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Water Quality Assessment using Principal Component Analysis: A Case Study of Historically Important Lake and Ponds of Chennai City, Coromandel Coast of the Bay of Bengal

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A B S T R A C T

This study evaluates the water quality of lake and ponds of Chennai city, located in the Coromandel Coast of the Bay of Bengal India, using Principal Component Analysis (PCA).The surface water samples were subjected to comprehensive physico-chemical analyses involving important physical parameters like pH, Temperature, Dissolved Oxygen, Alkalinity, Hardness, Nitrate, Nitrite, Phosphate and Silicate. Principal component analysis (PCA) has been used to assess the factors which influence the quality of water. The results revealed that water quality variations were mostly affected by dissolved mineral salts along with anthropogenic activities in the areas contiguous to the water bodies. The present study reveals that pH and DO play a central role in affecting the water quality of these systems. Further, an alarming fact that resulted from this study was that none of the systems assessed fell under good category. The water is not potable and is also becoming toxic for the aquatic organisms. The analyses of hydro chemical variables like pH, Temperature, Dissolved Oxygen, Alkalinity, Hardness, Nitrate, Nitrite, Phosphate and Silicate of the systems show that most of the water samples component represent the carbonate system and may play an important process in controlling the ionic richness of the water. These findings of this study will be useful for making decisions regarding water quality management and can also be applied in water modelling for better environmental management and planning perspectives.

***Key words*:** Surface water quality, PCA, Chennai city, Kolavoi lake, Chetpet pond, Madhavaram pond

Lakes are known to be ecological barometers of the health of a city as they regulate the micro-climate of any urban settings [1], thereby influencing the life of the people in their vicinity. They are thus an important part of our urban ecosystem, as they perform several environmental, social and economic functions viz. as a source of drinking water, recharging groundwater, acting as sponges to control flooding, supporting biodiversity and providing livelihoods [2]. Developmental pressures and increasing human population have made these water bodies vulnerable to sewage inflow, solid waste dumping, etc., in turn exerting pressure on the percolation and infiltration processes responsible for the groundwater recharge [3]. In recent decades, population growth, agricultural practices and sewage runoffs from urban areas have increased nutrient inputs many times higher than the level of their natural occurrence, resulting in accelerated eutrophication [4-5]. Many urban and rural lakes have vanished under this pressure, raising worldwide environmental concerns [6-7]. Understanding urbanization and its impact on water quality is important to sustain water bodies as community resources, particularly in the case of developing countries [8-9]. Land-use changes often affect the water quality over a long historical period [10] and future land-use.

Chennai, formerly known as Madras, is the capital of the state of Tamil Nadu and is India's fifth largest city. It is located on the Coromandel Coast of the Bay of Bengal. With an estimated population of 8.9 million in 2014, the 382-year-old city is the 31st largest metropolitan area in the world and is the most prominent cultural, economic and educational Centre of South India. According to the 2011 Indian census, Chennai is the sixth-most populous city in the country and forms the fourth-most populous urban agglomeration. The city of Chennai is coterminous with Chennai district, which together with the adjoining suburbs constitutes the Chennai Metropolitan Area,. According to Mohan and Vishnu [11], Chennai is the 36th-largest urban area in the world by population" UN Demographic Urban Areas" and one of the largest metropolitan economies of India. An established port of trade of British India since the 1600s, Chennai has the fifth-largest urban economy, "Global city GDP (2014) and had the

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third-largest expatriate population in India. The increased load of immigrants in search of employment or better education and other purposes from the other places to Chennai leads to huge population growth in the city. Increase in population has been causing scarcity of water in the cities of India. This issue can be solved to a large extent by proper management of the lakes in the urban areas.

