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Water quality assessment of Kavvayi Lake of northern Kerala, India using CCME water quality index and biological water quality criteria

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Abstract

Assessment of water quality status of 7 sites of Kavvayi Wetland in northern Kerala (India) was carried out. The physico-chemical, bacteriological and biological parameters were monitored during pre-monsoon, monsoon and post-monsoon seasons. Canadian Council of Ministers of the Environment (CCME) water quality index of the Kavvayi Lake samples ranged from 43.99-44.77; indicating that water quality was threatened or impaired. The poor water quality status might be due to dumping of wastes from municipal and domestic sources and agricultural runoff. Biological water quality criteria (BWQC) determined for wetland revealed that stations such as mixing point of Kariangode River into Kavvayi Lake and Kottikkadavu was moderately polluted in pre-monsoon and post- monsoon seasons. Mixing point of Nileswar River into Kavvayi Lake was moderately polluted in pre-monsoon season. Both calculated indices suggest that quality of lake was found to be influenced by anthropogenic activities such as unscientific tourism and infrastructure development, land encroachment, sand mining, pollution etc. The study was carried out as part of a programme, which aimed to conserve Kavvayi wetland because of its unique ecological and environmental characteristics.

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Introduction

Wetlands provide fundamental ecological services and are regulators of water regimes and sources of biodiversity at all the levels of species, genetic, and ecosystem. It comprises a resource of great economic, scientific, cultural, and recreational value for the community. Wetlands play a vital role in climate change adaptation and mitigation (Ramsar Convention on Wetland, 2008). The Kavvayi wetland is located in Kasargode and Kannur districts of Kerala, India. Most significant values of the wetland includes flood control, rich biodiversity, fishery, mussels culturing, pollution control, inland navigation and back water tourism. Presence of so many Islands in Kavvayi Wetland provides unique characteristics to the Wetland System. Majority of people living in and around the Kavvayi wetland system depends on its resources for their livelihood. Fishing, artificial mussel culturing, boat services for connecting islands and main land and coir retting are some of the important income sources of common man. Back water tourism is one of the fast growing sources of revenue of the wetland (CWRDM, 2014).

Nowadays, anthropogenic activities have become a major threat to biodiversity. Unscientific tourism activities, infrastructure development, land encroachment, sand mining, pollution etc., are the major threats to this wetland system.

Water quality is a critical factor that controls human health; and human activities are the major cause of surface and groundwater pollution (Oketola *et al*., 2013).Water quality can be assessed by evaluating the chemical, physical and biological parameters. The main problem in water quality monitoring is the complexity associated with analyzing large number of measured variables. In order to integrate the water quality variables, water quality indices have been developed and these summarizes large amounts of data in to simpler terms, like excellent, good, bad etc. (Nikoo*et al.,* 2010). By calculating the water quality indices suitability of surface and groundwater samples for domestic purpose and human consumption can be determined (Ravikumar *et al.,* 2013).

Biological monitoring is also an important tool in determining the water quality assessment programmes. Many biological water quality appraisal programmes based on the assessment of benthic macro-invertebrates, benthic diatoms and fishes have been developed; which provides integrated information on the interaction of water quality and integrity of biological communities (Park *et al*., 2014). Benthic macro-invertebrates are regarded as the most efficient diagnostic indicators of quality of aquatic environment. Since the response of macro-invertebrates to organic and inorganic pollution has been extensively documented, they are widely used in biological monitoring (Latha and Thanga, 2010).Macro invertebrate abundance, community structure and ecological function have been used to characterize the lake ecosystem and its health (Ghosh and Biswas, 2015).

The present study investigated the water quality status of the Kavvayi wetland by systematic monitoring of various physico-chemical, bacteriological and biological parameters. The study also aimed to calculate CCME Water Quality Index and Biological Water Quality Criteria (BWQC) developed by the Central pollution Control Board for water quality assessment.

