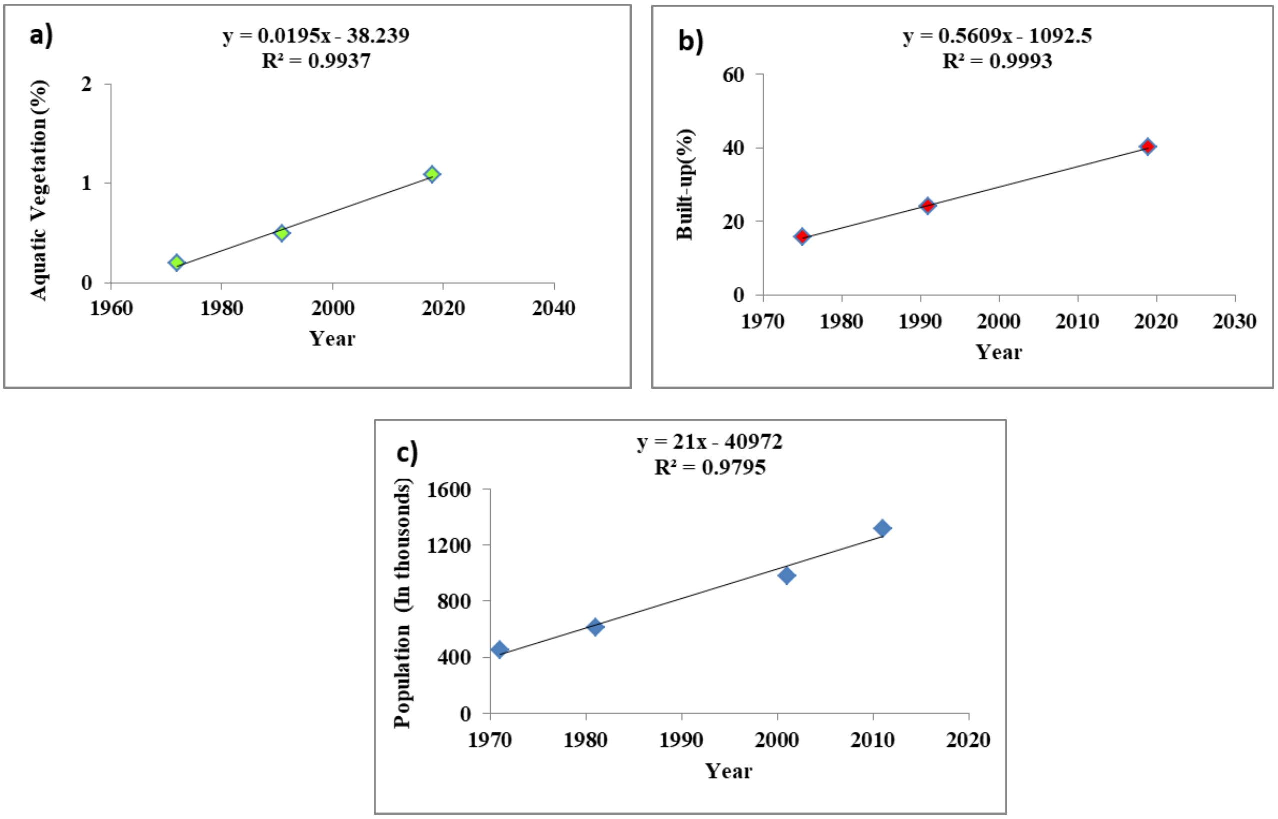
In this research work, it is critically observed that aquatic vascular plants/ algal bloom is rapidly increasing over the year (Figure 8a). It increased by a percentage share of 0.3% from 1972 to 1991 and increased by 0.6% during 1991 to 2018 with an overall increase of 0.9% during the study span.