Principal component analysis (PCA) has been used to assess the factors which influence the quality of water. The results revealed that water quality variations are mostly affected by dissolved mineral salts along with anthropogenic activities in the areas contiguous to the lakes. The present study points out that pH, DO and BOD played a central role in affecting the WQI of these lakes. The WQI values range from 74.78 to 178.55, indicating that majority of the lakes fall in "very poor" and "unsuitable" category. It also reveals an alarming fact that none of the water tanks fall under good category. Hence, the water is not fit for drinking, and is also becoming toxic for the aquatic fauna. These findings will be useful for decisions making regarding water quality management and can also be applied in water modelling for better environmental management and planning perspective [12]. Multivariate statistical approaches are the most appropriate and extensively used methods for processing and examining the data obtained over time. Statistical approaches like PCA are used for classifying the sampling sites and identifying the underlying pollution source [13-16]. In water quality assessment it helps to identify the potential water contamination sources [17-22]. It also helps to explain the correlation among large number of variants and also to reduce the number of variables into small number of factors without the loss of essential information [23]. This study will help to understand the water quality situation and determine the main factors which contribute to the water quality degradation in these urban lakes. It will also help the concerned citizens and policy makers in formulating policies and taking necessary action towards proper management and conservation of these lakes [12].

MATERIALS AND METHODS

Brief description of the lakes with their historical significance

The city of Chennai, capital of the state of Tamil Nadu, India, is dotted by several manmade lakes. Climatically, it is in the tropical region receiving cyclic rains. The summer temperature normally rises to about 43°C and falls down to a minimum of 20°C in winter. The topography of the city is almost flat and the ground level is slightly elevated up to 6-7 m above the mean sea level [24]. The sampling surveys covered 3 geographically distinct regions in the urban and suburban zones of Chennai city, the Chetpet pond (Urban zone), Madhavaram (Suburban) and Chenglepet lake (Suburban). These water bodies have been receiving much attention because they are used for multiple purposes including irrigation, fishing, recreation and bathing etc. It may be interesting therefore, to specifically examine the influence of the changes in water quality induced by urbanization process on the planktonic community. Such a study when compared with a control pond/lake which is not influenced by any other factors may be useful to document such impacts clearly. Therefore, it is proposed to examine the three water bodies, from urban and rural habitats periodically to analyze its abiotic components so that quality of water may be assessed and planktonic community monitored. So, a set of 3 fresh water habitats were chosen in the urban and suburban areas of Chennai city.

System	Code no	Latitude	Longitude	Type	Area
Chetpet pond	S_1	13°04′27″N	80.24238°E	Water storage	16.1 acres (6.5 ha) (Angling Pond: 3.10 acres; Boating Pond: 6 acres)
Madhavaram pond	S_2	13°17′55″N	80°10′40″E	Water storage	150 acres (61 ha)
Chenglepet lake	S_3	12° 42′ 28.8″ N	79° 59′ 20.4″ E	Water storage	Total capacity of the lake is 13.50Mm^3. The water spread area is 8.82Km^2. 476 million cubic feet of water

Chetpet pond

Chetpet lake (Chethupattu Aeri) is a lake spread over 16 acres in Chetput, Chennai, India. It is located to the north of Chetpet railway station. It is the only existing lake at the Centre of the city. The lake belongs to the Department of Fisheries of the Tamil Nadu government. Of the total area of the lake, the water body is spread across 9.1 acres and the land area covers 6.9 acres. An anglers club was functioning till the 1940s in the lake, whose members visited the small island in the midst of the waterbody for fishing. As the water quality is not saline, the lake has a few varieties of fishes such as rohu, catla and mrigal. Breeding is monitored to assess the water quality. Until recently, the waters of Chetpet pond supplied groundwater recharge for the surrounding neighbour hoods [25]. In 1934, the lake was taken over by the Department of Fisheries to conduct research. In the following decade, a hydro-biological research station was set up to conduct studies in fisheries. Fishing as a sporting activity began at the lake with the formation of Madras Anglers Club in 1962. In the dry summer months of 2019, about 4,500 cubic metres of silt was dredged. These were used to strengthen the bund Madhavan [26]. In recent years, the lake has been heavily encroached upon, particularly near the Chetpet railway station. There have been many plans to rejuvenate Chetpet lake since the mid-1990s, including developing a boat club, an aquarium, seafood stall and fish court besides a walkway around the water body. The last attempt to save the lake was in 2005, when the state environment department identified it along with 12 other lakes of Greater Chennai area for an eco-restoration project. The CPR Environmental Education Centre conducted a detailed survey, and based on that, the state government appointed the Tamil Nadu Urban Infrastructure Finance Services Limited to prepare a project report [27]. The State government had sanctioned 4 million to clean the overgrown water hyacinth and desilt the lake in 2007–2008 [28].

