IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

ANALYSIS OF THE WATER QUALITY OF DAL LAKE USING GIS AND IDENTIFICATION OF RESTORATION ZONES

Yameen Mir, Sukalpaa Chaki, Mulbah Rufus Flomo

Department of Civil Engineering, Sharda University, Greater Noida

Abstract:

Background: *Lakes worldwide are experiencing degradation, including Dal Lake in Srinagar, Jammu and Kashmir. Known for its beauty and cultural importance, Dal Lake's water quality has deteriorated over the past forty years due to human activities. The lake is home to over 50,000 residents living on houseboats and islands and supports various livelihoods such as tourism, agriculture, fishing, and vegetable farming.*

Aims: *This study aims to examine different regions of Dal Lake to assess its physical and chemical parameters. Using the Inverse Distance Weighting (IDW) technique and ArcGIS software, maps were generated to identify areas deviating from Indian norms and those in need of restoration and pollution mitigations stressing the importance of protecting micro watersheds and catchments.*

Results: *The analysis revealed that the lake's pH levels ranged from 7.6 to 8.4, indicating an alkaline nature. Conductivity varied, with Nigeen showing high saltwater levels at 390 mg/l. Alkalinity surpassed the permissible limit of 120 mg/l, attributed to sewage and waste disposal. Chloride concentrations ranged from 18.2 mg/l to 30 mg/l, suggesting potential organic contamination. Ammoniacal nitrogen levels were higher near the Nigeen Basin, at 0.603 mg/l, essential for plant and algae growth. Dissolved oxygen concentrations fluctuated seasonally, ranging from 5 mg/l to 9 mg/l. The biological oxygen demand indicated a eutrophic lake, with levels from 2 mg/l to 5 mg/l, increasing during the summer. Calcium levels fell below the BIS limits (35 mg/l to 55 mg/l), while magnesium concentrations ranged from 7 mg/l to 29 mg/l. Sulphate levels (17 mg/l to 62 mg/l) were influenced by acid rain and coal-burning activities. Algal blooms were observed, linked to chloride and nitrate levels, indicating nutrient enhancement and insufficient water flushing. High planktonic hardness showed seasonal variations. The study highlighted the interconnections among the parameters and proposed three pairs for further validation based on universal properties.*

Conclusion *The study of Dal Lake reveals significant water quality issues, such as high alkalinity, organic contamination, and nutrient enhancement causing algal blooms. These problems are mainly due to sewage and waste disposal, acid rain, and coal-burning activities. The results from the IDW technique and ArcGIS software emphasize the urgent need for restoration efforts to protect vulnerable areas. Prompt intervention is crucial to restore the lake's ecological balance and preserve its cultural and aesthetic value.*

Keyword: ***water Pollution, water quality, sewage,*** **human settlement, restoration**

1. Introduction

Water stands as a crucial element for life, yet the escalating anthropogenic pressures are posing a growing threat to both surface and groundwater quality [1]. The rise in human population, socio-economic development, and shifting consumption patterns are exerting pressure on water resources, a trend anticipated to intensify in the forthcoming decades [2]. Achieving environmental and societal sustainability necessitates maintaining high water quality standards [3]. Approximately 3.6 billion individuals lack access to adequately maintained sanitation facilities, and nearly 2 billion people do not have access to safe and readily available water in their homes [4]. Water is a vital resource crucial for human survival and progress, playing a fundamental and strategic role in fostering sustainable development within human societies and ecological environments. Over 40% of the global population resides in coastal regions, alongside lakes and rivers, a proportion that continues to rise. Coastal waters, being highly sensitive environments, are significantly affected. The surge in socio-economic development, urbanization, and industrialization has led to an increase in the discharge of industrial wastewater and domestic sewage. Consequently, water bodies are experiencing a decline in water quality, eutrophication, ecological harm, and the disappearance of essential and sensitive aquatic organisms. Surface waters and groundwater have experienced degradation due to a combination of natural and human-induced factors. Natural influences on water quality encompass hydrological, atmospheric, climatic, topographic, and lithological factors. In contrast, anthropogenic factors adversely impacting water quality include agricultural practices, industrial activities leading to the generation of substantial and often hazardous waste, discharge of municipal wastewater, soil erosion resulting from changes in land use, elevated temperatures due to water discharge cooling, and pollution from heavy metals, particularly associated with mining activities [5]. [6] Has asserted that the attainment of a sustainable water supply in urban areas necessitates the continuous, extended monitoring of water quality conditions in the existing water resources and watersheds. The crisis in biodiversity is particularly severe in freshwater ecosystems, suggesting that the Earth is on the brink of the sixth mass extinction in its history. The loss of biodiversity is a significant concern recognized by governments and economic stakeholders [2].[3] Suggested that in order to delve deeper into understanding the potential legacy explanations for challenges in mitigating pollution, delays, and uncertainties, it is essential to differentiate the contributions to water quality from legacy sources and active sources. Monitoring water quality is crucial not only for addressing water scarcity but also for ensuring the safe use of water and fostering sustainable development in water ecosystems [7]. Traditionally, the accurate monitoring of water quality data relies on sampling and laboratory analysis, a process that is time-consuming, inefficient, and susceptible to secondary contamination risks. Furthermore, conventional methods for water quality monitoring provide spatially limited information, often restricted to isolated single sampling points, which falls short of meeting the demands for continuous large-scale water quality monitoring in modern cities. In response to these challenges, remote sensing and hyper spectral methods have gained widespread use as effective non-contact monitoring technologies [7]. The suggested integrated framework, utilizing remote sensing and Geographic Information System (GIS), is designed to be universally applicable to any river system. This initiative aims to enhance transparency in river pollution monitoring by integrating GIS technology, potentially alleviating some of the decision-making challenges confronted by river authorities in pollution control. The implementation of GIS-based monitoring, if successfully executed, will allow for the extraction of near real-time information on the water quality status of any point along the river stretch. This capability is expected

