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MULTIVARIATE APPROACHES TO CLUB LARGE WATER QUALITY DATA FROM AQUATIC TOXICITY STUDIES: A REVIEW STUDY

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Review Article

ABSTRACT

Water is the most valuable, widespread resource, major constituent of all living creatures and extremely essential for the sustenance & existence of life. This is exemplified by its multiple uses such as drinking, cooking, washing, irrigation, farming, industrial activities and many more. Quality of surface waters are getting deteriorated as water resources are polluted due to the discharge of industrial effluents, agricultural run-off having insecticides, pesticides, heavy metals, fertilizers, chemicals, sewage and other domestic wastes. This review strongly recommends the incorporation of regular monitoring programmes for reliable estimation of water quality, effective pollution control and water resource management. The practice of conducting physicochemical studies is even essential/mandatory before conducting any toxicity study using fishes or any other sentinel organism both for in-vivo and in-vitro studies. Frequent sampling at many sites with a lot of water quality parameters generates a large & complex data matrix that needs data interpretation. The use of different multivariate approaches provide a rapid solution by identifications of factors that are mainly influencing water quality, clustering many parameters to identify the parameters mainly responsible for spatial and temporal variations linked to seasonality. In this way, reliable management of water resources as well as rapid solutions to pollution problems and effective environmental impact assessment can be approached.

Keywords: Physicochemical analysis; cluster analysis; principal component analysis; multivariate statistical methods; water quality; aquatic toxicity.

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1. INTRODUCTION

Water is a gift of nature, main driving force for life without which one could not imagine life on this beautiful planet earth. This is one of the reasons behind the establishment of ancient civilizations around water. "The pollution of surface and ground water due to the by-products of ever increasing industrial, agricultural and other human activities often places severe physiological stress on structure and function of aquatic ecosystems" [1]. "These contaminations involve a multitude of xenobiotics including heavy metals, herbicides and pesticides, can cause damage to aquatic habitats and are rarely limited to only one single toxicant" [2,3]. "All these activities degrade and impair its use for drinking, industrial, agricultural, recreation or other purposes" [4].

Worldwide, many countries are facing problems of poor water quality responsible for many health problems. Hence, very essential to understand and enforce water quality standards set by respective agencies by proper treatment of water/wastewater prior to discharge in water bodies.

"Therefore, regular monitoring programmes are required for reliable estimates of water quality, effective pollution control and water resource management" [5,6]. According to Chapman [5], "the conducted programmes that include frequent water samplings at many sites and determination of a large number of physicochemical parameters results in a large data matrix that needs a complex data interpretation".

Simeonov et al. [7] suggested "the application of environmetric (chemometric) methods of environmental data classification and modeling as a best approach to avoid misinterpretation of large set of environmental monitoring data. These methods also give better information about surface water quality, design of sampling & analytical protocols and an effective pollution control management of surface waters" [8]. "Studies further described the usefulness of chemometric methods as powerful tools to extract information from huge multivariate data arrays, finding relationships between groups of samples and/or variables and identifying the main pollution sources affecting the sampling points" [9]. Maximum information can be deduced from the calculated physicochemical parameters by performing multivariate statistical methods. This includes, principal component analysis, Pearson's correlation, factor analysis, and cluster analysis where a large number of calculated parameters can be grouped to assess the seasonal variations or relationship between different studied parameters [10]. The derived information about parameters that are responsible for greater change in water quality can be used in various toxicity studies. The toxicity studies aimed to show the effect of various pollutants such as heavy metals, pesticides, insecticides and many other toxicants using fishes, mollusks, and daphnia as specimen organisms. Each toxicity study must be supported by physicochemical analysis so as to establish that the toxicity is due to toxicant and not due to water in which experiments are performed. There are a number of physicochemical parameters and performing these entire prior to any experiment will lead to great effort and money. Hence going through this review work will clearly provide a knowledge regarding the important parameter that can be performed prior to any toxicity study. This will save a lot of effort and cost and results can be easily interpreted in the light of done physicochemical parameters.

