Evaluating the Spatial Variability of Water Chemical Parameters: An Analysis of Dal Lake Based on GIS Applications

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Abstract- ***Growing urbanization surrounding Dal Lake in the Himalayan region of Kashmir has prompted a critical analysis of its effects on aquatic life, geochemistry, and water quality. Using a thorough scientific methodology, this study examines important water quality metrics at 24 sampling locations in the summer and winter. The measurements—pH, dissolved oxygen, chloride, calcium, magnesium, and total alkalinity—are essential for determining the lake's trophic level. Seasons turn out to be important variables affecting Dal Lake's water's chemical composition. Wintertime brings lower water levels that could concentrate pollutants, while summertime brings increased sediment loads and turbidity from melting snow. The observed properties exhibit considerable spatial variability (CV >1), which is linked to anthropogenic activities such as domestic waste discharges, agriculture, and urban growth. This is highlighted by the coefficient of variation (CV). The spatial variability of water chemical characteristics is mapped using geostatistical analysis, most especially Ordinary Kriging. For varying parameters, Gaussian, exponential, and spherical models prove to be suitable representations. The spatial maps help identify regions that need focused conservation efforts by enabling a more sophisticated knowledge of localized variances. Essentially, this study highlights the necessity for quick and focused intervention techniques while providing important insights about Dal Lake's current situation. Amidst the growing problems of urban expansion, the integration of scientific analyses—from geostatistical mapping to water quality assessments—forms the basis for well-informed decision-making and sustainable conservation initiatives.***

Keywords: Spatial variability, GIS, Dal Lake, Water Chemical Properties

I INTRODUCTION

Unquestionably important resources, clean water bodies are necessary for the survival of all living things. Water is essential to life in the Himalayan region, home to lakes at both high and low elevations [1-3] With more than 13,000 lakes, the Himalayas are home to many of the freshwater reservoirs found worldwide, which are spread among nations including India, Pakistan, Bhutan, and Nepal. These mostly glacial lakes, especially those over 3000 meters, support domestic water supply, agriculture, recreation, fisheries, and energy generation among other environmental and ecological uses. But there's a serious hazard from the increasing global contamination of freshwater lakes; contaminants are getting into these bodies through rivers, streams, runoffs, and other waste discharges [4,5] A growing global water crisis that affects billions of people globally exacerbates this problem [6]. Particularly developing countries struggle with providing 2 billion people with inadequate sanitation and millions of them without access to clean water [7,8]. highlighted that it is expected that the water crisis will have an impact on other vital industries including agriculture and the energy industry. To combat water contamination and guarantee the sustainable management of these essential water resources, swift action and coordinated efforts are required. Because the Himalayan lakes are vital ecosystems, they must be carefully preserved in order to maintain human populations. A proactive and cooperative strategy is necessary to alleviate the effects on the environment and communities that depend on these vital water sources in the face of a complex and interrelated global water problem. With the aforementioned information in mind, the current study was conducted with the following goals in mind: to use GIS software to map the spatial variability of the chemical properties of the water in Dal Lake.

II LITERATURE SURVEY

Many works have been carried about different facets of Himalayan lakes in great detail, including [9-16] in particular examined the chemical, biological, and physical characteristics of Mansar Lake. Taking into account both their form and thermal behavior, [17] divided the lakes in the Jammu and Kashmir region into sub-tropical monomictic to dimictic categories. The limnology of Dal Lake in Kashmir was studied in [18]. Their findings showed that the lake's biological equilibrium is upset by erratic changes in physiochemical parameters caused by the lake's shallowness and surrounding disturbances. In order to comprehend hydrochemistry and pollution levels, a number of researchers have studied lakes in the Kashmir Himalayas, connecting reported enrichments to effluent flow from home sewage and agricultural runoff. Together, these studies highlight a thorough investigation of Himalayan lakes, including their physical properties and the complex interactions between environmental perturbations and ecological balance. By highlighting the critical need for sustainable management techniques to maintain the biological integrity of these essential water bodies, these studies greatly advance our knowledge of the distinctive ecosystems found in the Kashmir Himalayas.