Materials and Methods

Study area : Kavvayi wetland is a coastal belt spread over 10.6 Sq. km from Nileswaram to Ezhimala. The Kavvayi backwater is drained by five rivers- Kariangode, Kavvayi, Peruvamba, Ramapuram and Nileswar. Kariangode river originates from then Eastern Ghats of Kerala and all other rivers originate from the lateritic hills of midlands which flow westwards through the wetland system and join the Arabian Sea. The current maximum water spread area and storage volume of Kavvayi Wetland at MSL is 9.1sq.km and 31.58 MCM, respectively. The maximum and minimum depth of the wetland is between 8.9 m and 0.5m. The maximum and minimum width of the wetland is 1754.12m and 155.81m,

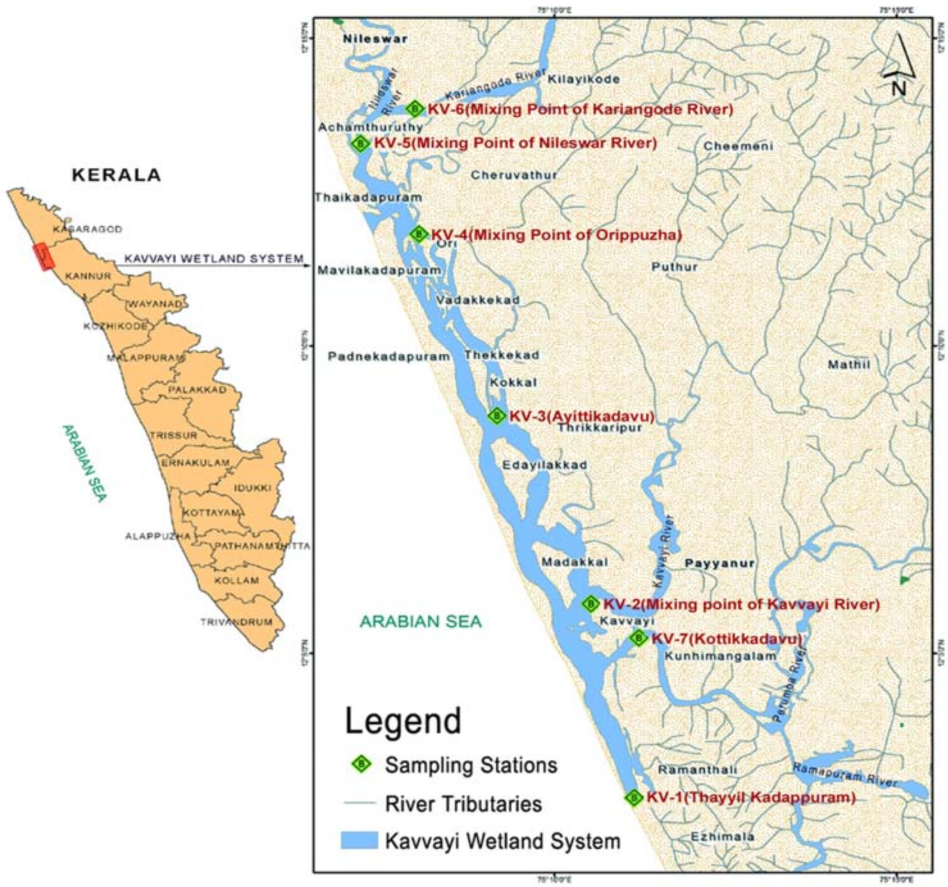

Fig. 1: Map of study area showing sampling locations

respectively. The length of Kavvayi wetland is 22.3 km which extends from Nileswaram in the north to Ezhimala in the south.

Sample collection and analysis : Water and sediment samples from 7 locations of Kavvayi Lake (Fig.1) were collected during three seasons (pre-monsoon, monsoon and post-monsoon, 2013 -2014).

Surface water samples were collected using a clean bucket. Parameters like pH, electrical conductivity and salinity were measured in situ. Dissolved oxygen was fixed in the field at the time of sample collection. Water for analysis of all other parameters was collected in acid cleaned pre-rinsed polythene bottle and was taken to the laboratory under refrigeration.

Water samples were analysed for various physicochemical parameters as per the standard procedure of APHA (2012). For analysis of heavy metals, water samples were filtered (Whatman no. 42) and preserved with 6N of HNO_3 for further analysis (APHA, 2012). Concentration of heavy metals in water samples was determined with the Atomic Absorption Spectrophotometer (Thermo M5 series) with a specific lamp for particular metal. Bacterial analysis i.e. the presence of total coliforms, fecal coliforms and *E.coli* from the water samples was carried out by the procedure described in APHA, 2012.