Madhavaram pond

Madhavaram Lake also known as Manali aeri, or Mathur aeri or Madhavaram aeri, is a 150-acre lake in the Manali-Mathur-Madavaram area of Chennai, India. Due to indiscriminate dumping of garbage and sewage, the lake has shrunk to less than 100 acres. A recent study by Nature Trust, an NGO working on the flora and fauna in the lake, showed that about 55 species of birds have been reported in the wetland. However, about 500 birds were regularly sighted till the mid-1990s. The lake was cleaned by NSS volunteers of JHA Agarcen College in Madhavaram in December 2009 [29]. Its water spread area covers 29.15 acres. It is mainly used for fishing and agricultural purposes. The dominant aquatic macrophytes present are the "water hyacinth".

Chenglepet lake

Kolavai Lake is a lake adjoining the town of Chengalpattu in Tamil Nadu, India [30]. The lake is located about 60 kilometres from Chennai, and is close to Paranurrail way station and Chengalpattu Junction railway station. During times of acute water shortage in summer, this lake serves as an additional source of water for the city of Chennai [31] and Jebaraj). The lake hosts migratory birds such as the whiskered tern, Indian spot-billed ducks, moorhens, coots, and small waders [32]. This lake is situated in the Chenglepet district and known as 'Kolavoi lake. It is 58 Km away from the Chennai city. It is one of the largest lake in the Chenglepet district. People use this lake for agriculture, recreation and fishing purposes. It is a perennial lake irrigating about 2000 ha area, covering 12 nearby villages. The National Highway (NH 47) is running parallel to the western end of the lake. The total capacity of the lake is 13.50M^3. The water spread area is 8.82Km^2. The Kolavoi lake is 3.3 Km long and 1.6Km wide. The lake has a well-developed boat club run by the State Government and is also infested by the aquatic macarophyte vegetation.

Analysis of water quality parameters

Totally nine sites were identified on the three habitats. Water samples were collected twice a month in 1 L polypropylene bottle for physical and chemical analyses and 100 mL filtered water sample for biological analysis. The sampling period covers four seasons which prevail in this part of our country: Winter (January – March), Summer (April –June), South west monsoon (July – September) and North east Monsoon (October – December).

Water samples

Key water quality parameters like pH, Temperature, Dissolved Oxygen, Alkalinity, Hardness, Nitrate, Nitrite, Phosphate and Silicate were estimated by adopting the methods given in APHA [33]. For the estimation of dissolved oxygen, water samples were collected separately in 250 mL DO bottles (Winkler type) and fixed in the field itself. Surface water samples were subjected to various physico-chemical analysis by following standard methods in the field itself.

Data analysis

The water quality data as well as plankton data were entered in the Excel (Microsoft, 2000) worksheets separately. The data screening, verification and calculations were done using built-in functions. The Principal Component Analysis (PCA) was performed using the factor procedure of the SPSS PC+. The extraction procedure being PCA with unrotated factor solution was used for the identification of component loadings on variables. The number of components extracted was restricted to eigen values more than 1. Separate analyses were done for each study area. Relationships between the lake/pond and environmental factors were examined using Principal Component Analysis. PCA is an ordination technique used to reduce the dimensionality of Multivariate data sets and enable graphical representation of the relationships between factors.

RESULTS AND DISCUSSION

Physico-chemical parameters

The analysis of result of physical and chemical parameters of water provides a considerable insight of water quality of the lake and ponds in the city. The obtained physicochemical parameters were compared with the Bureau of Indian Standard. The descriptive statistics showing minimum, maximum, mean and standard deviation are given in (Table 1).