Araoye et al, [19] studied pH and dissolved oxygen (DO2) variations in Asa Lake, Ilorin, Nigeria. Findings show low pH from October to December and high from January to July, with DO2 concentration low in October/November and high in March/April. Stratification occurred from March to September, destratification in November/December, and a sharp DO2 drop at the thermocline zone. pH and DO2 concentrations were positively correlated.

In order to calculate the variance in soil organic carbon (SOC) in the Medinipur block of West Bengal, India, Bhunia et al. [20] evaluated interpolation strategies in GIS. Five different methods were used to construct maps from samples taken from 98 different sites. With the lowest root mean square error and the highest coefficient of determination for SOC mapping, ordinary Kriging emerged as the winner.

In their 2017 study, Bhat et al. [21] looked at Dal Lake's current and potential nutrient levels, finding that NO3-N concentration was greatest. Dal Lake's physio-chemical features were examined and it was found that there is increased eutrophication linked to the watershed's farming practices.

Chashoo et al. [22] used principal component analysis and correlation analysis to look at the effects of sewage treatment facility effluent on the water quality of an urban Dal Lake. High concentrations of nitrate-nitrogen, ortho-phosphate, and electrical conductivity indicated the presence of a broken Fluidized Aerobic Bed reactor-based sewage treatment plant at the lake's entrance.

Rather and Dar [23] collected 456 samples from 38 places and examined the physio-chemical parameters of the water in Dal Lake before and during the monsoon seasons from 2016 to 2019. Comparative data showed that between 1997 and 2017, there was a 2.3-fold increase in total phosphorus (TP), a 2.0-fold increase in nitrate nitrogen (NO3-N), and a 1.75-fold increase in COD. Reduced dissolved oxygen suggested human influences and reflected the growing urbanization of the area.

III METHODOLOGY

The methodology adopted to achieve the different objectives of the study is given in Fig. 1. The description of the methodology is given below as

Step I: Delineation of study areas using GIS techniques

ARC GIS software was used to perform georeferencing on the National Watershed Atlas of India map in order to determine the study area's latitude and longitude. Rectification required superimposing hill shade data from the Digital Elevation Model (DEM) or pictures from Linear Imaging Self Scanning Sensors (LISS). Using hilltop drainage patterns, a precise boundary was drawn and shown in Fig. 2

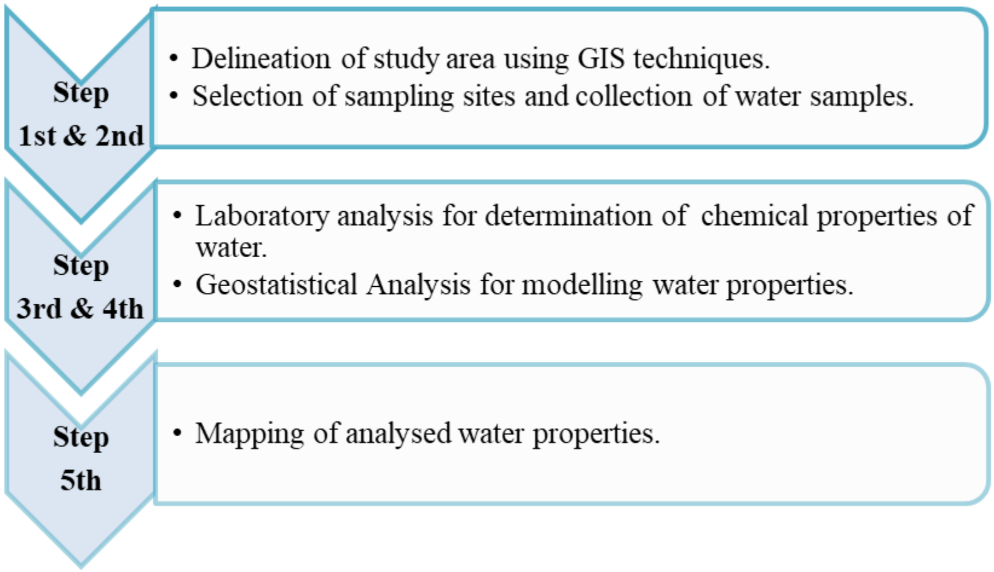

Fig. 1: Methodology adopted for mapping chemical properties of water.

