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EVALUATING THE AQUATIC HEALTH: A COMPREHENSIVE STUDY OF PHYSICO-CHEMICAL PROPERTIES OF UJANI RESERVOIR, MAHARASHTRA

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ABSTRACT

The Ujani Reservoir serves as a primary water source for the Pune, Ahilyanagar, and Solapur districts, fulfilling various needs such as agriculture, small-scale industries, electricity generation, drinking water, fishing, and tourism. Over a two-year period, from November 2021 to September 2023, we conducted a bimonthly analysis of the physico-chemical parameters of water, including temperature, pH, total dissolved solids (TDS), alkalinity, calcium hardness, magnesium hardness, total hardness, nitrates, chlorides, phosphates, dissolved oxygen (DO), and biochemical oxygen demand (BOD). This study involved fifteen different sampling sites, including backwater wetland areas along the Bhima River basin and the catchment area of the Ujani Reservoir. The selected sites for this research were Daund (S-1), Ajnuj-Devulgaon (S-2), Pedgaon (S-3), Baradgaon Sudrik (S-4), Khed-Shimpora (S-5), Rajegaon-Bhigwan (S-6), Khanota (S-7), Diksal (S-8), Kondhar Chincholi (S-9), Kumbhargaon (S-10), Dalaj (S-11), Palasdeo (S-12), Parewadi (S-13), Chikhalthan No.1 (S-14), and Shiral (S-15). Our findings revealed that many of the physico-chemical parameters at several sampling sites exceeded the permissible limits set by IS, ICMR, BIS, and WHO, indicating that the water quality is unsuitable for both drinking and irrigation purposes. Seasonal variations in these physico-chemical parameters significantly influence the biological communities in and around the water bodies, as well as the biodiversity of aquatic birds.

INTRODUCTION

Water security is one of the important consequences related to the risk of climate change worldwide (Hamieh *et al.*, 2020). Water is crucial for as far as human sustenance is concerned. An adequate, pure and safe water supply is vitally important for the population (de Silva *et al.*, 2022). Freshwater resources are under major stresses all over the world due to agricultural expansion, damming, diversion of water, over-use and enumerable types of water pollutants released in the in the irreplaceable resources in many parts of the globe. According to an assessment by the United Nations regarding the world's water resources, the availability of water is continuously declining due to excessive withdrawal of both surface and groundwater. The report also highlights a decrease in water runoff resulting from reduced precipitation and increased evaporation. A significant challenge we face is the need to prioritize action-oriented activities and policies aimed at the sustainable management of both the quantity and quality of water resources globally. In addition to the quantity of water, understanding the quality of water and the resources available on Earth is also a crucial aspect that must be addressed. The physico-chemical and biological properties of water determine the quality of water for its suitability for drinking, domestic, fishing, industrial and irrigational purposes. Water quality is influenced by chemical, microbiological, and thermal pollution. Chemical contamination arises from excess nutrients, acidification, salinity, heavy metals, trace elements, persistent organic pollutants, and alterations in sediment loads. Microbiological contaminants, such as bacteria, viruses, and protozoa, pose significant health risks to humans worldwide. Additionally, any disruption in the natural temperature cycles of water can impair its biological functions, affecting the metabolic rates of aquatic organisms and potentially leading to long-term declines in their populations. Among all the natural resources after forests, water is the fastest depleting natural resource now a day. Our survival on the earth depends on water management activities with respect to rivers, lakes and reservoirs. Water availability throughout the world, mostly depends upon geographical conditions. In some extent it also depends upon geological, climatic and demographic factors. As far as the population explosion pressure and increased water pollution is concerned, about 30,000 human deaths are caused daily by poor sanitation practices and contaminated water. The ecological monitoring of these water bodies plays a vital role in sustainable development.