The pH in the lakes varied between 6.46to 8.86with a mean value of 8.30. The variation of pH might be due to the presence of dissolved gases like carbon dioxide, hydrogen sulphide, ammonia etc. ApH range between 6.0 and 8.5 indicates productive nature of water body [12]. Total hardness of the water is the property attributed to the presence of alkaline earth metals. It is the property of water by which it prevents the lather formation with soap and increases the boiling point of water. Water can be classified into soft (75 mg/L), moderately hard (75-150 mg/L), hard (150-300 mg/L) and very hard (300 mg/L) based on hardness [34]. Total Hardness was found in the range between 60.00 mg/L to 608.00 mg/L, with a mean of 246.86. These values are well within the limits of BIS standards which is 300 mg/L. The results suggest that the lake and pond has moderately hard water. DO is the most important indicator of the health of water bodies and its capacity to support a balanced aquatic ecosystem of flora and fauna. The amount of oxygen dissolved in a reservoir is affected by temperature of water, salinity, altitude, water inflow and photosynthetic activity of algae and plants [35-36]. WHO guideline values for DO in aquatic water body is 4-6 mg/L. A concentration below 5 mg/L disturbs the equilibrium in a freshwater ecosystem which affects biological communities. The DO concentration in the study area varied between. 57 mg/L to 19.12 mg/L with a mean of 6.91mg/L. DO is a very important parameter as maximum physicochemical and biological processes are involved in its variation [37]. The low DO levels noticed in the present study may be due to the presence of dissolved and suspended solids. Moreover, it is observed that this pond is covered with water hyacinth which prevent direct entry of sunlight and obstructs photosynthesis in the water body. DO level in lakes vary according to the lake trophic levels, and depletion of DO in water probably is the most immediate result of water pollution [38].

Table 1 Descriptive statistics of the water quality parameters

Parameters	Minimum	Maximum	Mean	Std. Deviation	BIS Standards
Temperature °C	23.00	38.80	33.20	2.28	Shall not exceed 5°C above the receiving water temperature
pH	6.46	8.86	8.30	.45	6.5-8.5
DO – (mg/L)	.57	19.12	6.91	6.84	4
HARD- (mg/L)	60.00	608.00	246.86	162.67	200
ALK - (mg/L)	24.00	1804.00	153.45	22.29	200
NO_2 - (ppm)	0.001	1.94	0.70	0.70	45
NO_3 - (ppm)	0.01	2.57	0.42	0.76	45
PO_4 - (ppm)	0.001	3.50	0.98	1.11	5.0
SIO_2 - (ppm)	0.001	1.60	0.43	0.45	150

Bureau of Indian Standards (BIS)
All units in mg/L, Nitrate, Nitrate, Phosphate, Silicate (ppm)

Principal component analysis

The Principal Component Analysis (PCA) was performed on the water quality data to reduce the dimension and study the underlying processes operating in the three different study sites. Therefore, separate PCA were performed for each habitat with data belonging to the entire study period. The results of PCA are given in (Table 1-6).

The (Table 1) shows the number of components extracted, percent variance and cumulative variance accounted when data from Chepet pond was analyzed. Four principal components are retained by the analysis explaining a total variance of 73.93%. The component loadings on variables are shown in (Table 2). The component 1 had higher loadings for alkalinity, hardness, silicate and phosphorus and may probably represent the carbonate system; however, the inclusion of phosphorus is odd. The second component is loaded with nitrite and DO with a comparatively low loading on temperature, but negative in direction. This component may suggest the role of assimilation and release of nitrate. Component 4 also shows loadings in pH and DO again suggesting the interlinkage between these variables and the process of nitrification. Component 3 had higher loadings on temperature and pH only with a variance of 12%. This component may represent the physical factors operating in the Chetpet pond.