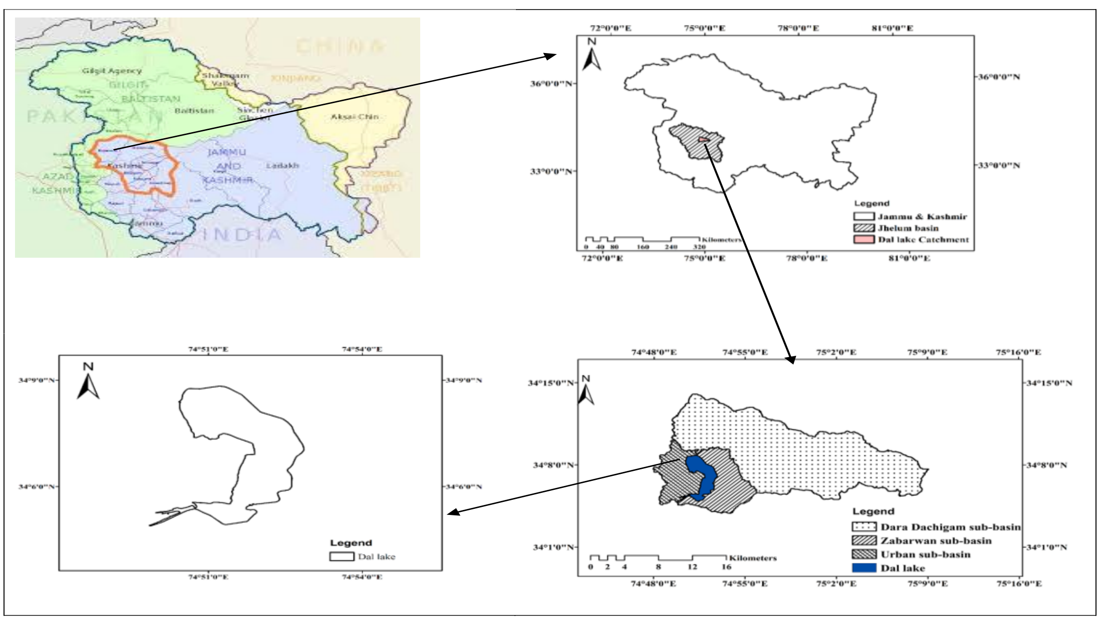

Fig 2: Delineation of Study area boundary of interest.

Step II: Selection of sampling sites and collection of water samples

The sites for collection of water samples to determine various properties were selected using random sampling. The co-ordinates of sampling sites were taken with the help of Geographical Positioning System (GPS). The co-ordinates of sampling sites are summarized in Table 1.

Table 1: Co-Ordinates of Sampling sites

Sampling Site	Latitude	Longitude
1.	34.145	74.847
2.	34.128	74.844
3.	34.132	74.852
4.	34.119	74.877
5.	34.103	74.867
6.	34.092	74.857
7.	34.126	74.859
8.	34.132	74.862
9.	34.117	74.866
10.	34.132	74.843
11.	34.145	74.843
12.	34.106	74.875
13.	34.084	74.835
14.	34.11	74.867
15.	34.1	74.874

16.	34.084	74.857
17.	34.091	74.847
18.	34.089	74.84
19.	34.142	74.854
20.	34.127	74.875
21.	34.113	74.863
22.	34.117	74.881
23.	34.147	74.854
24.	34.082	74.856

For the analysis of chemical parameters, water samples were collected and labeled in well drained HDPE (high density polyethylene) plastic containers. Plastic containers were chosen in order to reduce sample contamination that could change the components of the water. A total of 300 water samples were collected from Dal Lake, during 2022, out of which 150 samples were collected during the months of summer (March-August), and 150 samples were collected during winter months (September-February).

Step III: Laboratory analysis for determination of chemical properties of water

For precision, the Hydrogen Electrode technique was used to test pH. To construct a hydrogen electrode dipped in the test solution, platinum black was added. Equation Nernst connected pH and EMF. By using oxygen-sensitive dyes that are stimulated by light, the fluorescence method was used to detect the amount of dissolved oxygen. Gravimetric analysis of the chloride content was performed by precipitating the chloride ions as silver chloride. Using an EDTA titration, the contents of calcium and magnesium were measured. Titrating with standardized sulfuric acid was used to quantify total alkalinity until the indicator's color changed. Precise analysis of water quality parameters is ensured by these approaches.