CCME water quality index was calculated to assess the overall quality of water samples. Hence, for calculating the water quality index, pH, colour, turbidity, total dissolved solids, total hardness, total alkalinity, calcium, magnesium, chloride, sulphate, nitrate, dissolved oxygen, total coliform, faecal coliform and iron were estimated. CCME water quality index has the ability to convey relative difference in water quality between the sites even when the same objectives and variables are used (CCME, 2001).

For water quality assessment using macro-invertebrates as biological indicators, sediment samples were collected as per the standard procedure prescribed by Central Pollution Control Board, India (CPCB, 1999). Sediment samples were collected and benthic macro invertebrates was soon filtered through the sieves of mesh size 0.5mm and 0.2mm and preserved in 5% formaldehyde, sorted and identified using standard keys (Edmondson, 1993; Pennak, 1989). Biological water quality criteria (BWQC) proposed by Central pollution Control Board, India (CPCB, 1999) was used to assess the actual health of water bodies. Biotic diversity was evaluated by using Shannon-Wiener Diversity Index (Shannon, 1963).

BWQC was calculated based on saprobic values and diversity of benthic macro-invertebrate families with respect to water quality. Saprobic score method involves a quantitative inventory of the presence of macro-Invertebrate benthic fauna up to family level of taxonomic precision. All the possible families having saprobic indicator value were

Table 1 : Water quality characteristics of Kavvayi Lake during Pre-monsoon, monsoon and post-monsoon seasons (2013-2014)

Parameters	Pre-monsoon		Monsoon		Post-monsoon	
	Range	Mean	Range	Mean	Range	Mean
pH	7.05-7.55	7.37±0.16	6.38-7.15	6.75±0.23	6.95-7.82	7.51±0.32
EC (micro siemens cm^{-1})	36800.0-45700.0	41086.0±3065.0	120.0-997.0	475.0±345.0	36200.0-52900.0	45207.0+5356.0
TDS (mg l^{-1})	26864.0-33361.0	29993.0±2237.0	90.0-748.0	345.0±254.0	25340.0-37030.0	31645.0±3749.0
Colour (Hazen)	ND-1.80	0.43±0.68	ND-2.30	0.59±0.88	ND-1.20	0.17±0.45
Salinity (ppt)	23.30-29.80	26.36±2.23	0.04-0.38	0.19±0.13	22.90-32.79	27.79±3.25
Turbidity (NTU)	ND	-	1.20-3.20	2.19±0.81	ND-2.80	0.74±1.24
Total alkalinity (mg l^{-1})	44.0-167.0	117.50±37.30	9.41-37.65	24.88±9.30	118.90-213.20	163.40±27.55
Total hardness (mg l^{-1})	6000.0-15200.0	10114.0±3779.0	20.0-124.0	54.86±37.20	10400.0-17600.0	13714.0±2589.40
Chloride (mg l^{-1})	12898.0-16496.0	14590.0±1236.0	24.0-344.0	126.29±123.0	12676.0-18150.0	15385.0±1799.0
Sulphate (mg l^{-1})	3208.0-5484.0	4111.0±745.0	3.16-44.0	18.7±15.0	1816.0-2708.0	2146.0±325.0
Phosphate-P (mg l^{-1})	0.03-0.05	0.04±0.01	ND-0.19	0.04±0.07	ND	-
Nitrate-N (mg l^{-1})	0.02-0.40	0.27±0.12	0.05-0.28	0.16±0.08	ND-0.02	0.004±0.01
Calcium (mg $l)^{-1}$	3.20-8.0	4.80±1.60	3.20-9.60	6.17±2.20	480.0-1920.0	1211.0±470.0
Magnesium (mg l^{-1})	1455.0-3690.0	2455.0±918.20	1.94-24.3	9.58±8.0	1944.0-3305.0	2597.0±611.0
Sodium (mg l^{-1})	6000.0-7840.0	6917.0±658.30	19.80-262.0	102.70±103.0	9580.0-12920.0	10763.0±1135.0
Potassium (mg l^{-1})	220.0-396.0	300.0±58.70	2.50-24.0	8.40±8.30	290.0-1020.0	556.0±248.0
Iron (mg l^{-1})	ND	-	ND-0.19	0.03±0.07	0.15-0.31	0.23±0.06
Manganese (mg l^{-1})	ND	-	ND-0.03	0.004±0.01	0.01-0.05	0.03±0.01
Dissolved oxygen (mg l^{-1})	4.90-8.46	6.89±1.17	7.40-8.80	8.20±0.50	4.93-6.20	5.53±0.38
Biochemical oxygen Demand (mg l^{-1})	1.0-7.20	3.65±2.0	0.87-2.87	1.67±0.72	1.0-4.66	2.89±1.42