Increasing of built-up (Figure 8b) and other development activities might be the probable reason for the growth and spreading of the areal distribution of aquatic vascular plants. An increase of population (Figure 8c) and discharge of untreated sewage (as mentioned earlier) may provide favorable conditions (nutrients: phosphorus, nitrogen) for the growth of aquatic vegetation and algal bloom. It is directly responsible for the deterioration of water quality as well as the aesthetic beauty of the lake. It is also observed that the patterns and positions of the aquatic vascular plants is highly dynamic. It is observed that the de-weeding procedure is going on in Dal lake throughout the year by Jammu and Kashmir Lake Conservation and Management Authority (LCMA), which may be one of the probable reasons for the shifting of aquatic vascular plants. As a critical observation, it is figured out that, in 1975 a patch of an aquatic vascular plant is located near the marshy land that signifies the availability of nutrients for the growth, while that patch has been shifted along the Boulevard road during 1991 reflects the impact of anthropogenic activities on the growth of the aquatic plants. In 2019 aquatic vascular plants have been spread over the central lake area where house-boat, marshy land, and agricultural activities were found. The direct release of sewage from those house-boats, various drains and agricultural runoff might be the possible reasons shifting and overgrowth of aquatic vascular plants over this lake.

In this research work, it is critically figured out that there is a strong correlation between population, built-up and growth of aquatic vascular plants. This scenario tells that increasing population and built-up is the valid reason for increasing of untreated sewage (50 million liters/day) discharge into the lake and unwanted growth of aquatic vascular plants/weed

TABLE 4
Accuracy Assessment Matrix

Class	Agriculture	Aquatic Vegetation	Built-up	Forest	Pasture land	Plantation	Vegetation	Marshy	Waterbody
Agriculture	4								
Aquatic Vegetation		9						2	
Built-up			3						
Forest				5			2		
Pasture land					2		1		
Plantation						2	1		
Vegetation				1			3	1	
Marshy								2	
Waterbody									2
Total	4	9	3	6	2	2	7	5	2
Producer Accuracy (%)	100	100	100	83.3	100	100	43	40	100
Overall Accuracy (%) = 80									
Kappa Coefficient (K_{HT}) = 0.71									



Source: Population Census 2011

Figure 8: Relation among Population, Built-up and Aquatic vascular plants of the lake area
(a. Population vs. Year b. Built-up vs. Year and c. Aquatic vegetation vs. Year)

IV. Conclusion

The geospatial study has evaluated the development in the periphery as well as changes in the lake due to the manmade activities and its impact can be seen in the excessive growth of aquatic vascular plants / algal blooms. LULC analysis reveals how built-up area is considerably increasing throughout the study span and it is directly related to sewage generation and discharges in the lake. Nutrient (nitrogen, phosphorous) load from domestic sewage, agricultural runoff, and wastewater from hotels industries provide favourable environment for aquatic plants and pressure on eutrophication.

In this situation, study suggests the conservation of world-famous Dal and Nigeen lakes. Dredging and desilting of the lake should be the major activity to maintain the hydraulic capacity and frequent de-weeding exercise to control and spread of aquatic plants. Some other measures like identification of sites from where sewage is discharging into the lake, improvement of treatment capacity in terms of nutrient removal from the existing STPs, problem-specific solution like in-situ drain treatment for sewage, proper sanitation facility for houseboats, conservation of lake from agriculture runoff, awareness among the people about sewage pollution and protection of lake from sewage discharge might be the key components to preserve the Dal and Nigeen lakes.

V. Acknowledgement

Authors are thankful to the Director CSIR-NEERI, Nagpur for providing the necessary infrastructure and support to carry out this research study. The authors are also grateful to USGS earth explorer for downloading satellite data for this research study.

VI. Declaration

Data Availability Statement

Satellite data were downloaded from USGS Earth Explorer. Direct requests for these materials may be made to the provider as indicated in the Acknowledgements. All data, models, and code generated or used during the study appear in the submitted article.

Conflict of statement

No

VII. References

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