Table 2 Principal component analysis of water quality data from Chepet pond

Component	Initial eigenvalues		
	Total	Percent of variance	Cumulative percent
1.	2.856	31.737	31.737
2.	1.435	15.946	47.683
3.	1.232	13.694	61.377
4.	1.130	12.557	73.934

Extraction Method: Principal component analysis
a. Only cases for which Study ponds = Chepet pond are used in the analysis phase

Table 3 The variable loadings for the components retained in the PCA of water quality data from Chepet pond

	Component			
	1	2	3	4
ALK	.852	-.105	-.218	.181
HARD	.800		-.291	-.121
SIO2	.754	-.276		
PO4	.724			
NO2	.397	.704	.113	-.191
DO		.659		.586
TEMP	.463	-.407	.816	
pH	.101		.523	.521
NO3		.494	.384	-.646

Extraction Method : Principal Component Analysis.
a. 4 components extracted
b. Only cases for which Study ponds = Chetpet pond are used in the analysis phase

The (Table 3) shows the results of PCA on water quality data from the Madhavaram pond. In this case, only three components are extracted with a total variance of 59%. The first component accounted for 28% and the other two components accounted for 15% each. The component loadings are shown in (Table 4). The first component had higher loadings for alkalinity, hardness, phosphate and pH. The inclusion of pH, unlike in the case of Madhavaram pond, strongly revealed that this component represents the carbonate system and may form an important process controlling ionic richness of the water. The second component may be termed as nutrient component as there were higher loadings only for nitrite and nitrate. The third component identified DO, temperature and silicate with more or less equal loadings (Table 4). This component may signify the importance of the physical environment, as in the case of Madhavaram pond.

Table 4 Principal component analysis of water quality data from Madhavaram pond

Component	Initial eigenvalues		
	Total	Percent of variance	Cumulative percent
1.	2.553	28.367	28.367
2.	1.383	15.368	43.735
3.	1.298	14.418	58.153

Extraction Method: Principal component analysis
a. Only cases for which Study ponds = Chepet pond are used in the analysis phase

Table 5 The variable loadings for the components retained in the PCA of water quality data from Madhavaram pond

	Component		
	1	2	3
ALK	.811	-.127	-.179
HARD	.795	-.291	-.135
PO4	.680	.194	-.428
pH	.542		.231
NO3		.827	.286
NO2	.406	.538	.276
DO	.412		.573
TEMP	.342	- .372	.521
SIO2	.232	.367	-.503

Extraction Method : Principal Component Analysis.
a. 3 components extracted
b. Only cases for which Study ponds = Chetpet pond are used in the analysis phase

Table 6 Principal component analysis of water quality data from Chenglepet lake

Component	Initial eigenvalues		
	Total	Percent of variance	Cumulative percent
1.	2.125	23.616	23.616
2.	1.739	19.317	42.933
3.	1.251	13.904	56.837
4.	1.062	11.802	68.640

Extraction Method: Principal component analysis
a. Only cases for which Study ponds = Chepet pond are used in the analysis phase

The (Table 5) shows the number of components extracted, percent variance and cumulative variance when data from Chenglepet lake was analyzed. Four principal components are retained by the analysis explaining a total variance of 68.64%. Table 5 shows the first component accounted for 23.61% while the other two components accounted for 42.93% and 56.83% respectively. The component loadings on variables are shown in (Table 6). Component 1 had higher loadings for alkalinity, hardness and phosphorus and may probably represent the carbonated system, as in the case of Chenglepet lake. The second component had higher loading for pH, DO and nitrate, but negative in direction. The third component may be termed as nutrient component as there was higher loadings only for silicate and nitrite associated with the combination of hydro