ND- Not Detected

classified on a score scale of 1 to 10 according to the preference for saprobic water quality. The families which were more sensitive to pollution had of score of 10 while the most pollution tolerant families are getting a score of 1 and 2. The diversity score is the ratio of total number of different animals (runs) and total number of organisms encountered. The ratio of diversity has a value between 0 and 1.To indicate changes in water quality to different grades of pollution level, the entire taxonomic groups with their range of saprobic score from 1 to 10, in combination with the range of diversity score from 0 to 1 has been classified into five different classes of water quality. The abnormal combination of saprobic score and diversity score indicates sudden change in environment conditions (Harikumar *et al.,* 2014).

The SYSTAT 12 software was used for statistical interpretation of analytical data. Pearson correlation coefficients were calculated in order to study the inter-relationship between different parameters.

Results and Discussion

The pH of lake samples ranged from 7.05-7.55 in pre-monsoon, 6.38-7.15 in monsoon and 6.95-7.82 in post-monsoon respectively. The electrical conductivity is an index to represent total concentration of soluble salts in water (Purandara *et al.,* 2005) and has significant impact on the potability of water (WHO, 2004) The maximum electrical conductivity was found at station (KV-4) near to estuary (mixing point of Orippuzha) in pre-monsoon (45700 μScm^{-1}) and post-monsoon seasons (52900 μScm^{-1}). Same trend was also found for total dissolved solids. Salinity values ranged from 23.30ppt-29.80ppt in pre-monsoon, 0.04ppt-0.38ppt in monsoon and 22.90ppt-32.79ppt in post-monsoon, respectively.

DO level in lake vary according to their trophic levels, and frequent pollution of water leads to the depletion in DO (Srivastava *et al.,* 2009). Dissolved oxygen level varies seasonally, daily and with variation in temperature (Rao and Rao, 2010). DO of Kavvayi lake ranged from 4.90 mg l^{-1} - 8.46 mg l^{-1} in pre-monsoon. The minimum value was observed for sample collected from (KV-4) near to estuary (mixing point of Orippuzha). In monsoon season, DO concentration varied from 7.40 - 8.80 mg l^{-1}. Comparatively less DO concentration was reported during the post monsoon season (4.93 to 6.20 mg l^{-1}). Depletion in DO is due to addition of a variety of biodegradable pollutants from domestic and municipal sources which in turn stimulates the growth of microorganisms. Organic pollution in aquatic ecosystem is usually expressed in terms of biochemical oxygen demand (BOD). Higher BOD concentration was (7.20 mg l^{-1}) found in the sample collected from mixing point of Nileswar River into lake during pre-monsoon season. Iron and manganese was detected in all the seven water samples during post-monsoon seasons. But in monsoon, iron was detected in the water sample collected from KV-6, (mixing point of Kariangode River into lake) and manganese was detected in the sample collected from station KV-1 (Thayyil Kadappuram (near Naval Academy)).

In Kavvayi lake water, during pre-monsoon season the predominant cation trend was in the order of $Na^+ > Mg^{2+} > K^+ > Ca^{2+}$ with sodium being dominant cation where the predominant anion trend was in the order of $Cl^- > SO_4^{2-} > HCO_3^{2-} > NO_3^- > PO_4^{3-}$ with chloride being the dominant anion (Fig. 2a-2b).

During monsoon season the predominant cation trend was in the order of $Na^+ > Mg^{2+} > K^+ > Ca^{2+}$ with sodium being dominant cation whereas predominant anion trend was in the order of $Cl^- > HCO_3^{2-} > SO_4^{2-} > NO_3^- > PO_4^{3-}$ with chloride being the dominant anion (Fig.2c-2d).

But in post- monsoon season the predominant cation trend was in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ with sodium being dominant cation whereas predominant anion trend was in the order of $Cl^- > SO_4^{2-} > HCO_3^{2-} > NO_3^-$ with chloride being the dominant anion (Fig. 2e-2f). PO_4^{3-} was not detected in any of the water samples in post-monsoon season.