2. PHYSICOCHEMICAL PARAMETERS

The indiscriminate dumping of untreated wastes (sewage, industrial wastes, heavy metals, various acids, alkalis, dyes and other chemicals) into aquatic environments brings about physical, chemical and biological deterioration of such water bodies, when these discharges are beyond their self-purifying capacity [11-15] and are detrimental to aquatic and human health [16-18]. The research conducted by various workers pointed towards the usefulness of multivariate statistical techniques for analysis and interpretation of water quality [19-22].

A review of literature on physicochemical parameters of various effluents and surface water quality assessment by various workers is presented here. For manuscript, more than 200 papers were scanned and data from more than 65 papers is presented from 1996-2022. Physicochemical parameters that ranged from 08 to 35 tests are presented along with clubbing of different parameters. Standard methods of sample collection, transportation and analysis were used by different workers [23,24]. Data interpretation and statistical analysis was performed using different statistical softwares such multivariate statistical methods like principal component analysis (PCA), Pearson correlation coefficient, cluster analysis (CA), t-test, etc.

Benka-Coker and Ojior [25] detected a sharp decrease in dissolved oxygen (DO) content from 7.2 to 2.4 mg/l while Biological oxygen demand (BOD), nitrates (NO_3^-) and phosphate (P) levels increased appreciably on mixing the slaughterhouse wastewater to the receiving river waters in Nigeria. Multivariate statistical techniques, such as cluster analysis (CA), factor analysis (FA) and principal component analysis (PCA) were applied to the data sets (34 parameters) on water quality of the Gomti River (India) by Singh et al. [6]. Three significant groups, upper catchments (UC), middle catchments (MC) and lower catchments (LC) of sampling sites were obtained through CA on the basis of similarity between them. FA/PCA applied to the data sets pertaining to three catchment regions of the river resulted in seven, seven and six latent factors explaining 74.3, 73.6 and 81.4% of the total variance of the respective data sets. These included the trace metals group (leaching from soil and industrial waste disposal sites), organic pollution group (municipal and industrial effluents), nutrients group (agricultural runoff), alkalinity, hardness, EC and solids (soil leaching and runoff process). The water quality of Sanganur canal (Tamil Nadu), the major open drainage system which has intricate linkage with storm water supply, domestic sewage and industrial effluent disposal was reviewed by Kumari et al. [26]. The study revealed that physicochemical parameters like pH (6.84-11.47), electrical conductivity (EC) (1.39-3.84 mmhos/cm), total dissolved solids (TDS) (2100-12000 mg/l), DO (3.57-7.81mg/l), BOD (127.33-384.67 mg/l) and chemical oxygen demand (COD) (266.67-1800 mg/l) exceeded the permissible limits, clearly indicating the need of proper treatment of waste water before discharge into the Noyyal River. As per Asia and Akporhonor [27], physicochemical analysis of wastewater collected from rubber processing factory showed that values of turbidity (TD), total solids (TS), total suspended solids (TSS) and total dissolved solids (TDS) were 702 FTU, 1528.5, 1078.5 and 450 mg/l respectively. These values were high when compared to effluent discharge standards. The DO content was 4.72 mg/l, BOD and COD were 2610.18 and 3142 mg/l respectively. The values for ammonium (NH_4^+), NO_3 and P were 1.49, 1.36, 1.32 mg/l respectively. The results showed high pollution potentials of the wastewater and need to be treated before discharged to the environment. Ranganathan et al. [28] recorded physicochemical parameters of wastewater of paper manufacturing and textile dyeing industries in India and found the increased values (mg/l) for TSS (236-580), TDS (1114-1574), COD (819-1522), BOD (250-600) and total hardness (TH) (164-700). Akan [29] studied physicochemical determination of pollutants in wastewater along the Jakara, Nigeria. Levels of pH (8.94-10.34), EC (1021.17-1534.21µS/cm), Temperature (Temp) (31.11±0.11-36.34±2.94ºC), NO_3^- (211.43±0.34 284.33±1.74 mg/l), Sulfates (SO_4^{2-}) (154.33±1.02-252.21±1.32 mg/l), P (103.23±0.11-164.22±0.56 mg/l), TSS (1131.23±14.32-2673.22±17.32 mg/l), TDS (2210.21±22.32-2655.43±16.33 mg/l), BOD (223.43±4.23- 341.11±4.34 mg/l) and COD (512.45±7.21-698.11±6.45 mg/l) were higher than the maximum permissible limits set by Federal Environmental Protection Agencies (FEPA), Nigeria.