chemical processes in the study area. It represents the lake's catchment geology which are linked to the parent rock materials in the catchment area [39-40]. Moreover, itis a high rainfall area, where the runoff from the nearby hills also plays a major role. The positive loading of BOD, COD and NO3- indicates inorganic pollution from anthropogenic sources [41]. The third component identified DO, temperature and silicate with more or less equal loadings. This component may signify the importance of the physical environment, as in the case of Chetpet pond. In the second principal component DO show high positive loading, with moderate loading of pH. High loading of pH and DO reflects biological activity in the water bodies [42]. The presence of such contaminants is indicative of organic as well as inorganic pollution from anthropogenic sources, such as domestic waste water, untreated municipal sewage discharge, release from industrial effluents and water treatment plants [43]. The surface water quality depends on natural processes such as precipitation inputs, erosion, and weathering of crustal material, as well as on anthropogenic influences (urban, industrial, and agricultural activities [44]. It has been estimated that in Guwahati, about 70-90% of the total consumption of water is discharged as waste water in the form of sanitary sewerage and domestic sewerage together with liquid waste from commercial establishments like hotel/restaurant, hospital/health care units [45].

CONCLUSION

According to principal component analysis (PCA) results, the water quality is influenced by mineral components of the catchment area as well as anthropogenic sources. Most of the water quality parameters of the selected lakes indicates that they are not in a hygienic condition at all and were found to be lacking in maintenance and management. While Chennai city faces an acute solid waste management problem, the authorities seem less concerned about the dumps of waste near these lakes. The waste remains open for several days and ultimately finds its way to the nearby lakes with the storm water runoff. The lakes also get polluted by various factors like domestic sewage, discharge of large volume of effluent, urbanization, industrialization, construction works adjacent to the lakes, unplanned drainage system etc. By bringing to light the actual condition of these water bodies, this study would be a meaningful tool in the hands of planners and policy makers for deciding the future course of action for making Chennai city clean and green. A planned management of water quality of these lakes, their reclamation and conservation of their ecosystems will assume a very significant role in sustainable and environment friendly growth of Chennai city.

Table 7 The variable loadings for the components retained in the PCA of water quality data from Chenglepet lake

	2	3
ALK		-.121
HARD		
PO4	-.274	.201
PH	.767	
NO3	.607	.534
NO2	-.565	-.463
DO	.510	.560
TEMP	- .326	.520
SIO2	-.138	.325

Extraction Method : Principal Component Analysis.
a. 3 components extracted
b. Only cases for which Study ponds = Chenglepet lake are used in the analysis phase

LITERATURE CITED

1. Benjamin R, Chakrapani BK, Devashish K, Nagarathna AV, Ramachandra TV. 1996. Fish mortality in Bangalore Lakes, India. *Electronic Green Journal* 1(6).
2. Saha S, Mandal A, Sahoo D. 2017. Study of physico-chemical parameters of three different urban pond water of Nadia district, West Bengal, India. *Introduction Journal Fish Aquatic Science* 5(6): 23-27.
3. Ravikumar P, Mehmood MA, Somashekar RK. 2013. Water quality index to determine the surface water quality of Sankey tank and Mallathahallilake, Bangalore urban district, Karnataka, India. *Applied Water Science* 3(1): 247-261.
4. Choudhary P, Routh J, Chakrapani GJ. 2010. Organic geochemical record of increased productivity in Lake Naukuchiyatal, Kumaun Himalayas, India. *Environmental Earth Science* 60: 837-843.
5. Zan F, Huo S, Xi B, Li Q, Liao H, Zhang J. 2010. Phosphorus distribution in the sediments of a shallow eutrophic lake, Lake Chaohu, China. *Environ. Earth Science* 62(8): 1643-1653.
6. Iscen CF, Emiroglu O, Ilhan S, Arslan N, Yilmaz V, Ahiska S. 2008. Application of multivariate statistical techniques in the assessment of surface water quality in Uluabat Lake, Turkey. *Environmental Monitoring and Assessment* 144: 269-276.
7. Prasanna MV, Chidambaram S, Gireesh TV, Ali TVJ. 2010. A study on hydro chemical characteristics of surface and sub-surface water in and around Perumal Lake, Cuddalore district, Tamil Nadu, South India. *Environmental Earth Science* 63: 31-47.
8. Yin C, Shan B, Mao Z. 2006. Sustainable water management by using wetlands in catchments with intensive land use. *Ecological Studies* Volume 190.
9. Wang J, Da L, Song K, Li BL. 2008. Temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, China. *Environmental Pollution* 152: 387-393.
10. Garnier J, Brion N, Callens J, Passy P, Deligne C, Billen G, Servais P, Billen C. 2013. Modeling historical changes in nutrient delivery and water quality of the Zenne River (1790s-2010): the role of land use, waterscape and urban wastewater management. *Journal of Marine System* 128: 62-76.
11. Mohan V. 2021. Scorching hot during summer and unbelievably crowded, the modern city of Chennai dipped in traditions from its Madras days never fails to surprise a traveller. Outlook Traveller. Retrieved 31 December 2021.
12. Sharma P, Bora PJ. 2020. Water quality assessment using water quality index and principal component analysis: A case study of historically important lakes of Guwahati City, North-East India. *Applied Ecology and Environmental Sciences* 8(5): 207-217.
13. Fan X, Cui B, Zhao H, Zhang Z, Zhang H. 2010. Assessment of river water quality in Pearl River Delta using multivariate statistical techniques. *Procedia Environmental Science* 2: 1220-1234.
14. Najar I, Khan A, Hai A. 2017. Evaluation of seasonal variability in surface water quality of Shallow Valley Lake, Kashmir, India, using multivariate statistical techniques. *Pollution* 3: 349-362.