Ujani water reservoir is composite type of dam, also known as 'Yashwant Sagar'. It is located at Ujani village of

Madha Tehsil of Solapur district. The coordinates of the place are 18°4´26´´N, 75°07´12´´E. The gross storage of reservoir is 110 TMC and live storage is 55 TMC. The reservoir is spread over the catchment area of 14856 Km2. The sunken area of the dam is 29,000 hectors, which includes 605 hectors of forest area, 26,750 hectors of private area and 1,645 hectors of government area. The catchment area of the reservoir is mostly urbanized and industrialized having extreme physiographic and agro-climatic variations. The catchment area of the reservoir i.e. of Bhima basin is broadly divided into three zones according to topography viz. Western, Middle and Eastern. The Southern zone is characterized by highly degraded rivers, Mula and Mutha, which carries sewage and industrial waste from Pune and Pimpri-Chinchwad urban areas and finally polluting the Ujani reservoir. The Ujani Reservoir is undergoing lake aging, a process known as eutrophication, which ultimately leads to ecological succession. Ujani reservoir is the important birding site as Ujani wetlands nurtures more than 25 species of winter migrants (Kumbhar and Mhaske, 2021). Now a days these wetlands experiencing large number of threats (Kumbhar and Mhaske, 2023). As far as the work done with respect to hydrobiology of Ujani reservoir under investigation for the present study, only limited investigations have been carried out so far. The current study focuses on fifteen selected sampling sites, including backwater wetland areas in the Bhima River basin and the Ujani Reservoir. This research aims to assess spatial variations in physico-chemical parameters to evaluate water quality in relation to the extent of human disturbance.

MATERIAL AND METHODS:

Study area: Study area is located around Ujani reservoir, Ujani, Tahsil Madha, Dist Solapur, Maharashtra, India. Sampling sites are distributed among three different districts Solapur, Ahilyanagar and Pune were selected for study. Fifteen sampling sites were selected around Ujani reservoir (Fig. 1). The water samples were collected from fifteen sampling sites covering entire reservoir area including backwater wetland sites in Bhima river basin from November 2021 to September 2023. The sampling sites were abbreviated as S1 to S15; S1 (Daund), S2 (Ajnuj-Devulgaon), S3 (Pedgaon), S4 (Baradgaon Sudrik), S5 (Khed-Shimpora), S6 (Rajegaon-Bhigwan), S7 (Khanota), S8 (Diksal), S9 (Kondhar Chincholi), S10 (Kumbhargaon), S11 (Dalaj), S12 (Palasdeo), S13 (Parewadi), S14 (Chikhalthan No.1) and S15 (Shiral).

Sampling Schedule and Procedure: The water samples were collected bimonthly from fifteen sampling sites covering entire reservoir area including backwater wetland sites in Bhima river basin from November 2021 to September 2023. Plastic containers of two liters capacity were used to collect water samples. Surface water samples were collected by gently wading the container in the upper layer of water to prevent bubbling. All samples were collected in the morning between 7:30 AM and 9:30 AM. Each sample was carefully labeled and transported to the laboratory, where it was stored in a refrigerator at approximately 4°C prior to analysis. For the determination of dissolved oxygen (DO) and biochemical oxygen demand (BOD), water samples were collected directly into dark DO bottles, to which a few drops of manganese sulfate solution were added to fix the dissolved oxygen. These samples were then stored at room temperature (Shekhar *et al.*, 2020). Water samples were analyzed within 48 hrs. Methods of analysis are mentioned in table 1. The physico-chemical analysis was performed by using standard literature of APHA (1989, 1998, 2012), Ragothaman and Trivedi (2002) and Koderkar (1992). Data obtained was analyzed statistically through Analysis of variance (ANOVA) and standard deviation (SD).