Kumar and Reddy [30] assessed the seasonal effects of municipal sewage pollution on the water quality of Buckingham canal at Kalpakkam, India. They concluded that NO_3, PO_4, BOD, COD and DO showed significant spatio-temporal variation in the water quality. The concentrations were higher in the downstream mainly due to the discharge of anthropological inputs and untreated effluent. They suggested that the untreated sewage need to be properly treated prior to its release. Zhang et al. [19] evaluated temporal and spatial variations in river water quality of Daliao River Basin. Hierarchical CA grouped 12 months into three periods and 18 sampling sites into three groups based on their similarity of water quality characteristics. The FA/PCA applied to datasets of two special clusters calculated four factors for each region, capturing 72.5% and 62.5% of the total variance, respectively. Strong loadings included DO (0.886), BOD (0.830), total nitrogen (TN) (0.919), COD (0.820) NH_4^+ (0.874), TP (0.944), and EC (0.824). The PCA helped in identifying five latent pollution sources for the groups, i.e., oxygen consuming organic pollution, toxic organic pollution, heavy metal pollution, fecal pollution and oil pollution.

Multivariate statistical techniques were applied by Palma et al. [31] to evaluate spatial/temporal variations, and to interpret water quality data set obtained at Alqueva reservoir (south of Portugal). The PCA/FA identified six varifactors, which were responsible for 64% of total variance in water quality data set. The principal parameters, which explained the variability of quality water, were TP (0.849**), oxidability (0.816**), Fe (0.769**), parameters that at high concentrations indicate pollution from anthropogenic sources and herbicides indicative of an intensive agricultural activity. The spatial analysis showed that the water quality was worse in the north of the reservoir.

Razmkhah et al. [32] investigated “the water quality of Jajrood River (Iran) so as to assess and discriminate the relative magnitude of anthropogenic and natural influences on the quality of river water”. The calculated values for various parameters were temp (21.0±2.4-21.9±2.6 ºC), EC (301±29-483±87 mmho/cm), pH (8.3±0.1-8.4 ±0.1), TDS (189±26-283±53 mg/l), NH_4 (0.07±0.01-0.25±0.5 mg/l), NO_3^- (0.10±0.07-0.25±0.5 mg/l) and NO_2^- (0.03±0.01-0.06±0.03 mg/l) and total carbon (TC) (6598±744-111463±148 mg/l). PCA identified a reduced number of mean 5 varifactors that pointed to 85% of both temporal and spatial changes. CA classified similar water quality stations and indicated Out-Meygoon as the most polluted one.

Fadeyibi et al. [33] analyzed physicochemical properties of abattoir wastewater samples. The range of values for Temp (27.2-30.0^oC) pH (6.4-9.7), EC (520-600 µS/cm), TD (28.1-30.2 NTU), Cl^- (31-50 mg/l), K^+ (3.2-5.2 mg/l), Na^+ (16-32 mg/l), Mg^{2+} (5.4-9.2 mg/l), Fe^{2+} (2.5-3.8 mg/l), Cu (0.01-0.02 mg/l), Zn (0.05-014 mg/l), Mn (0.05-1.12 mg/l), BOD (133-260 mg/l), COD (400-750 mg/l), DO (2.5-7.2 mg/l) and TDS (270-300 mg/l) were established and their mean values found to be within the WHO recommendations for discharge of wastewaters into rivers or streams. Ibeh and Omoruyi [34] studied physico-chemical properties of hospital wastewater. The results showed that the values of BOD (43.77-235.64 mg/l), COD (572.46-792.70 mg/l), NO_3^- (1.0-1.77 µg/l), K (3.34-10.63 µg/l), Zn (0.02-0.08 µg/l), Pb (0.2-0.5 µg/l) and SO_4^{2-} (10.68-19.10 µg/l) were higher than the WHO acceptable limits. Kolhe and Pawar [35] analyzed untreated diary effluents and reported values were Temp (28ºC), pH (8.8), DO (3.5 mg/l), BOD (760 mg/l), COD (1230 mg/l) TDS (1000 mg/l), TS (1310 mg/l), TSS (310 mg/l), Cl^- (630 mg/l), SO_4^{2-} (395 mg/l) and oil and grease (OG) (80 mg/l) for various studied parameters.