to aid in tracking impaired river segments effectively [8]. Lake restoration refers to all of the techniques used to improve and restore damaged lakes. When a natural lake drifts from its original form, or when a man-made design changes in negative ways, restoration techniques aim to return the lake to its intended and healthiest form. The majority of natural lake restoration projects aim to go back in time and restore lost species or habitats. Man-made restoration is less constrained by previous patterns of use, so it is often more ambitious and may involve redesigning the lake from the ground up. The same techniques are used around the world to restore the important benefits of healthy lakes, regardless of the type or scale of the lake restoration process. Lake restoration helps in silt management, reduction of flood risk, reduction of phosphorus and nitrogen levels and controlling excessive growth of macrophyte [9]. In countries such as India, characterized by developing economies, the accepted strategy for economic growth should be the sustainable development, efficient utilization, and effective management of water bodies. Unfortunately, in recent times, inadequate management and inefficient utilization of natural resources for various purposes have led to several issues. These include problems like waterlogging and salinity in the field of agriculture, as well as contamination by heavy metals due to mining industries and municipal uses [10]. Dal Lake, spanning an enchanting 22 square kilometres, is a captivating wetland located in the city of Srinagar, adorned with significant historical landmarks such as Zabarwan, Shankar Achariya, and Hari Parbat Mountain ranges. This picturesque lake holds a pivotal role in both the daily lives of the locals and the region's historical heritage. Extending over a considerable expanse within the Srinagar municipal limits, Dal Lake draws tourists from across the globe. The lake's origin is a subject of debate, with one perspective suggesting it is a post-glacial relic formed through the gradual contraction of an ancient glacial lake from the Pleistocene period. Regrettably, unsustainable development practices and uncontrolled tourist influx in the vicinity have led to a decline in the lake's carrying capacity and macrophyte growth. Additionally, unchecked runoff and sewage discharge from nearby hotels and Srinagar city's municipal waste pose a potential threat, causing pollution in the lake and fostering the growth of algal blooms and red tides. Unfortunately, projections indicate that Dal Lake may cease to be a sought-after tourist destination in the coming years, resulting in significant economic losses for Srinagar. This downturn would also impact the per capita income of locals who heavily depend on tourism for their livelihoods [6] . The novel objective of this paper is to bring to light the challenges faced in managing urban watershed pollution, and to demonstrate the efficacy of integrating GIS into the existing WQ monitoring procedures through advanced monitoring strategies.

Study Area

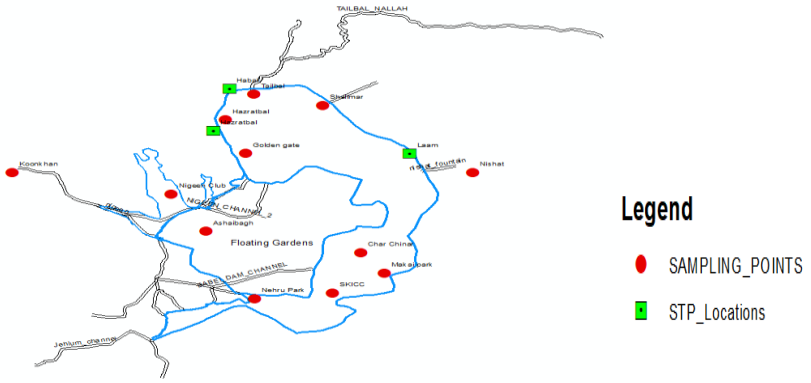


Figure No1: *Area of Study*

A pleasant addition to Srinagar's list of attractions is the city's well-known Dal Lake. The lake is second in size in the region of Jammu and Kashmir and has gardens all around it. The Dal Lake is one of the most picturesque lakes in India and is very well-liked by tourists because of its dazzling calm waters and stunning snow-capped mountains on three sides. The beautiful "shikaras," which are laden with new flowers, resemble a symbolic take on Venice's gondolas. A few Mughal structures and the Kashmir University campus are positioned along the lake's edge. On the two hillocks that overlook the lake, there are temples dedicated to Shankaracharya and Hari Parbat. The Lake encompasses an area of 22sq kms with a floating garden called REED which blossoms in summer with delightful flowers and vegetables. Inflow Channels of Dal Lake are_Nishat pipe line, Khwaja nallah, Gam kul, Dal gate nallah, Tailbal nallah, Barinambal, Safakadal nallah. Boant kul, Horish kul and Doub kul and on the other hand the outflow channels of Dal Lake are namely_Dal Gate and Amir Khan Nallah

1.1 Present Condition of Dal Lake:

- The lake is currently a mixture of mossy marshes, dense weeds, and sections with trash scattered around them, and floating gardens made of reed rafts.
- Over a thousand houseboats produce over 9,000 metric tonnes of trash annually, which is discharged into the lake.
- Around 18 tonnes of phosphorus and 25 tonnes of nitrogen-rich nutrients enter the lake through 15 drains.
- In two of the Dal Lake basins, Lokut Dal and Bod Dal, sewage production amounts to 97,000 kg.
- High BOD levels were discovered, indicating eutrophication, which has an impact on aquatic life.
- The Dal Lake receives daily contamination from the 15 main city drains that open onto it.
- The lake's area has decreased from its original 22 square kilometres to roughly 10 square kilometres as a result of silt deposition. The lake's depth has also decreased by almost 12 metres, which is a serious indication of the risks the lake confronts.
- The unique treatment facilities that clean the sewage water before releasing it into Dal Lake need to be upgraded because they are not operating as intended.
- Every day, water from different nallahs containing different types of contaminants is released into the lake, ultimately degrading the water quality

- Dal is struggling with the issue of sediment deposition, which makes the lake more eutrophic, encourages the growth of vegetation, and speeds up the demise of the aquatic life.