Step IV: Geostatistical Analysis for modelling water properties

Semi-variograms are used in geostatistics to analyze spatial variability, which shows the relationship between variables at various distances. The nugget, sill, and range parameters are displayed by the semi-variogram, which graphs variance against lag distance. The range represents the breadth of spatial continuity, whereas the nugget represents measurement error and local variation. To quantify spatial distribution, models such as spherical, Gaussian, exponential, or linear plateau match the semi-variogram data. By applying weighted averaging, Kriging makes precise predictions by interpolating values between regions of interest using the fitted semi-variogram. This technique helps in resource management and environmental studies, among other subjects, to map and comprehend spatial patterns.

Step V: Mapping of analyzed water properties

This work maps spatial variability using Ordinary Kriging and semi variogram analysis in ArcGIS10.4. Semi variograms are used to guide Ordinary Kriging interpolation and quantify variability. Based on Mean Square Error, Average Standard Error, Root-Mean-Square Error, and Standardized Root-Mean-Square Error, automatic cross-validation finds the best-fitting model. Three common models' equations are used: Gaussian, exponential, and spherical. Spatial dependence is characterized by parameters including range, sill, and nugget. Dependency strength is categorized by the degree of spatial dependence (DSD). For precise spatial soil property prediction, ordinary kriging is preferred since it reduces the impact of outliers.

IV RESULTS AND DISCUSSION

Overview of the basic statistical values of the data-set for the water properties in the study area during summer and winter season is given in Table 2 and 3 respectively. The mean value of pH during summer (6.73) and winter (8.03) season revealed that temperature has significant effect on pH. The coefficient of variation (CV) was applied to elucidate the total variation or heterogeneity of the given properties. Nielsen and Bouma's (1985) criterion was used to classify parameters into low (CV < 0.1), moderate (CV 0.1–1), and high (CV > 1) variable classes. From the values of CV (Table 1& 2), it was inferred that all the measured water properties having CV >1 exhibit high spatial variability. The high spatial variability in the chemical properties of water can be attributed to a variety of reasons, as water is influenced by a range of natural and anthropogenic factors. The high variability is also the consequence of anthropogenic activities. Human activities such as waste discharges from households, agriculture, and urban development have introduced various pollutants and chemicals into the lake area, leading to localized variations in water quality. Furthermore, majority of area near the lake is urban area with high population density which have resulted higher concentrations of pollutants affecting water quality. From Table 1 & 2, it is clearly observed that the chemical properties of water have been affected by seasonal changes. During the summer the snowmelt from rivers may carry higher sediment loads and be more turbid, while in winter, water levels and flow rates may decrease, potentially concentrating pollutants.

Table 1: Descriptive statistical analysis of water properties during summer season.

Properties	Min	Max	Mean	Median	SD	CV	Skewness	Kurtosis	DT
pH	6.2	7.4	6.73	6.60	0.39	5.79	0.63	-1.08	N
DO	1.4	5.1	3.92	4.23	0.95	24.18	-1.08	0.63	N
Calcium	44.7	110.7	56.45	52.70	13.17	23.32	3.27	13.01	N[a]
Chloride	32	53.2	41.58	41.10	5.49	13.20	0.36	-0.25	N
Magnesium	3.8	7.5	6.32	6.63	0.95	15.01	-1.08	0.63	N
Total Alkalinity	200.9	234.5	215.83	212.10	10.91	5.06	0.62	-1.07	N

Table 2: Descriptive statistical analysis of water properties during winter season.