15. Xue W, Huang D, Zeng G, Wan J, Zhang C, Xu R, Deng R. 2017. Nanoscale zero-valent iron coated with rhamnolipid as an effective stabilizer for immobilization of Cd and Pb in river sediments. *Journal of Hazardous Material* 341: 381-389.
16. López-Morales CA, Mesa-Jurado MA. 2017. Valuation of hidden water ecosystem services: the replacement cost of the aquifer system in Central Mexico. *Water* 9: 571.
17. Sabia G, Petta L, Moretti F, Ceccarelli R. 2018. Combined statistical techniques for the water quality analysis of a natural wetland and evaluation of the potential implementation of a FWS for the area restoration: the Torre Flavia case study, Italy. *Ecological Indicator* 84: 244-253.
18. Alilou H, Nia AM, Keshtkar H, Han D, Bray M. 2018. A cost-effective and efficient framework to determine water quality monitoring network locations. *Science of Total Environment* 624: 283-293.
19. Li B, Yang G, Wan R, Hörmann G, Huang J, Fohrer N, Zhang L. 2017. Combining multivariate statistical techniques and random forests model to assess and diagnose the trophic status of Poyang Lake in China. *Ecological Indictor* 83: 74-83.
20. Iqbal M, MasumBillah M, NurulHaider M, Shafqul Islam M, RajibPayel H, KhurshidAlamBhuiyan M, Dawood MA. 2017. Seasonal distribution of phytoplankton community in a subtropical estuary of the south-eastern coast of Bangladesh. *Zoology and Ecology* 27: 304-310.
21. Villas-Boas MD, Olivera F, Azevedo JPS. 2017. Assessment of the water quality monitoring network of the Piabanha River experimental watersheds in Rio de Janeiro, Brazil, using auto associative neural networks. *Environmental Monitoring and Assessment* 189: 439.
22. Zhao Y, Guo L, Liang J, Zhang M. 2016. Seasonal artificial neural network model for water quality prediction via a clustering analysis method in a wastewater treatment plant of China. *Desalination and Water Treatment* 57: 3452-3465
23. Nadiri AT, Moghaddam AA, Tsai FTC, Fijani E. 2013. Hydrogeochemical analysis for Tasuj plain aquifer, Iran. *Journal of Earth System Science* 122: 1091-1105.
24. District Environment Profile DEP. 2000. Chennai, Final Report, March 2000, submitted to the Director, Department of Environment, Government, Tamil Nadu, Chennai. Submitted by Operations Research Group, No.9, Lyar Wood Lane, Mahalingapuram, Chennai -34.
25. Lakshmi K. 2009. Hyacinth robbing Chetpet lake of life. *The Hindu* 132(102): 3.
26. Madhavan D. 2019. Chetpet lake bustling once again with sports activities. *The Hindu*. Chennai: Kasturi & Sons. pp 6.
27. Whitehead PG, Crossman J, Balana BB, Futter MN, Comber S, Jin L, Skuras D, Wade AJ, Bowes MJ, Read DS. 2013. A cost effectiveness analysis of water security and water quality: impacts of climate and land-use change on the river Thames system. *Philosophical Transactions of the Royal Society* A 371: 20120413: 1-16.