1.2 Sources of Pollution

Due to the discharge of effluents from nearby hotels and residential areas, the lake has transformed into a landfill. Household waste and sewage from houseboats are consistently dumped into it. The impurity of the lake is significantly contributed to by the inflow from various nallahs:

- Nishat Pipe Line: Transports sewage from several Nishat region neighbourhoods.
- Sheikh Kul Nallah: Transports clay, silt, and mud-filled agricultural runoff water.
- Gam Kul: Transports clay and silt from nearby agricultural areas.
- Dal Gate Nallah: Carries sewage from adjacent areas.
- Khwaja Mohalla Drain: Used for dumping sewage and household waste into the lake.
- Telbal Nallah: Directly deposits agricultural runoff water, soaps, and detergents into Dal Lake. Sewage through Barinambal and Safakadal Naallah add to the deterioration of the lake

1.3 Recommended strategies for the restoration of the Dal Lake

These strategies address the root causes of pollution, involve the community, and ensure long-term sustainability of the restoration efforts.

1. Building and upgrading sewage treatment plants (STPs) is crucial to ensure that all wastewater is treated before being discharged into the lake. This reduces the input of harmful nutrients and organic matter, which degrade water quality.

2. Solid Waste Management: Establishing an efficient waste management system is essential to prevent garbage from being disposed of in the lake. Regular cleanups and waste collection points can keep the lake free from debris and pollutants.

3. Encroachment Control: Enforcing regulations to prevent further encroachment into the lake and reclaiming previously encroached areas can restore the lake's natural boundaries. This increases water volume and reduces pollutant concentration.

4. Public Awareness and Community Involvement: Educating the local population about the lake's importance and the impact of pollution through awareness campaigns fosters a sense of responsibility. Involving the community in restoration activities ensures sustained efforts and community-driven initiatives for the lake's health.

These strategies address pollution causes, involve the community, and ensure long-term restoration sustainability

2. MATERIALS AND METHOD

ARC GIS Software and IDW Analysis

Arc GIS is a software in which geographical data can be viewed, edited, managed, and analysed using geospatial software named ArcGIS. Esri developed ArcGIS for mapping on computers, mobile devices, and the web. Their tagline is The Science of Were. Therefore, ArcGIS places a strong emphasis on intelligence about locations and statistical evaluation.

2.1 The ArcGIS programme was used for the following tasks:

- Mapping the outside edge of Dal Lake
- The inflow and outflow canals were fully labelled, mapped and identified
- The IDW Technique was used to do a geo-spatial analysis of the various parameters in order to generate a map that anticipated

the value of these parameters geographically and assisted us in analysing the water quality assessment of the Dal Lake

2.2 Inverse distance weighted method

The explicit premise of (IDW) interpolation is that objects close to one another are more similar than those farther away. IDW predicts a value for every unrecorded place using the measured values in the vicinity of the prediction site. The predicted value is more influenced by the measured values that are in close proximity to the forecast location than by those that are farther away. IDW claims that the local influence of each observed place changes with distance. The term "inverse distance weighted" refers to the fact that points farther away from the predicted location are given less weight, and vice versa. This IDW technique was used to produce maps which showed the distribution of various physical and chemical parameters values over the surface of the lake

2.3 Limitation of ArcGIS and IDW software that may limit data validation

The ArcGIS software used to detect the pollution level in the Dal Lake could be limited the accuracy and calibration of sensors and the variable flow and distribution of pollutants. georeferencing errors also pose challenges. These factors can lead to incomplete or inaccurate representations of pollution levels, which are crucial for effective environmental management and policy-making to protect public health and ecosystems and Inverse Distance Weighting (IDW) software in water analysis is affected by the density and spatial distribution of sampling points, the choice of IDW parameters (such as power parameter and search radius), and environmental factors like topography and temporal variations. Measurement errors, data preprocessing mistakes, and inherent limitations of the IDW algorithm, which assumes that closer points have more influence, also impact accuracy. Ensuring high-quality, well-distributed data we carefully selected parameters which was crucial for accurate interpolations, which are essential for effective water resource management and environmental protection and all effort was made to produce a Reliable data ensures informed decision-making to mitigate pollution and improve water quality

3. RESULT

Various Physical and chemical parameters that were analysed using IDW technique are as follows:

1) pH 2) Conductivity 3) Calcium 4) Magnesium 5) Total Dissolved Solids 6) Biological Oxygen Demand 7) Chemical Oxygen Demand 8) Dissolved Oxygen, 9) Ammoniacal Nitrogen 10) Phosphate 11) Hardness 12) Alkalinity 13) Chloride 14) Sulphate15) Turbidity were collected from the site of Jammu and Kashmir Lakes Conservation and Management Authority website which is the nodal agency for the conservation of Dal Lake for the year 2022.