Properties	Min	Max	Mean	Median	SD	CV	Skewness	Kurtosis	DT
pH	7.5	8.7	8.03	7.90	0.39	4.85	0.63	-1.08	N
DO	3.8	7.5	6.32	6.63	0.95	15.01	-1.08	0.63	N
Calcium	32	98	43.75	40.00	13.17	30.09	3.27	13.01	N[a]
Chloride	23	44.2	32.58	32.10	5.49	16.84	0.36	-0.25	N
Magnesium	2.5	6.2	5.02	5.33	0.95	18.89	-1.08	0.63	N
Total Alkalinity	227.9	261.5	242.83	239.10	10.91	4.49	0.63	-1.08	N

The skewness coefficient was used to infer the distribution's normality. Normal distribution (skewness coefficient 1) was observed for pH, DO, chloride, magnesium, and total alkalinity; hence no transformation was necessary. Since calcium content data did not follow a normal distribution (skewness coefficient > 1), a logarithmic treatment was performed to reduce the skewness (Tables 1& 2). To achieve normalcy and meet the prerequisite for geostatistical analysis, the logarithmic transformation was chosen as the best method [45]. While there is no evidence of outliers in the investigated soil parameters, there is a slight variation between mean and median values (Tables 1 and 2).

Geostatistical Analysis

The geostatistical analysis of the work is given below as.The spatial dependence of the measured water properties was determined by calculating experimental semi variogram. The semi variogram parameters for the chemical properties of water in the study area are given in Table 3

Table 3: Summary of best-fitted semi variogram models of water chemical properties.

Property	Model	Range (a)	Nugget (C_o)	Partial sill (C)	Sill ($C_o + C$)	DSD	SD	MSE	ASE	RMSE	RMSSE
pH	Spherical	2896	51	54	105	0.48	M	-0.012	8.5	7.8	0.93
DO	Gaussian	3466	11	10	22	0.53	M	0.002	3.7	3.4	0.92
Calcium	Exponential	3599	0.01	0.01	0.02	0.43	M	0.020	5.1	5.04	0.97
Chloride	Spherical	3264	0.01	0.01	0.02	0.47	M	-0.012	0.1	0.09	0.95
Magnesium	Spherical	3415	22	30	52	0.43	M	0.012	5.7	5.5	0.97
Total Alkalinity	Exponential	4784	0.004	0.014	0.02	0.22	S	-0.009	0.1	0.09	0.98

DSD- Degree of spatial dependence; SD- Spatial dependence; MSE – Mean square error; ASE – Average standard error; RMSE – Root mean square error; RMSSE – Root mean square standardized error; (S) strong; (M) moderate.

The geostatistical model with the lowest MSE, ASE, RMSE, and RMSSE values was chosen as the best fit for the given parameters. Figure 5 displays the semi variogram in accordance with several geostatistical models. The semi variograms of pH, chloride, and magnesium were best fit by the spherical model (Figs. 5a, 5d, 5e); the semi variograms of calcium content and alkalinity were completely fitted by the Exponential model (Figs. 5c, 5f); and the semi variogram of dissolved oxygen in water best fit by the Gaussian model (Fig. 5b). For each parameter, the spatial variability was assessed using the semi variogram measures; *a*, C_o and ($C_o + C$). The range denotes the distance across which spatial dependency appears, and it can serve as a useful criterion for water property mapping and sampling scheme estimation [24]. Table 4 displays the range of measured water parameters, which include pH at 2896 m and total alkalinity at 4784 m. The wide range of water characteristics could be linked to variability in the properties caused by different pedogenic processes, different rates of erosion under different land cover conditions, eluvial transfer from the area, and soil particle detachment from runoff [25].