Kushwah et al. [36] reported wastewater quality studies (influent and effluent water) at municipal wastewater treatment plant, Bhopal (India). The present study revealed values within the acceptable standards for pH (7.49-8.58), DO (2.4-5.2 mg/l) but BOD (30.2-102.6 mg/l) and TD (18.5-35.2 mg/l) depicted maximum values when compared with the BIS standard. [14] reported that effluent samples collected from textile industries showed extremely high values for TDS (12023.6 mg/l), TS (13499.2 mg/l) and chloride (Cl^-) (238.4 mg/l) than the acceptable limits. The BOD values of effluent samples collected from pharmaceutical, dyes, engineering and paint industries were 1047.3, 776.2, 604.8 and 535.8 mg/l respectively. The physicochemical characterization of the textile industry effluent collected from Coimbatore, Tamil Nadu was carried out by Prasad and Rao [37]. The results showed high rates of temp (40°C), pH (7.51), EC (9565 µmhos/cm), BOD (275 mg/l), COD (789 mg/l), TSS (1750 mg/l) and TDS (587 5mg/l).

The studied parameters of pollutants in wastewater showed concentrations of TSS (240-733 mg/l), COD (795-1420 mg/ml), BOD (270-610 mg/l) in entrance points and TSS (13-76 mg/l), COD (59-141 mg/l), BOD (15-87 mg/l) in exit points in different regions of Tunisia as given by Salem et al. [38]. The physico-chemical parameters of municipal wastewater disposed of in the rivers and outlet of ponds of entire Indore city were studied by Sharma and Dubey [39]. The results indicated values for parameters like pH (7.37-8.39), TD (54.3-64.5 mg/l), TDS (728.87-786.15 mg/l), TSS (230.25-283.1 mg/l), TH (277.3-354.0 mg/l), BOD (136.15-158.27 mg/l) and COD (301.05-324 mg/l). Although, the municipal wastewater contain heavy metals in the range (mg/l), Fe (0.41-0.64), Pb (0.06-0.08), Zn (0.06-0.08), Cr (0.03-0.04) and Cu (0.02-0.04) but appropriate dilution can make them worth for use in agricultural fields to minimize its hazardous effects. The physicochemical results of wastewater collected from Amanishah Nallah (Jaipur) indicated several point sources of water pollution that are posing negative effects on aquatic lives and human health. The recorded values included pH (7.31-9.33), TS (955.8-2000.9 mg/l), Ca (34.88-103.24 mg/l), Mg (466.23-1044.34 mg/l), TH (513.0-1133.0 mg/l), Cl^- (221.7-539.52 mg/l) BOD (18.83-39.42 mg/l) respectively. The study recommended that wastewater from the textile industry should be treated before being discharged into the water body as concluded by Yadav et al. [18].

The water quality of three lakes was assessed through multivariate statistical analysis of data sets as confirmed by Najar and Khan [40]. Hierarchical CA grouped 10 sampling sites into three clusters of less polluted, moderately polluted and highly polluted sites, based on similarity of water quality characteristics. FA/PCA applied to data sets resulted in three principal components accounting for a cumulative variance of 69.84, 65.05 and 71.76% for Anchar Lake, Khushalsar Lake and Dal Lake respectively. FA obtained from PCs indicated that factors responsible for accelerated eutrophication of the three lakes are domestic waste waters, agricultural runoff and to some extent catchment geology.

Zhao et al. [21] focused on “the evaluation and interpretation of complex water quality data (21 physicochemical parameters and 13 sites) and the sources of pollution in Baiyangdian Lake (China). PCA was used to identify a reduced number of five principle components, demonstrating up to 92% of both temporal and spatial changes. CA classified similar water quality stations into 5 clusters based on the PCA scores. The results showed that cluster 5 (site 2) was characterized as the most heavily polluted site”.