Coliform bacteria are present in the environment and feces of all warm-blooded animals and humans. Their presence in drinking water indicates that, disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies come from the feces of humans or animals. *E. coli* is a subgroup of the fecal coliform group. The presence of *E.coli* in water sample usually indicates recent fecal contamination.

Coliform bacteria have been used for microbial analysis of drinking water, groundwater, food, pharmaceuticals, freshwater, marine water and other environmental samples (Chetna *et al*., 2006).The results of bacteriological analysis of water samples revealed that all the stations had high bacteriological load in monsoon season. The percentage of *E.coli* contamination was high in monsoon season as compared to other two seasons. In pre-monsoon, monsoon and post-monsoon seasons, the percentage contamination rate of *E.coli* was 29%, 86% and 14%, respectively.

CCME provides detailed information regarding index calculation and its application in summarizing complex water quality data that can be easily understood by the public (Hurley, *et al*., 2012). CCME water quality index technique was used to assess the water quality status of Kavvayi Lake. Water quality Index calculated for the selected sampling stations of the Kavvayi Lake was found to be less than 45, which indicated poor water quality of the

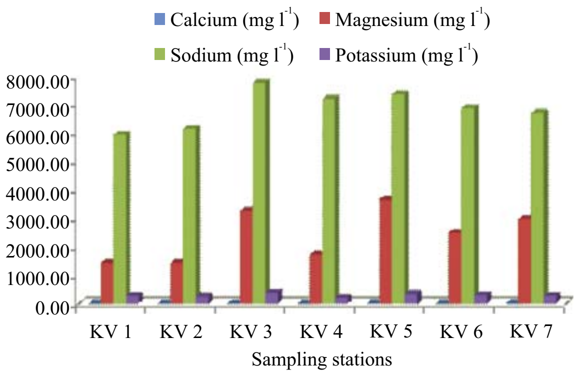

Fig. 2a : Major cationic concentrations in pre-monsoon season

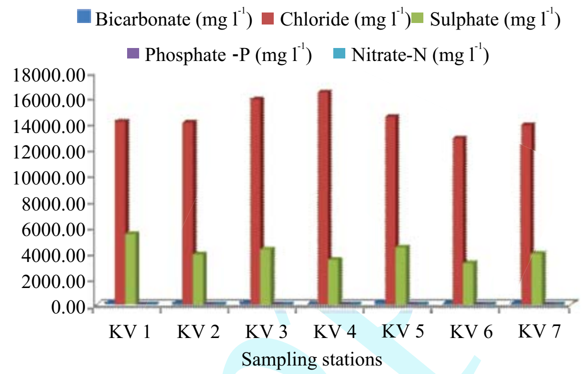

Fig. 2b : Major anionic concentrations in pre-monsoon season

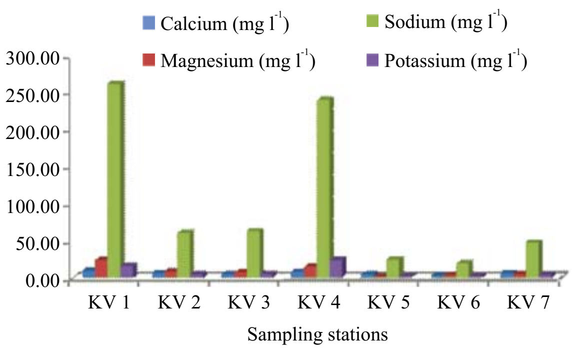

Fig. 2c : Major cationic concentrations in monsoon season

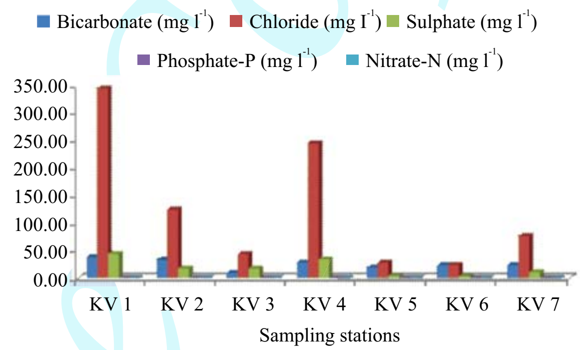

Fig. 2d : Major anionic concentrations in monsoon season

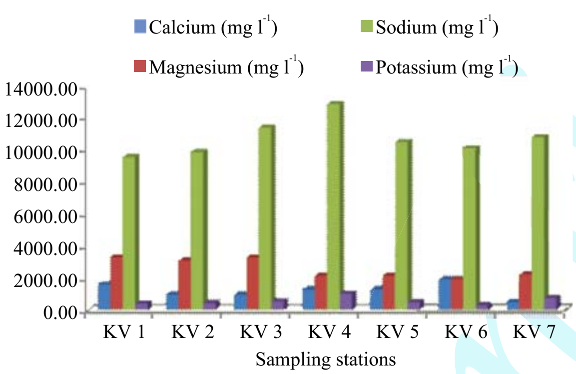

Fig. 2e : Major cationic concentrations in post-monsoon season

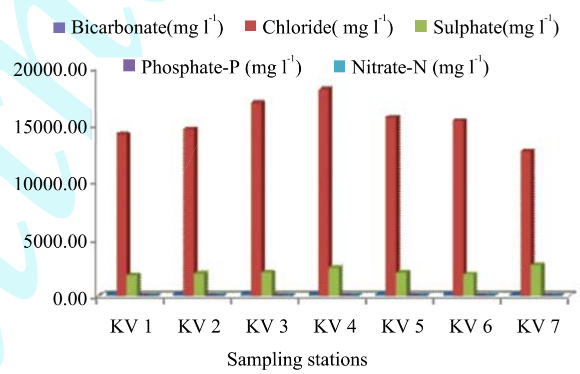

Fig. 2f : Major anionic concentrations in post-monsoon season