RESULTS AND DISCUSSION:

Water Temperature: Water temperature is a crucial physical parameter that influences various abiotic characteristics and biotic activities within an aquatic ecosystem (Sharma and Sarang, 2004; Radhika *et al.*, 2004; Singh and Mathur, 2005, Ramchandra and Solanki, 2007). The temperature affects acceptability of inorganic constituents and chemical contaminants (Soran N. Sadeq, 2021). The water temperature ranges between 21.3°C to 30.4°C; minimum temperature was recorded during Nov. 2021 at Chikhalthan No.1 and maximum temperature was recorded during May 2023 at Rajegaon-Bhigwan. The mean temperature at all sampling sites was 23.6 ± 0.57 during winter, 27.9 ± 1.39 during summer and 25.0 ± 0.68 during monsoon season; similar trend in water temperature was also recorded by Raut *et al.*, 2011. ANOVA represents there was no any statistically significant variation in the surface water temperature between the sites ($F = 1.120466$, $df=14$, $p<0.343$; **Table: 2**). The study of seasonal variations in mean temperature at all sampling sites revealed an upward trend in water temperature from winter to summer, followed by a downward trend starting in the monsoon season for both years.

pH: pH represents the hydrogen ion (H^+) concentration of a solution at any given temperature. Measurement of pH in water sample gives quick and easy idea regarding the acid-base equilibrium in an ecological system. The water pH ranges of between 6.3 to 8.9. Concentration of bicarbonate and carbonate ions affected the pH value in natural water (Soran Sadeq, 2021). The minimum pH was recorded during July, 2022 at Ajnuj-Devulgaon and maximum pH was recorded during May, 2022 at Kondhar-Chincholi and Kumbhargaon. The mean pH at all sampling sites was 7.78 ± 0.19 during winter, 8.32 ± 0.15 during summer and 7.37 ± 0.17 during monsoon season. ANOVA represents statistically significant variation in the pH between the sites ($F = 6.957$, $df=14$, $p < 0.05$; **Table: 3**). The recorded findings in relation to pH conformity with the work of Jaybhaye *et al.*, (2008), Bade *et al.*, (2009) and Meenaxi Saxena, (2011). It was observed that, upward trend in water pH was from monsoon to summer.

Alkalinity: Alkalinity detect ability of water to neutralize the acids. It reflects the buffering capacity of water sample. The alkalinity range of Ujani reservoir was 370 mg/lit to 716 mg/ lit. The minimum alkalinity was recorded during September 2022 at Palasdeo and maximum 716 mg/ lit was recorded during May 2023 at Daund. The mean alkalinity at all sampling sites was 518.10 ± 9.76 during winter, 536.60 ± 11.26 during summer and 499.60 ± 6.60 during monsoon season. ANOVA represents there was statistically significant variation in the Alkalinity between the sites ($F = 120.9288$, $df=14$, $p < 0.05$; **Table: 4**). The present results in terms of alkalinity are in broad agreement with Garg *et al.*, (2009), Rathod *et al.*, (2010) and Simpi *et al.*, (2011). It was observed that, the upward trend of alkalinity was from winter to summer and decreased in the same way from summer to monsoon season.

Total Dissolved Solids (TDS): With high dissolved solids, water become inferior for palatability and it may induce unfavourable physiological reactions in the transient consumer. TDS is used to determine the strength of domestic wastewater and efficiency of treatment units (Verma and Saxena, 2010). Total dissolved solids ranges between 378.56 mg/lit to 770.21 mg/lit. The minimum TDS was recorded during September, 2022 at Palasdeo and maximum 770.21 mg/lit was recorded during May 2023 at Daund. The mean TDS at all sampling sites was 569.31 ± 13.97 during winter, 594.70 ± 10.61 during summer and 518.31 ± 18.33 during monsoon season. There was statistically significant variation in the TDS between the sites ($F = 45.537$, $df = 14$, $p < 0.05$; **Table: 5**). The results obtained during both the years of study are in line with the results of Kumbhar *et al.*, (2009), Sharma *et al.*, (2010), Meenaxi Saxena, (2012) and Sawant and Chavan, (2013). The high amount of TDS during summer season might be due to increased rate of evaporation and high concentration of TDS indicates nutrient enrichment that leads to eutrophication (Goher, 2002). Gonzalves and Joshi (1946). Low TDS during monsoon season is result of dilution of water due to raining which decreases amount of TDS.