Table No. 1: Showing data of physical and chemical characteristics of various parameters for the year 2022

Sampling Point	pH	EC	TDS	DO	COD	BOD	Am N	Sulphate	Hardness	Ca	Mg	Alkalinity	Cl	Turbidity
Berlin shikara Ghat region	7.8	297	156	8.5	23.3	2	0.495	18.33	184	50.9	12.63	148	20	3

Pokhri Bal Devi Temple	7.8	297	156	6.3	28.3	3.5	0.574	19.99	156	41.6	12.6	168	18	5
Malroo Ghat	8.36	293	155	9.6	31.6	3.9	0.511	23.22	152	40.08	12.6	160	18	5
Hazaratbal shrine	7.93	302	159	9.4	41.6	5.5	0.464	21.21	162	40.88	14.5	156	20	5
Nehru Park	7.84	289	158	7.6	24.9	2.8	0.448	17.72	176	46.49	14.5	156	20	3
Shalimar	7.8	329	172	6.8	38.3	4.7	0.365	33.6	174	49.6	12.1	118	30	4
Tailbal Basin	7.62	346	183	9.5	19.8	1.8	0.443	46.51	168	37.67	17.9	166	22	4
Hazratbal	7.79	404	213	7	31.6	3.2	0.579	50.14	206	55.3	16.5	200	24	4
Tuilp Garden srinagar	7.62	300	158	5.2	34.9	2.7	0.481	18.63	162	54.5	9.5	170	24	6
Zabarwan Park	8	378	199	9.1	31.6	4	0.527	47.57	210	35.2	29.6	228	22	4
Nigeen Club	7.89	395	208	9.1	29.9	3.8	0.603	62.41	206	53.7	17	208	24	3
Nishat	7.8	337	179	7.1	44.9	6	1.706	27.27	152	48	7.7	146	28	4

Table No. 2: Showing Specific sampling point and coordinate

Sr. No.	**Sampling point region**	**Coordinate**	
		North point	**East point**
1	Nishat Garden	34°° 07' 28''N	74°° 52' 42''E
2	Nigeen Region	34°° 06' 54''N	74°° 49' 56''E
3	Shalimar Region	34°° 08' 33''N	74°° 51' 39''E
4	Berlin shikara Ghat region	34°° 06' 34''N	74°° 52' 36''E
5	Nehru Park	34°° 05' 24''N	74°° 50' 44''E
6	Pokhri Bal Devi Temple	34°° 06' 35''N	74°° 49' 33''E
7	Tailbal Basin	34°° 08' 55''N	74°° 50' 36''E
8	Tuilp Garden srinagar	34°° 05' 50''N	74°° 52' 21''E
9	Hazaratbal shrine	34°° 07' 44''N	74°° 50' 36''E
10	Zabarwan Park	34°° 05' 11''N	74°° 51' 02''E
11	Malroo Ghat	34°° 05' 25''N	74°° 52' 35''E

3.1 IDW ANALYSIS USING GIS

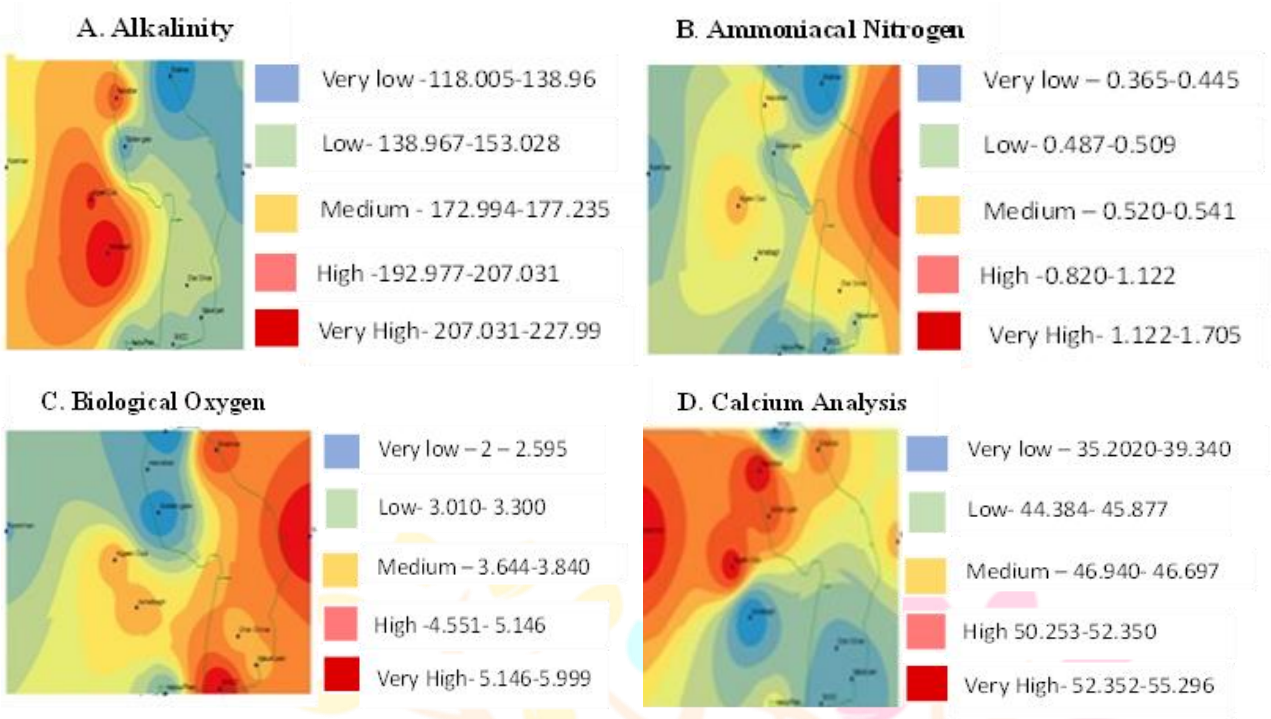


Figure No 2: *Showing distribution of Alkalinity, Ammoniacal Nitrogen, Biological Oxygen Demand, and Calcium over the surface of the dal lake*