lake due to the presence of high concentrations of total dissolved solids, total hardness, chloride, sulphate, calcium, magnesium and high total coliforms and faecal coliforms content. Correlation analysis of CCME water quality index with physico-chemical parameters such as pH, total dissolved solids, total alkalinity, total hardness, chloride, sulphate, calcium, magnesium, sodium and potassium was carried out. CCME water quality index was found to be positively correlated with 10 selected physico-chemical parameters in monsoon season. Of these, total hardness, chloride, sodium, potassium and total dissolved solids were moderately correlated ($r>0.5$) and magnesium showed strong correlation with CCME index ($r=0.61$). But in post-monsoon, pH and sulphate were negatively correlated and total alkalinity ($r=0.67$), total hardness ($r=0.69$), chloride ($r=0.70$) and total dissolved solids ($r=0.74$) established a strong correlation with CCME water quality index. The results indicated that significant positive correlation coefficient for CCME with total dissolved solids ($r=0.549$), chloride ($r=0.561$) and calcium ($r=0.594$) in pre-monsoon

Table 2 : The benthic community identified in Kavvayi Lake during three seasons (2013-2014)

Phylum	Class	Order	Family	Genus
Annelida	Oligochaeta	Tubificida	Naididae	*Aulophorous* sps
				Stylaria sps
			Tubificidae	*Tubifex* sps
Arthropoda	Insecta	Tricoptera	Rhyachophilidae	*Himalopsyche* sps
			Hydropsychidae	*Macrostemum* sps
		Diptera	Chironomidae	*Chironomas* larvae
		Coleoptera	Dryopidae	*Dryops* larvae
Mollusca	Gastropoda	Hygrophila	Lymnaeidae	*Lymnaea* sps

Table 3 : Biological water quality during different seasons (2013-2014)

Stations	Seasons	Saprobic score	Diversity score	Water quality	Water quality class
KV-1	Pre monsoon	6.99	0.76	Slight pollution	B
	Monsoon	6.11	0.64	Slight pollution	B
	Post monsoon	6.14	0.75	Slight pollution	B
KV-2	Pre monsoon	6.05	0.54	Slight pollution	B
	Monsoon	6.18	0.51	Slight pollution	B
	Post monsoon	6.98	0.80	Slight pollution	B
KV-3	Pre monsoon	6.11	0.56	Slight pollution	B
	Monsoon	6.56	0.72	Slight pollution	B
	Post monsoon	6.82	0.59	Slight pollution	B
KV-4	Pre monsoon	6.15	0.82	Slight pollution	B
	Monsoon	6.11	0.54	Slight pollution	B
	Post monsoon	6.13	0.78	Slight pollution	B
KV-5	Pre monsoon	5.22	0.45	Moderate pollution	C
	Monsoon	6.56	0.62	Slight pollution	B
	Post monsoon	6.73	0.61	Slight pollution	B
KV-6	Pre monsoon	4.67	0.59	Moderate pollution	C
	Monsoon	6.32	0.67	Slight pollution	B
	Post monsoon	5.12	0.39	Moderate pollution	C
KV-7	Pre monsoon	4.87	0.76	Moderate pollution	C
	Monsoon	6.23	0.91	Slight pollution	B
	Post monsoon	5.78	0.82	Moderate pollution	C