Dissolved Oxygen (DO): Analysis of dissolved oxygen reflects the health of an aquatic ecosystem and protects aquatic life. DO indicate trophic status and magnitude of eutrophication in fresh water ecosystem. The dissolved oxygen range was 3.2 mg/lit to 7.2 mg/lit during the study period. The minimum DO was recorded during May, 2022 at Rajegaon- Bhigwan, Diksal and Kumbhargaon and Parewadi; While, maximum DO was recorded during September, 2023 at Palasdeo. The mean dissolved oxygen at all sampling sites was 4.79 ± 0.23 during winter, 4.13 ± 0.19 during summer and 5.41 ± 0.21 during monsoon season. There was statistically significant variation in the dissolved oxygen between the sites ($F = 17.166$, df =14, $p < 0.05$; **Table: 6**). The similar observations were also recorded by A.J.Dhembare, (2011) and Hujare *et al.*, (2008). Low oxygen concentration was recorded in summer as DO decreases with increasing temperature and vice-versa.

Biochemical Oxygen Demand (BOD): Measurement of BOD is an important indicator to determine the water quality as it reflects the organic pollution load on freshwater bodies. BOD is the reliable parameter to judge extent of pollution in water bodies. The BOD values range was 3.4 mg/lit to 9.9 mg/lit. The minimum BOD was recorded during September 2022 at Khanota and maximum BOD was recorded during May 2022 at Daund. The mean values of BOD at all sampling sites were 7.00 ± 0.28 during winter, 7.88 ± 0.23 during summer and 6.16 ± 0.535 during monsoon season. ANOVA represents there was statistically significant variation in the biological oxygen demand between the sites ($F = 32.092$, df =14, $p < 0.05$; **Table: 7**). It is clearly represented that, low BOD values during monsoon, high during summer and intermediate during winter season.

Phosphates: The amount of phosphate represents the extent of eutrophication of the aquatic ecosystem. Natural sources of phosphate in water include the leaching of phosphate-bearing rocks, the decomposition of organic matter, detergents, used boiler water, fertilizers, and various biological processes. Excess quantity of phosphates enters in water body through untreated domestic sewage and agricultural runoff (Malathi, 1999). The phosphate value ranges from 1.0 mg/lit to 5.0 mg/lit during the entire study period. The minimum phosphate was recorded during May 2022 at Dalaj and maximum phosphate recorded during November 2021 at Rajegaon-Bhigwan. The mean phosphate level at all sampling sites during the entire study period was observed as 3.05 ± 0.429 during winter, 2.29 ± 0.429 during summer and 3.15 ± 0.320 during monsoon season. ANOVA showed that there was statistically significant variation in the phosphates between the sites ($F = 12.806$, df =14, $p < 0.05$; **Table: 8**). Our results are corroborating with the investigations of Rathod and Pathade, (2010), Raut *et al.*, (2011) and Shaikh and Nikam, (2015). It was clear that, low phosphate values during summer, high during monsoon and intermediate phosphate values during winter season.

Magnesium Hardness: Magnesium is mainly present as Mg^{+2} (aq.) in water. It is also found in combined forms like $MgOH^{+}$ (aq.) and Mg $(OH)_2$ (aq). Most minerals contain magnesium, such as dolomite (calcium-magnesium carbonate, Ca-$Mg(CO_3)_2$) and magnesite (magnesium carbonate, $MgCO_3$). Two years bimonthly variations in magnesium hardness at all sampling sites of Ujani reservoir during entire study period were analyzed and found that, the magnesium values ranges from 61.48 mg/lit to 266.4 mg/lit. The minimum magnesium content was recorded during July 2023 at Dalaj, while maximum magnesium content was recorded during May 2023 at Rajegaon- Bhigwan. The mean magnesium values at all sampling sites during entire study period was observed as 166.31 ± 2.187 during winter, 178.65 ± 4.023 during summer and 159.91 ± 4.485 during monsoon season. ANOVA analysis showed statistically significant variation in the magnesium hardness between the sites ($F = 392.767$, df =14, $p < 0.05$, **Table: 9**). Similar trend of seasonal variations in magnesium was also recorded by Meenaxi Saxena, (2012), Sawant and Chavan, (2013) and Sawant and Chavan, (2015). It was observed that, the upward trend in magnesium was from monsoon to winter followed by summer season. Magnesium is essential for the growth of phytoplankton. Notable increasing trend of Magnesium was observed during summer season due to increased ionic concentration and movement and lower values were recorded during monsoon as the water becomes diluted.