The effluent taken from a textile mill of Sonepat (Haryana) was characterized for its physico-chemical properties and heavy metal content by Chhikara et al. [41]. The results revealed that pH, BOD (210±57.66

mg/l), COD (591.33±171.35 mg/l), TSS (1263.33±441.06 mg/l), were higher than the prescribed permissible limits, indicating the toxic nature of the effluent. The Cl^- content, TDS and TSS showed a significant positive correlation with COD and BOD. A significant positive correlation was found to exist between Cd and Cr, Cu and Pb while a significant negative correlation was observed between Ni & Pb and Ni & Cu.

CA and FA were applied to the water quality data of Lake Taoranting (Beijing) by Qu et al. [42]. The CA grouped the eight months (March to November) into three periods and classified five sites into two clusters based on water quality characteristics. The FA applied to datasets calculated three factors for each region, capturing 72.89% and 78.88% of the total variance, respectively. Factors obtained from FA indicated that parameters such as Chl-a, TSS, TP and NH_4^+-N were key factors responsible for water quality. . Shivsharan et al. [43] tested and found high levels of pH (9.8), BOD (650 mg/l), COD (1448 mg/l), TDS (1222 mg/l), and TSS (290 mg/l) in dairy industry effluent, Maharashtra. The study concluded that proper waste water treatment systems should be installed for the protection of the environmental health and for the ecological balance.

Multivariate statistical approaches were used to evaluate temporal/spatial variations in water quality and identify latent sources of water pollution in the Songhua River Harbin region. Hierarchical CA grouped the six monitored sites into three clusters based on their similarities, corresponding to regions of low pollution (LP), moderate pollution (MP) and high pollution (HP). PCA/FA of the three different groups resulted in five latent factors accounting for 70.08%, 67.54% and 76.99% of the total variance in the water quality datasets of LP, MP and HP, respectively. The parameters responsible for water quality variation are primarily related to heavy metal, oil and petrochemical pollution, oxygen-consuming organic pollution and nutrients in HP areas of the Harbin region as indicated by Wang et al. [22].

Bhat et al. [44] statistically analyzed the deteriorated water quality of the Sukhnag Stream of Wular Lake. PCA identified 2 varifactors from 26 water quality parameters and indicated 96% of temporal and spatial changes affecting the water quality. Bray-Curtis cluster analysis showed a 96% similarity between sites IV and V and 94% between sites II and III. The dendrogram of seasonal similarity showed a maximum similarity of 97% between spring and autumn and 82% between winter and summer clusters. The results suggested that most of the variations in water quality are explained by the natural soluble salts, nonpoint source nutrients and anthropogenic organic pollutants.

Mehta et al. [45] characterized the physico-chemical parameters of distillery effluent. The results of study presented an account of pH (3.7), EC (15.2 ms/cm), COD (80500 mg/l) TS (22382 mg/l), TSS (4332 mg/l), K (6080 mg/l), Ca (1950 mg/l), Cl^- (7120 mg/l), SO_4^{2-} (3250 mg/l), P (472 mg/l), Na (490 mg/l). The study concluded that the discharge of distillery waste water into water bodies leads to problems like eutrophication and other adverse environmental effects.

Kaur and Dua [10] observed values of 34 physicochemical parameters of municipal wastewater of Tung Dhab drain studied for four seasons (winter, spring, summer, rainy) over a period of two years. The average concentration of variables such as TD, TSS, BOD, COD, OG, NO_3-N and heavy metals like Cr, Mn, Ni, Pb, Zn, As were much higher than the recommended discharge limits into inland waters. All these values showed significant temporal variations in different months. The results showed that the DO values varied from 0.19±0.02 to 0.83±0.02 mgL^{-1}, TD values ranged from 126.17±1.59 to 306.22±1.83 mgL^{-1}, TSS values varied from 117.23±1.27 to 422.17±0.49 mgL^{-1}, NO_3-N values ranged from 3.50±0.56 to 15.67±0.46 mgL^{-1}, COD values varied from 181.33±1.45 to 283.00±1.53 mgL^{-1}, BOD values ranged from 135.0±1.15 to 224±1.15 mgL^{-1}, OG values varied from 262.33±1.20 to 343.67±2.73 mgL^{-1} and values of heavy metals like Cr, Mn, Ni, Pb, Zn, As ranged from 0.42±0.33 to 0.77±0.02, 2.08±0.01 to 2.65±0.01, 1.67±0.008 to 3.43±0.01, 1.66±0.01 to 3.73±0.08, 1.70±0.62 to 9.63±0.60 and 0.02±0.005 to 0.20±0.11 mgL^{-1}.