season. But total alkalinity, total hardness, magnesium, sodium and potassium showed negative correlation with CCME water quality index in this season.Thus, interrelationships were established between some physicochemical parameters and water quality index where reliable correlations were established using correlation analysis (Sharma *et al.,* 2015). A total of seven sediment samples were collected from Kavvayi lake to determine the Biological Water Quality Criteria (BWQC). The benthic community which was identified in the Kavvayi lake during three seasons (2013-2014) is given in Table 2.

The Biological Water Quality Criteria of Kavvayi Lake water samples, based on the range of saprobic and diversity values of the benthic macro invertebrate families are given in Table 3.

The lowest diversity of benthic macro invertebrates was noticed during monsoon season in all the stations of Kavvayi Lake. Due to high amount of water flushing in to the lake from all the rivers and its tributaries draining into it, probably the pollution content in water become dilute and many of the aquatic organisms that are not able to thrive in these extreme conditions either move way or die out. Hence, in monsoon season all the sampling stations of Kavvayi Lake showed slight pollution as per BWQC**.**

Stylaria was the most dominant species found in the samples of Kavvayi Lake. Presence of pollution tolerant Oligochaetas like *Stylaria* and *Tubifex* is a clear indication of environmental stress and possible organic pollution at different points of the study area. The highest diversity score (0.91) was found at Kottikkadavu station in the monsoon season and the lowest diversity score (0.39) at the mixing point of Kariangode River into Kavvayi Lake during the post monsoon season. Whereas, the highest saprobic score (6.99) was found at station, Thayyil Kadappuram (near Naval Academy) during pre-monsoon season and lowest saprobic score (4.67) was noticed at mixing point of Kariangode River into lake, during the pre-monsoon season itself.

The station KV-6 (mixing point of Kariangode River into lake), recorded lower saprobic score and diversity score resulting in disclosure of moderate pollution at the sampling station. This could mean that there were unfavourable conditions existing at the station, KV-6, which has led to decline in the aquatic life including the macro-micro organisms at the spot. Pollution at this area could be so intense that it had affected the biotic life of the Kavvayi Lake water.

In short, it can be concluded from the Biological Water Quality Criteria that stations like mixing point of Kariangode River into Kavvayi Lake, mixing point of Nileswar River into Kavvayi Lake and Kottikkadavu was moderately polluted in pre monsoon season. Mixing Point of Kariangode River into lake and Kottikkadavu reported moderate pollution in post-monsoon season also. Physicochemical and biological water quality indicators will be influenced by both anthropogenic and natural agents (Abate *et al.,* 2015). The statistical analysis carried out by Pearson's correlation coefficient between saprobic score and 7different physico-chemical parameters (pH, total alkalinity, dissolved oxygen, calcium, magnesium, chloride and sulphate) of water samples of Kavvayi Lake, to find out the inter dependence among the components. The results on correlation analysis revealed that saprobic score showed moderate positive correlation with chloride(r=0.56) and strong positive correlation with sulphate (r=0.64) in pre-monsoon, whereas all the 7 parameters were negatively correlated with saprobic score in monsoon. Negative correlation was obtained for the combinations of saprobic score with pH, calcium and sulphate in post-monsoon season. Apart from this, a strong positive correlation of saprobic score with magnesium (r=0.60), moderate positive correlation of saprobic score with total alkalinity (r=0.42) and dissolved oxygen(r=0.48) was also evidenced in this season.

Kavvayi wetland has considerable impact on the water management of the area from the view of containing floods, recharging groundwater, cleaning polluted waters, protecting shorelines (mangroves), promoting tourism, etc. This aquatic ecosystem provides unique habitat for a wide variety of flora and fauna of commercial, aesthetic and environmental value. As per CCME water quality index, all the sampling stations of Kavvayi Lake showed poor water quality. BWQC of the Kavvayi Lake also proved that the stations were polluted. Both the indices suggest that anthropogenic activities were influencing the water quality of lake.