Chlorides: The principal source of chloride in natural water is leaching of chloride containing rocks and soils in which water come in contact. Chlorides in water bodies play metabolically active role in photolysis of water and photophosphorylation. It was record that; the chloride range was between 34.23 mg/lit to 207.58 mg/lit. The minimum chloride content was recorded during November 2022 at Dalaj while maximum chloride content was recorded during May 2023 at Rajegaon- Bhigwan. The mean chloride content at all sampling sites were 111.56 ± 3.114 during winter, 128.38 ± 3.744 during summer and 118.83 ± 3.447 during monsoon season. There was statistically significant difference in the chloride content between the sites ($F = 297.755$, df=14, $p < 0.05$; **Table: 10**). Similar finding were also recorded by Sharma *et al.*, (2010) and Simpi *et al.*, (2011). It was observed that, downward trend in chloride content was from summer to monsoon followed by winter season.

Total Nitrates: The nitrate ion (NO_3-) is the prevalent form of combined nitrogen found in natural waters. Under anaerobic conditions, nitrate can be biochemically reduced to nitrite (NO_2-) through the process of denitrification. High Nitrate content correlated with high density of phytoplankton and high rate of organic decomposition. Two years bimonthly variations in Nitrates at all sampling sites of Ujani reservoir during entire study period ranges between 1.12 mg/lit to 28.45 mg/lit during first year of study. The minimum nitrates were recorded during May 2022 at Dalaj, while maximum nitrates were recorded during November 2022 at Rajegaon- Bhigwan. The mean nitrate content at all sampling sites were 9.56 ± 3.075 during winter, 4.40 ± 1.836 during summer and 13.92 ± 2.156 during monsoon season. ANOVA shows statistically significant difference in the nitrates content between the sites ($F = 5.608$, df =14, $p < 0.05$; **Table: 11**). Similar trend in seasonal fluctuations of nitrate concentration was also recorded by Harney *et al.*, (2013), Shaikh and Nikam, (2015). It was observed that, the downward trend was from monsoon to summer season.

Calcium Hardness: Calcium plays a significant role in plants and animal nutrition as it is an essential component of bones, shell and plant structure. Calcium contributes to the total hardness of water and serves as an essential micronutrient in aquatic habitats, particularly required in large quantities by mollusks and vertebrates. The calcium hardness range was between 161.56 mg/lit to 326.06 mg/lit. The minimum calcium hardness was recorded during September 2023 at Dalaj, while maximum calcium hardness was recorded during May 2023 at Rajegaon-Bhigwan. The mean values of chloride content at all sampling sites were 422.79 ± 8.871 during winter, 449.39 ± 8.026 during summer and 408.86 ± 5.228 during monsoon season. ANOVA showed statistically significant difference in the calcium hardness between the sites ($F = 181.337$, df=14, $p < 0.05$; **Table: 12**). The results obtained are in line with the investigations of Garg *et al.*, (2006), Meenaxi Saxena (2012),Verma *et al.*, (2010) and Sawant and Chavan, (2013). It was observed that, upward trend in calcium hardness was from monsoon to summer and vice versa.

Total Hardness: In freshwater, hardness is mainly due to presence of divalent metallic cations like Calcium, Magnesium and Manganese ions. Two years bimonthly variations in total hardness at all sampling sites during entire study period ranges between 230.69 mg/lit to 595.17 mg/lit. The minimum total hardness was recorded during July 2023 at Dalaj and maximum total hardness was recorded during May 2023 at Rajegaon-Bhigwan. The mean total hardness at all sampling sites were 422.79 ± 8.871 during winter, 449.39 ± 8.026 during summer and 408.86 ± 5.268 during monsoon season. There was statistically significant difference in the total hardness between the sites ($F = 254.438$, df =14, $p < 0.05$; **Table: 13**). It was observed that, the upward trend in total hardness was from monsoon to summer season.