For alkalinity, BIS specifies a maximum permissible level of 120 mg/L [6]. With the exception of Nigeen and Ashai Bagh, the mean total alkalinity value has been determined to be within 160 and 390 mg/l. The results of the study's total alkalinity analysis indicate that the water was especially hard as specify by[11] **.** The existence of a surplus of free Carbon Dioxide product as a consequence of the process of decomposing combined with the mingling of sewage and residential waste may be the cause of the higher alkalinity levels observed throughout the summer. The low levels of alkalinity during the wet season could be caused by dilution [12]**.** In previous research by [13] stated that ammoniacal nitrogen are used for the growth of lake plants and algae, nitrogen is a vital component [6]. Runoff from the surface or groundwater may carry nitrogen into a lake. Sediments definitely produce a variety of nitrogen alterations [4]. Algae development is slowed by nitrogen rather than phosphorus [14]**.**

The nitrogen content in this research was found higher near Nigeen Basin of Dal Lake. Because it indicates whether biological activity in lakes and rivers is aerobic or anaerobic, an indicator of the level of organic matter in a body of water is the bio-chemical oxygen demand as elaborated by [3]**.** The BOD concentration ranged from 2 mg/l to 5 mg/l, indicating a eutrophic water body. According to [15]observations, it was highest during the summer season. All of the above findings of physicochemical parameters lead to the conclusion that the water body exhibits eutrophication characteristics. The Dal Lake appears to be very eutrophic based on its minimal dissolved oxygen content, excessive biochemical oxygen demand, as well as elevated nitrate concentrations. The observed average calcium amount fell below the BIS permissible limit of 75 mg/l, falling in the range of 35 to 55 mg/l. Geology and the sorts of rocks found in the watershed determine the quantity of calcium in natural water [16]**.**

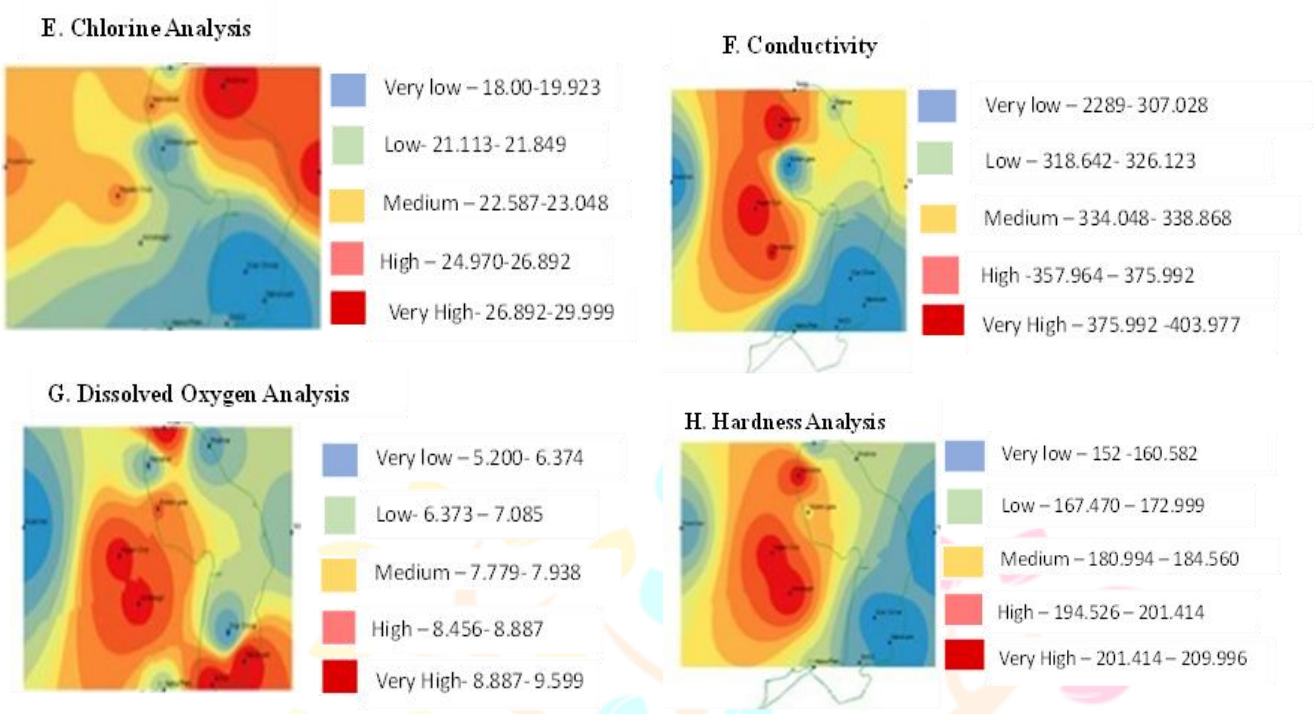


Figure No 3*: Showing distribution of Chlorine, Conductivity, Dissolved Oxygen and Hardness over the surface of the dal lake*