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References

Abate, B., A. Woldesenbet and D. Fitamo: Water quality assessment of lake Hawassa for multiple designated water uses. *Water Utility J.*, **9**, 47-60(2015).

APHA: Standard methods for examination of water and waste water. 22nd Edn. APHA, AWWA, WPCF, Washington, DC.USA (2012).

Canadian Council of Ministers of the Environment (CCME) Canadian water quality guideline for the protection of aquatic life, CCME water quality index: technical report, 1.0 (2001).

Chetna, A., A. Pratima and C. Rina: Bacteriological water quality status of River Yamuna in Delhi. *J. Environ. Biol*., **27**, 97-101 (2006).

CPCB: Bio-Mapping of Rivers, Parivesh, A news letter from ENVIS Centre-Central Pollution Control Board (1999).

Edmondson, W.T.: Ward and Whipple's Fresh Water Biology. 2nd Edn., John Wily and Sons, New York (1993).

Ghosh, D. and J.K. Biswas: Macroinvertebrate diversity indices: A quantitative bio assessment of ecological health status of an oxbow lake in Eastern India. *J. Adv. Environ. Hlth. Res.,* **3**, 1-13 (2015).

Harikumar, P.S., R. Deepak and A.R. Sabitha: Water quality assessment of Valapattanam river basin in Kerala, India, using macro-invertebrates as biological indicators. *Open. Environ. Bio. Monit. J.*, **6**, 1-9 (2014).

Hurley, T., R. Sadiq and A. Mazumder: Adaptation and evaluation of the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) for use as an effective tool to characterize drinking source water quality, *Water Research*., **46**, 3544-3521 (2012).

Latha, C. and S.G. Thanga: Macroinvertebrate diversity of Veli and Kadinamkulam lakes, South Kerala, India. *J. Environ. Biol*., **31**, 543-547 (2010).

Nikoo, M.R., R. Kerachian, S.M. Estalaki, S.N. Bashi-Azghadai and M.M. Azimi-Ghadikolaee: A probabilistic water quality index for river water quality assessment: a case study. *Environ. Monit Assess*., **181**, 465-478 (2011).

Oketola, A.A., S.M. Adekolurejo and O. Osibanjo: Water quality assessment of River Ogun using multivariate statistical techniques. *J. Environm.Protec*., **4**, 466 479 (2013).

Park, Y.J., J.S. Choi and H.S. Kim: Water quality assessment of the Sinchun stream based on epilithic diatom communities. *J. Environ. Biol*., **35**, 1053-1059(2014).

Pennak, R.W.: Fresh water invertebrates of the United States; Protozoa to Mollusca. John Wily and Sons, Inc., USA. (1989).

Purandara, B.K., N. Varadrajan and K. Jayshree: Impact of sewage on ground water, a case study. *Poll. Res*., **22**, 189-197 (2005).

Ramsar Convention on Wetland: The introductory Ramsar brochure. 3rd Edn. (2008).

Rao, G.S. and G.N. Rao: Study of groundwater quality in greater Visakhapatnam city, Andhra Pradesh (India). *J. Environ. Sci. Eng.,* 52, 137–146 (2010).

Ravikumar, P., M.A. Mehmood and R.K. Somashekhar: Water quality index to determine the surface water quality of Sankeytank and

Mallathahallilake, Bangalore urban district, Karnataka, India. *Appl. Water Sci.,* **3**, 247-261 (2013).

Report on Management action plan for Kavvayi wetland system of northern Kerala. Centre for Water Resources development and Management (CWRDM), submitted to Kerala State Council for Science Technology and Environment (KSCSTE) (2014).

Shannon, C.E. and W. Weaver: The Mathematical Theory of Communication. Champaign, IL: University of Illinois Press; p. 117 (1963).

Sharma, J.N., R.S. Kanakiya and S.K. Singh: Characterisation study and correlation analysis for water quality of Dal Lake, India. *Inter. J. Lak. Riv.*, **8**, 25-33 (2015).

Srivastava, N., G.H. Harit and R. Srivastava: A study of physicochemical characteristics of lakes around Jaipur, India. *J. Environ. Biol*., **30**, 889–894 (2009).

World Health Organization (WHO): Guidelines for Drinking-Water Quality. 3rd Edn., World Health Organization (WHO), Geneva (2004).