CONCLUSION

Two years analysis of physico-chemical properties of water revealed that, pH, Electrical conductivity, Alkalinity, Total Dissolved Solids, Dissolved Oxygen, Biochemical Oxygen Demand, Magnesium, Calcium hardness and Total hardness were beyond permissible limits, So river and reservoir water was not suitable for drinking purpose. Daund (S1), Baradgaon-sudrik (S4), Rajegaon-Bhigwan (S6), Diksal (S8), Kondhar-chincholi (S9) and Kumbhargaon (S10) were most polluted sites under study. ANOVA study showed that, except temperature, all the parameters were with significant seasonal variations among all the sampling sites. The higher values of Temperature, pH, EC, alkalinity, TDS, BOD. Magnesium, Chlorides, Calcium hardness and Total hardness were recorded during summer season and minimum during monsoon and winter season. The concentration of

Phosphates and Nitrates were maximum during winter whereas, maximum DO was recorded during monsoon season.

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Conflict of Interest

No Conflict of Interest.

- Verma, A.K. and D.N. Saksena (2010). Assessment of Water Quality and Pollution Status of Kalpi (Morar) River, Gwalior, Madhya Pradesh: With Special Reference to Conservation and Management Plan. *Asian J. Exp. Biol. Sci.*, Vol 1(2): 419-429.
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FIGURE:

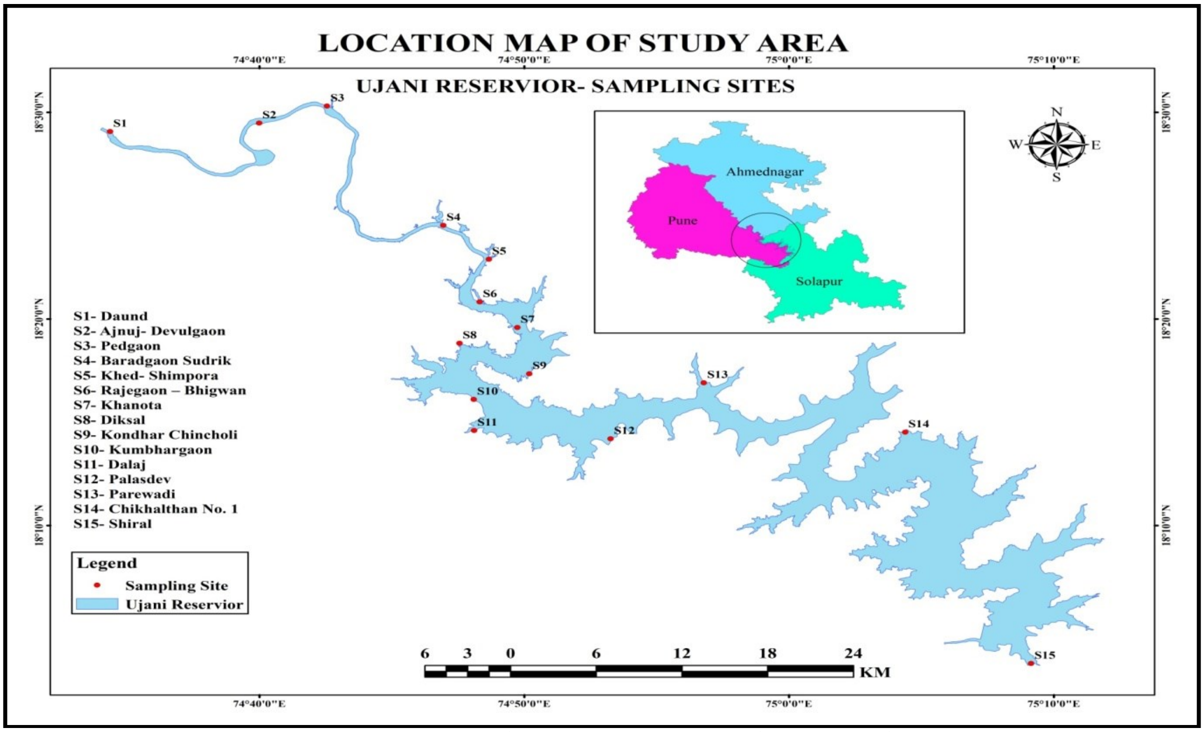

Fig. 1: Location map of study area- Ujani Reservoir showing sampling sites

TABLES:

Table: 1. Methodology used for physico-chemical analysis of water samples.