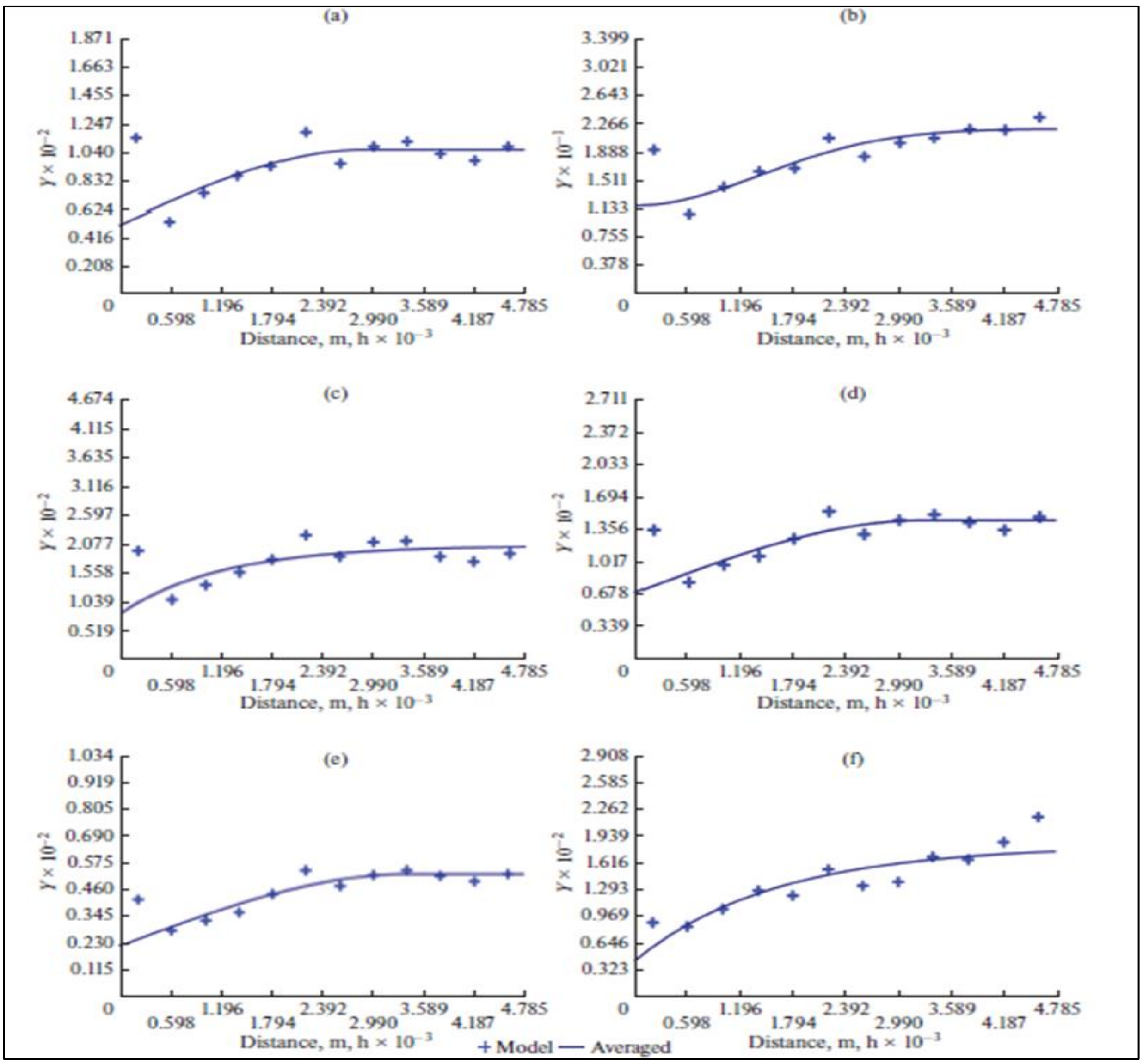

Fig 3: Semi variogram with fitted models of (a) pH (b) DO (c) Calcium (d) Chloride (e) Magnesium (f) Alkalinity

The vertical stratification of water layers, driven by differences in temperature, have led to spatial variations in water properties. Seasonal changes and weather conditions have disrupted or enhanced these stratified layers. Inferences about the potential roles played by different environmental elements in shaping the spatial pattern of soil physical qualities can be drawn from the results presented above. Nugget effect (Co) values varied from 0.004 to 51, as shown in Table 3 The small nugget effect and a value close to zero suggested decreased measurement error and spatial continuity between neighboring places [26]. Consistent with the findings of [27], who noted that the variogram of water properties exhibited little nugget effect, the nugget effect value for calcium, chloride, and alkalinity content is small. The irregular geographic variability distribution likely causes the significant nugget effect for pH (51), magnesium (22), and DO (11), all of which are likely the result of the intense anthropogenic activities taking place in the lake.

V CONCLUSION

In conclusion, research on the geographical variability of water's chemical characteristics has a wide range of applications in the future that could help with environmental issues, enhance water management techniques, and protect ecosystem and human health. Technological developments, data analytics, and interdisciplinary cooperation will probably be important factors in determining how this profession develops.

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