One of the most essential parameters in determining water quality is chloride [17]**.** [18] believe that increased chloride concentrations suggest a higher degree of organic contamination. The chloride content in the current research ranged from 18.2 mg/l to 30 mg/l which is in agreement with [10]. The calculation of DO is an essential factor in water pollution research [19].[14] Emphasized that dissolved oxygen concentration is affected by physical, chemical, and biological activity in a body of water, and its measurement offers an accurate estimate of water quality. According to the findings of this investigation, the content of dissolved oxygen ranged between 5mg/1 and 9mg/1 which correlated with [20]. Dissolved oxygen concentrations were highest during the monsoon and lowest throughout the summer. As a result, the dissolved oxygen concentration varies with temperature and water supply amount [3]. The ability of a substance or solution to transmit electric current is measured by its conductivity [21]. Conductivity is used to estimate the quantity of dissolved solids in water [16]. Except for Hazratbal which had electrical conductivity of 404mg/l, where the Electro Conductivity may be attributed to high saltwater levels and mineral content, the rest of the lake have an average range of Electro Conductivity ranging from 297mg/l to 377mg/l. The Kashmir Valley's freshwater bodies' high concentrations of hardness have been linked to a dense population of plankton, particularly Cyanophycean

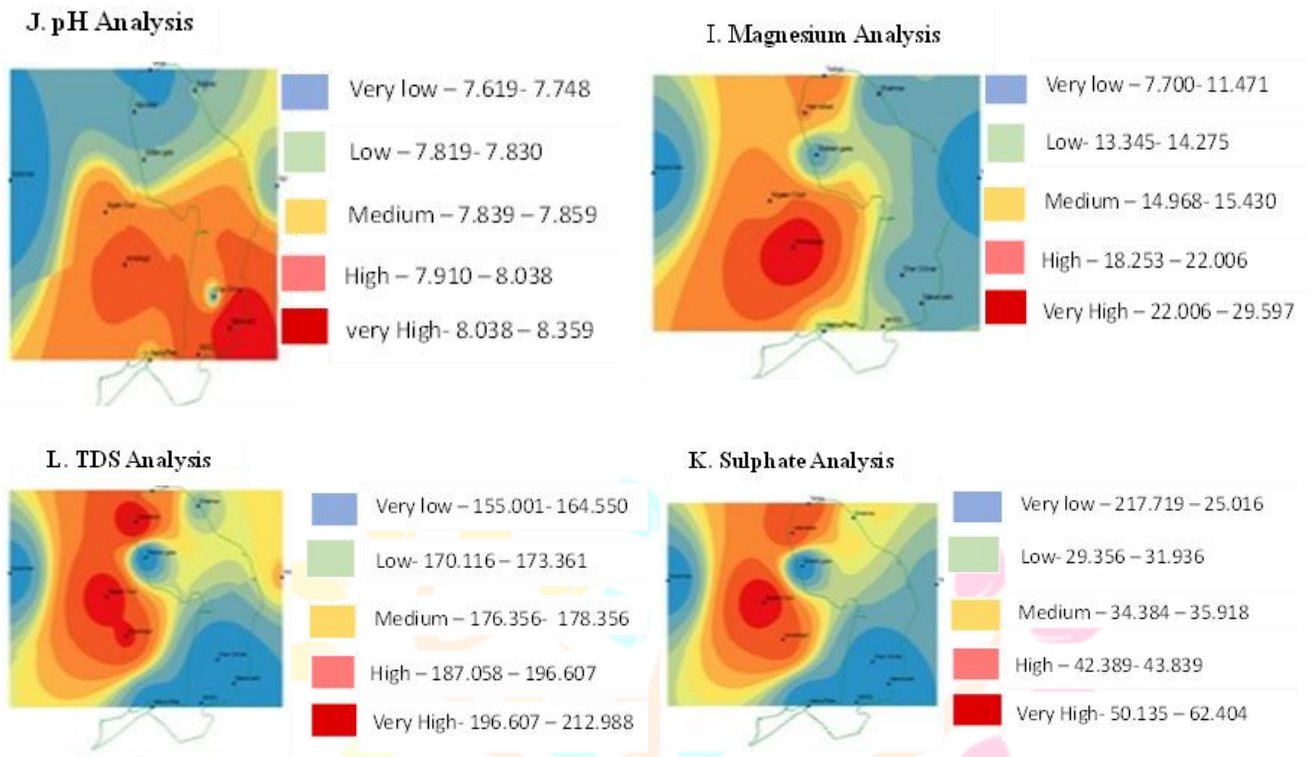
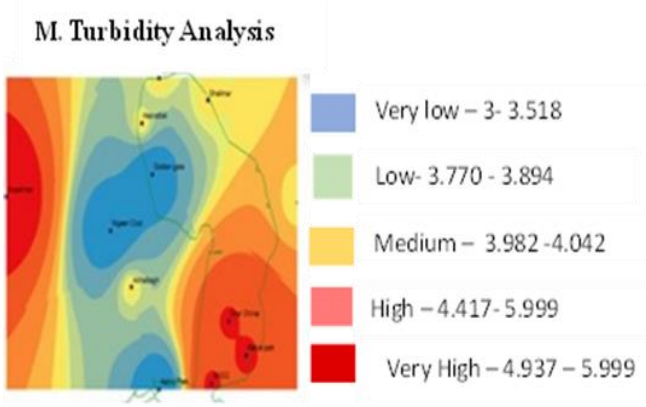
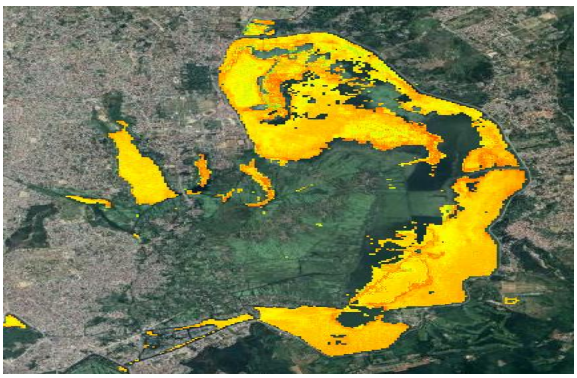