Bakar et al. [46] concluded that parameters such as COD, BOD, colour, TSS, cadmium, and zinc of textile wastewater did not meet the standards and could not be safely discharged. The concentrations of parameters like COD, BOD, colour, TSS, cadmium, and zinc were between the range of 55 – 294 mgL^{-1}, 7.1 – 85 mgL^{-1}, 17 – 140 mgL^{-1}, 69 – 205 mgL^{-1}, 0.001 - 0.047 mgL^{-1}, and 0.488 - 2.220 mgL^{-1} respectively, higher than the standard values.

Rahman et al. [47] assessed “the magnitude of water quality decline in the Turag River of Bangladesh and revealed that 40% of water quality indices were within the permissible limits with the exception of EC, Cl^- concentration, TA, turbidity, DO concentration, BOD_5, and COD in all seasons. TDS, BOD_5, COD, EC, turbidity, DO, and Cl^- were mainly responsible for pollution loading and were caused by the significant amount of industrial discharge and toxicological compounds. The cluster analysis showed the seasonal change in surface water quality, highest values of pollutants were recorded in the winter". Goswami and Kalamdhad [48] concluded that various multivariate factors indicated pollution from runoff sources during the pre-monsoon and monsoon season, which changes to domestic and metal pollution mainly in post monsoon season.

3. DISCUSSION

The increased value of physicochemical parameters directly indicates deteriorated water quality. Singh et al. [6] and Siraj et al. [56] suggested that parameters like BOD and COD are important indicators of contamination with organic wastes. Similar results were reported by Kumar and Reddy [30] and Palharya and Malvia [57]. The higher values of COD depicted increased anthropogenic stress on water quality as previously indicated by Khuhawar et al. [58]. The amplified values of COD are due to the discharge of huge amounts of the untreated urban and industrial wastewater/effluents as explained by Singh et al. [59]. BOD reflects organic pollution due to dissolved and undissolved organic matter. Highest BOD values were correlated with the direct dumping of wastes and

Table 1. Summary of physicochemical studies prepared from recent works

S. No	Site	Parameters studied	Elevated parameters	Fish species	Reference
1	Harike Wetland, Nangal Wetland	Water temperature, DO, total dissolved solids and pH, Total alkalinity, salinity and heavy metals	Fluctuated water quality parameters	Liver profile of *Labeo rohita*	Kaur and Brraich [49]
2	Lake Hawassa, Ethiopia	Metals and metalloids	Metal accumulation in liver than muscle	*Barbus intermedius Oreochromis niloticus*	Melake et al. [1]
3	Halda River, Bangladesh	2 physicochemical properties and 10 traces elements (Cd, Cr, Mn, Fe, Co, Cu, Zn, As, Pb, and Hg)	Higher Trace Elements	-	Rakib et al. [50]
4	Pulp and paper industries	TS, TSS, TDS, COD, BOD, total phenols, total nitrogen, sulphate, phosphate, and color	High pH, COD, BOD, TS, TSS, TDS, total phenols, total nitrogen, sulphate, and phosphorus, along with different heavy metals.	-	Sharma et al. [51]
5	Shilabati River, West Bengal	Eleven parameters pH, COD, BOD, DO, TDS, Total Hardness, Total Alkalinity, Phosphate, Chloride, Nitrate, and Turbidity measured at eighteen different sites.	Water quality is poor and seriously polluted indicating unfit for use	-	Roy et al. [52]
6	Yamuna River	12 Physicochemical parameters (TDS, Chloride, Alkalinity, Temperature, pH, COD, BOD, DO, Total Hardness, Total Coliform, Magnesium and Calcium	Total Coliform (MPN/100 ml), Alkalinity/Visual titration $CaCO_3$, Hardness as $CaCO_3$, Calcium as $CaCO_3$, Magnesium as $CaCO_3$ and Temperature	-	Sharma et al. [53]
7	Ganga River	12 Physicochemical parameters	The value of WQI indicates better water quality at Rishikesh (35.23) than that at Haridwar (47.34)	-	Tyagi et al. [54]
8	Samples containing Lead Nitrate	Analysis of DO, alkalinity and pH of water samples containing different doses	DO and Alkalinity	*Cyprinus carpio*	Paul et al. [55]