28. Jebaraj PA. 2017. *Chennai Hunts for Water in Near-Dry Kanchi*. Deccan Chronicle. Retrieved 20 November 2019.
29. Jagannath G. 2012. Civic body steps up garbage clearance. *Deccan Chronicle*. Chennai: Deccan Chronicle.
30. Lakshmi K. 2012. A step in time for the resurrection of a dying lake. *The Hindu.* ISSN 0971-751X. Retrieved 20 November 2019.
31. Kabirdoss, Yogesh. 2019. Kolavai lake may quench the thirst of southern suburbs. *Chennai News Times of India*. The Times of India. Retrieved 20 November 2019.
32. Akundi, Sweta. 2019. Rediscovering Lake Kolavai, Chengalpattu's hidden waterbody. *The Hindu.* ISSN 0971-751X. Retrieved 20 November 2019.
33. APHA. 1992. American Public Health Association, Standard Methods for Water and Wastewater Analysis, Washington, D.C., U.S.A.
34. Sawyer CN, McCarty PL. 1967. *Chemistry of Sanitary Engineers*. 2nd Edition. McGraw Hill, New York.
35. George DG, Marberly SC, Hewitt DP. 2004. The influence of North Atlantic oscillation on the physics, chemistry and biology of four lakes in the English Lake District. *Freshwater Biology* 49: 760-774.
36. Abowei JFN. 2010. Salinity dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria. *Advanced Journal of Food Science and Technology* 2(1): 36-40.
37. Kazi TG, Arain MB, Jamali MK, Jalbani N, Afridi HI, Sarfraz RA, Baig JA, Shah AQ. 2009. Assessment of water quality of polluted lake using multivariate statistical techniques: a case study. *Ecotoxicology and Environmental Safety* 72: 301-309.
38. Srivastava N, Harit GH, Srivastava R. 2009. A study of physicochemical characteristics of lakes around Jaipur. *India Journal of Environmental Biology* 30(5): 889-894.
39. Khan MA, Shah MA, Mir SS, Suzana B. 2004. The environmental status of a Kashmir Himalayan wetland game reserve: Aquatic plant communities and eco-restoration measures. *Lakes and Reservoirs: Research and Management* 9(2): 125-132.
40. Singh KP, Malik A, Singh VK, Basant N, Sinha S. 2006. Multi-way modeling of hydro-chemical data of an alluvial river system-A case study. *Analytica Chimica. Acta* 571: 248-259.
41. Zhou F, Guo HC, Liu L. 2007. Quantitative identification and source apportionment of anthropogenic heavy metals in marine sediment of Hong Kong. *Environmental Geology* 53(2): 295-305.
42. Yousry MM, El-Gammal HAA. 2015. Factor analysis as a tool to identify water quality index parameters along the Nile River, Egypt. *Journal of American Science* 11(2): 36-44.
43. Ahmad I, Chaurasia S. 2019. Water quality index of Ganga River at Kanpur (U.P.). *Thematics Journal of Geography* 8(11): 66-77.
44. Papatheodorou G, Demopoulou G, Lambrakis N. 2006. A long-term study of temporal hydrochemical data in a shallow lake using multivariate statistical techniques. *Ecological Modelling* 193: 759-776.
45. Bakshi AR, Roy I. 2014. Proc. Water Resource Day Seminar; Institute of Engineers; Guwahati. pp 68-80.