Figure No 4: *Showing distribution of Magnesium, pH, Sulphate, and TDS over the surface of the dal lake*

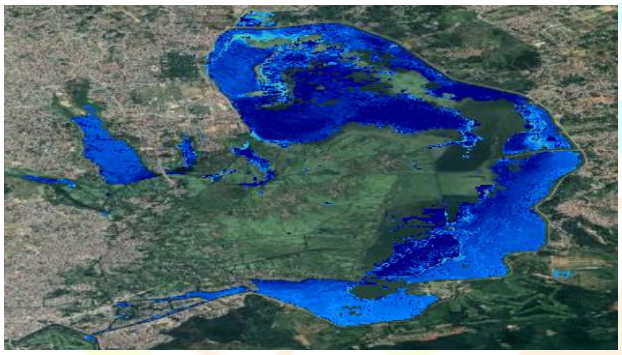
While the average magnesium concentration was found to be between 7 and 29 mg/l [22] **.** For those who are not acclimated to it, the hardness of magnesium especially that associated with the sulphate ion has a laxative effect [23]. The pH of water is an essential characteristic that impacts its appropriateness for various applications [6]. The pH in the current investigation varied between 7.6 and 8.4. Because of the variance in readings, it was discovered to be somewhat alkaline in nature. Acid rain and the minerals in the watershed play a major role in determining the sulphate levels in lakes [16]**.** [17]found that Sulphur compounds are released into the atmosphere by coal-burning businesses and utilities and are then carried into lakes by precipitation. Sulphate can be transformed to hydrogen sulphide (H2S) in anaerobic water, which lacks oxygen. The range of sulphate concentrations is 17 mg/l to 62 mg/l.



N. Chlorophyll Analysis



O. Sechi Depth Analysis



P. Algae Concentration Analysis

Figure No. 5: *Showing distribution of Turbidity, Chlorophyll, Sechi Depth, Algae Concentration*

Algal blooms have been often observed in Dal Lake with the passage of time and as a result of growing and uninterrupted human intrusions into the lake and its periphery. Such blooms have started to occur often in the lake's numerous basins. Chloride and nitrates were found to be closely related, and they almost exactly matched the levels of high euglenoid population. The Dal Lake euglenoid bloom was most likely caused by enhancement of nutrients, lack of water flushing, and a buildup of free carbon dioxide, according to what can be inferred.

4. Conclusion

The conclusion of the analysis indicates that certain areas in Dal Lake, particularly Nagen and Ashai Bagh, exhibit values exceeding permissible limits for various physical and chemical characteristics, demanding urgent restoration. Alkalinity levels in these areas are significantly higher than the allowed limit. Ammoniacal Nitrate is elevated near Nishat due to STP plant discharge. The eastern region of the lake, including SKICC, Nishat, and Char Chinar, faces high Biological Oxygen Demand (BOD), indicating greater pollution compared to the western side. Sechi Depth reveals clearer water around Hazratbal and Nigeen, while algae concentration is higher in Nigeen and Ashai Bagh due to floating gardens and Amir Khan Nallah discharge. Limited community involvement, insufficient pasture management, and inadequate desilting impact the lake. The invasion of Azolla, an exotic weed, is linked to recent desilting of Telbal Nallah. Regulatory gates along the Fore Shore Road are non-functional, hindering sediment regulation. Conservation of mini watersheds and catchment regions is crucial to prevent soil erosion. Controlling the growth of aquatic plant species and promoting biodiversity are essential. To improve water storage capacity, clearing vegetation, implementing sewage treatment chambers, and

establishing proper sewage disposal systems are recommended. Such measures are deemed more advantageous than traditional wastewater treatment .

systems. Addressing waste entry from nallahs and canals is vital to mitigate a major pollution source.

Declaration of competing interest

The authors assert that there are no conflicts of interest and no information or details to be disclosed.

Credit authorship contribution statement

All author equally contributed to this work

Acknowledgements

We acknowledge the effort of all the author of this work by successfully conducting this research

Disclosure of funding

This research was self-sponsor by the author with no external support

5. References:

[1] M. G. Uddin, A. Jackson, S. Nash, A. Rahman, and A. I. Olbert, "Comparison between the WFD approaches and newly developed water quality model for monitoring transitional and coastal water quality in Northern Ireland," *Science of the Total Environment*, vol. 901, Nov. 2023, doi: 10.1016/j.scitotenv.2023.165960.

[2] É. Pierrat, A. Laurent, M. Dorber, M. Rygaard, F. Verones, and M. Hauschild, "Advancing water footprint assessments: Combining the impacts of water pollution and scarcity," *Science of the Total Environment*, vol. 870, Apr. 2023, doi: 10.1016/j.scitotenv.2023.161910.

[3] J. Cantoni, Z. Kalantari, and G. Destouni, "Legacy contributions to diffuse water pollution: Data-driven multi-catchment quantification for nutrients and carbon," *Science of the Total Environment*, vol. 879, Jun. 2023, doi: 10.1016/j.scitotenv.2023.163092.

[4] A. Murei, I. Kamika, and M. N. B. Momba, "Selection of a diagnostic tool for microbial water quality monitoring and management of faecal contamination of water sources in rural communities," *Science of the Total Environment*, vol. 906, Jan. 2024, doi: 10.1016/j.scitotenv.2023.167484.