discharge of sewage effluents into the streams [30,60]. Das and Acharya [61] attributed the high BOD load with the lower DO to the presence of biodegradable organic matter in the sewage and the utilization of DO by microorganisms and macro fauna. The lowest DO values clearly demonstrate high levels of contamination and pollution as given in various studies by Najar and Khan [40] and Srivastava et al. [62]. Simeonov et al. [8] concluded that nonpoint sources such as agricultural runoff and atmospheric deposition constitutes the nutrient factor and heavy metals are considered as representing ‘‘anthropogenic-toxic’’ pollution from metal activities and industrial effluents. The increased values of NO_3-N indicated accelerated eutrophication that resulted in enhanced phytoplankton activity. NO_3 ions are usually derived from sources like untreated domestic sewage and its effluents, agriculture watershed and storm water containing nitrogenous compounds [22,30]. Palma et al. [31] concluded that increased chloride values were indicators of point source pollution by urban wastewater discharges.

“The higher EC values are attributed to the high degree of activities that are anthropogenic in origin like waste disposal and agricultural runoff” as depicted by Najar and Khan [40] and Bhat et al. [44]. “The occurrence of heavy metals was due to the discharge of industrial effluents from various sources including untreated sewage, municipal waste and agrochemical runoff” [59]. The increased values of As can be interpreted as the toxic pollution from pharmaceutical industries. The increased values of heavy metals like Pb and Zn explained the pollution from point sources such as wastewater from the electroplating and battery manufacturing factories situated along the drain [22]. Joshi et al. [63] concluded that oxygen is dissolved more during high photosynthetic catabolic activity. DO decreases as the total suspended solids increases and retards the photosynthetic activity of biota.

Data interpretation from different studies confirmed that most of the variation in water quality was explained by nutrients, agricultural runoff, domestic wastewater and industrial effluents. Similar results were reported by Yerel and Ankara [12]; Zhang et al. [19]; Zhao et al. [21]; Wang et al. [22]; Panda et al. [64]; Shreshta and Kazama [65] when worked on river and estuarine water systems of Daliao river, Baiyangdian river, Songhua river, Mahanadi River, Fuji river basin respectively.

4. CONCLUSION

The increased values of studied physicochemical parameters directly points towards the deteriorated water quality of concerned water body. Hence such waters become unfit for daily consumption and other household chores. These waters poses a great threat to the inhabiting flora and fauna since decreased oxygen levels results in mortality of inhabiting individuals. Hence the various pollution monitoring agencies worldwide recommends proper disposal of polluted waters and their proper treatment prior to disposal in water bodies. The incorporation of physicochemical parameters in such studies holds a prime importance. A number of parameters are laid to assess water quality of any ecosystem and hence a large data is obtained when done on seasonal basis. So the interpretation of such huge data can be done with different multivariate data analysis programmes. Such data analysis helps us to conclude which parameters are mainly influencing the water quality, and cluster analysis can cluster data on seasonal basis. The paper also concludes that fish toxicity studies must incorporate physicochemical checkup both for in-vivo and in-vitro studies. The prior knowledge of parameters such as temperature, pH, Electrical Conductivity, Total solids, BOD, COD, O_2 , Heavy metals are necessary as any change in these parameters from standard values can lead to fake observations about the test chemical.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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