Sr.No.	Parameters	Methods used for Analysis
01	Temperature (°C)	Mercury Thermometer (on site)
02	pH	Hanna Champ pH Meter (on site)
03	Alkalinity (mg/lit)	Determined by methodology of APHA (1998) and Koderkar (1998) (in Lab)
04	Phosphates (mg/lit)	
05	Magnesium (mg/lit)	
06	Chlorides (mg/lit)	
07	Total Nitrates (mg/lit)	
08	Ca Hardness (mg/lit)	
09	Total Hardness (mg/lit)	
10	Total Dissolved Solids (TDS) (mg/lit)	Gravimetric Analysis (in Lab)
11	Dissolved Oxygen (DO) (mg/lit)	Winkler method :Titration (on site)
12	Biochemical Oxygen Demand (BOD) (mg/lit)	BOD Incubator followed by Tritometry (in Lab)

Table 2: ANOVA table for Temperature variation between sites

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	69.07244	14	4.933746	**1.120466**	0.343458	**1.75214**
Within Groups	726.5442	165	4.403298			
Total	795.6166	179				

Table 3: ANOVA table for pH variations between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Between Groups	19.5814	14	1.39867	**6.95701**	3.97954E-11	**1.75214**
Within Groups	33.1725	165	0.20105			
Total	52.7539	179				

Table 4: ANOVA table for Alkalinity variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	962978.3667	14	68784.17	**120.9288**	5.7E-79	**1.75214**
Within Groups	93851.83333	165	568.799			
Total	1056830.2	179				

Table 5: ANOVA table for Total Dissolved Solids (TDS) variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1168716.805	14	83479.77	**45.53662**	3.04E-49	**1.75214**
Within Groups	302485.3752	165	1833.245			
Total	1471202.18	179				

Table 6: ANOVA table for Dissolved Oxygen (DO) variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	87.20244444	14	6.228746	**17.16625**	1.61E-25	**1.75214**
Within Groups	59.87	165	0.362848			
Total	147.0724444	179				

Table 7: ANOVA table for Biological Oxygen Demand (BOD) variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	360.7543978	14	25.76817	**32.09234**	7.03E-40	**1.75214**
Within Groups	132.4848333	165	0.802938			
Total	493.2392311	179				

Table 8: ANOVA table for Phosphates variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	63.0347	14	4.50248	**12.8064**	5.30281E-20	**1.75214**
Within Groups	58.0108	165	0.35158			
Total	121.046	179				

Table 9: ANOVA table for Magnesium variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	564272	14	40305.1	**392.767**	9.649E-119	**1.75214**
Within Groups	16932.1	165	102.619			
Total	581204	179				

Table 10: ANOVA table for Chloride variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	284497	14	20321.2	**297.755**	3.5633E-109	**1.75214**
Within Groups	11260.9	165	68.2481			
Total	295758	179				

Table 11: ANOVA table for total Nitrate variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1982.32	14	141.595	**5.60805**	8.37305E-09	**1.75214**
Within Groups	4165.99	165	25.2484			
Total	6148.31	179				

Table 12: ANOVA table for Calcium Hardness variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	276153.029	14	19725.2	**181.337**	2.46963E-92	**1.75214**
Within Groups	17948.0949	165	108.776			
Total	294101.124	179				

Table 13: ANOVA table for Total Hardness variation between sites

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1463738.53	14	104553	**254.438**	8.6421E-104	**1.75214**
Within Groups	67801.2299	165	410.917			
Total	1531539.76	179				