[5] P. L. Georgescu *et al.*, "Assessing and forecasting water quality in the Danube River by using neural network approaches," *Science of the Total Environment*, vol. 879, Jun. 2023, doi: 10.1016/j.scitotenv.2023.162998.

[6] X. Cao, J. Zhang, H. Meng, Y. Lai, and M. Xu, "Remote sensing inversion of water quality parameters in the Yellow River Delta," *Ecol Indic*, vol. 155, Nov. 2023, doi: 10.1016/j.ecolind.2023.110914.

[7] L. Li *et al.*, "An advanced remote sensing retrieval method for urban non-optically active water quality parameters: An example from Shanghai," *Science of the Total Environment*, vol. 880, Jul. 2023, doi: 10.1016/j.scitotenv.2023.163389.

[8] S. Sekharan *et al.*, "River pollution monitoring over an industrial catchment in urban ecosystem: Challenges and proposed geospatial framework," *Environmental Challenges*, vol. 7, Apr. 2022, doi: 10.1016/j.envc.2022.100496.

[9] H. Alena, D. Jan, and D. Jana, "Threats, biodiversity drivers and restoration in temperate floodplain forests related to spatial scales," *Science of the Total Environment*, vol. 854. Elsevier B.V., Jan. 01, 2023. doi: 10.1016/j.scitotenv.2022.158743.

[10] Z. Jamshed and P. VAmit, "Review on heavy metal pollution in major lakes of India: Remediation through plants," *Afr J Environ Sci Tech*, vol. 11, no. 6, pp. 255–265, Jun. 2017, doi: 10.5897/ajest2017.2299.

[11] T. M. Nolan *et al.*, "Land use as a critical determinant of faecal and antimicrobial resistance gene pollution in riverine systems," *Science of the Total Environment*, vol. 871, May 2023, doi: 10.1016/j.scitotenv.2023.162052.

[12] K. S. Parmar and R. Bhardwaj, "Wavelet and statistical analysis of river water quality parameters," *Appl Math Comput*,

vol. 219, no. 20, pp. 10172–10182, Jun. 2013, doi: 10.1016/j.amc.2013.03.109.

[13] L. Casso-Hartmann *et al.*, "Water pollution and environmental policy in artisanal gold mining frontiers: The case of La Toma, Colombia," *Science of the Total Environment*, vol. 852, Dec. 2022, doi: 10.1016/j.scitotenv.2022.158417.

[14] S. B. Ramírez, I. van Meerveld, and J. Seibert, "Citizen science approaches for water quality measurements," *Science of the Total Environment*, vol. 897. Elsevier B.V., Nov. 01, 2023. doi: 10.1016/j.scitotenv.2023.165436.

[15] J. Piao, S. W. Nam, Y. Kim, and E. Park, "Enhancing groundwater management using aggregated-data analysis and segmented robust regression: A case study on spatiotemporal changes in water quality," *Science of the Total Environment*, vol. 899, Nov. 2023, doi: 10.1016/j.scitotenv.2023.165981.

[16] B. M. J. K. Balasooriya, J. Rajapakse, and C. Gallage, "A review of drinking water quality issues in remote and indigenous communities in rich nations with special emphasis on Australia," *Science of the Total Environment*, vol. 903. Elsevier B.V., Dec. 10, 2023. doi: 10.1016/j.scitotenv.2023.166559.

[17] N. Markert, B. Guhl, and C. K. Feld, "Water quality deterioration remains a major stressor for macroinvertebrate, diatom and fish communities in German rivers," *Science of the Total Environment*, vol. 907, Jan. 2024, doi: 10.1016/j.scitotenv.2023.167994.

[18] N. Nitzsche, J. P. Nunes, and J. Parente, "Assessing post-fire water quality changes in reservoirs: Insights from a large dataset in Portugal," *Science of The Total Environment*, vol. 912, p. 169463, Feb. 2024, doi: 10.1016/j.scitotenv.2023.169463.

[19] J. I. P. Di Blasi, J. Martínez Torres, P. J. García Nieto, J. R. Alonso Fernández, C. Díaz Muñiz, and J. Taboada, "Analysis and detection of outliers in water quality parameters from different automated monitoring stations in the Miño river basin (NW Spain)," *Ecol Eng*, vol. 60, pp. 60–66, Nov. 2013, doi: 10.1016/j.ecoleng.2013.07.054.

[20] D. E. Nnane, J. E. Ebdon, and H. D. Taylor, "Integrated analysis of water quality parameters for cost-effective faecal pollution management in river catchments," *Water Res*, vol. 45, no. 6, pp. 2235–2246, 2011, doi: 10.1016/j.watres.2011.01.018.

[21] E. Foley and A. D. Steinman, "Urban Lake water quality responses to elevated road salt concentrations," *Science of the Total Environment*, vol. 905, Dec. 2023, doi: 10.1016/j.scitotenv.2023.167139.

[22] R. A. Takenaka, R. B. Sotero-Santos, and O. Rocha, "Water quality assessment by ecotoxicological and limnological methods in water supplies, Southeast Brazil," *Ecotoxicology*, vol. 15, no. 1, pp. 73–82, 2006, doi: 10.1007/s10646-005-0048-y.

[23] S. I. El-Kowrany *et al.*, "Water pollution in the Middle Nile Delta, Egypt: An environmental study," *J Adv Res*, vol. 7, no. 5, pp. 781–794, Sep. 2016, doi: 10.1016/j.jare.2015.11.005.