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Research Article

Physico-Chemical Attributes and Water Quality Index (WQI) Of Tropical River Systems

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ABSTRACT

This paper deals with the physico-chemical attributes and Water Quality Index (WQI) in the lower reaches (L=10 Km) of three tropical river systems, *viz,* Neyyar, Karamana and Vamanapuram rivers of Kerala State, southwest coast of India. Almost all chemical constituents in the three rivers exhibit wide spatial and temporal variations. The various physico-chemical constituents of the rivers were compared with Indian (ICMR) and international (WHO) standards to assess the quality. Further, the WQI, expressed as a single number, is used to describe overall water quality status using multiple water quality variables like pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), hardness, alkalinity and sulphate. The rivers were categorized into various levels of quality based on WQI. The various natural and anthropogenic sources of river degradation and various management strategies in the study area were also discussed herewith.

Keywords: Sulphate; Degradation; Tropical rivers; Physico-chemical

INTRODUCTION

Water is an important commodity that sustains life and the global economy. However, due to the influence of natural and man-made factors, the global water quality has declined rapidly for decades. Assessing water quality for different water purposes, such as domestic water, irrigation, protection and industrial water, is an important strategy for food safety and human health. Water quality assessment aims to determine the source of water pollution and formulate sustainable water source management strategies to maintain and promote human health and other social and economic. The use of Water Quality Index (WQI) was originally proposed by Horton and Brown. When Horton proposed the first WQI, a great deal of consideration has been given to the development of index methods. The WQI in terms of a number indicates the overall quality of water for any intended use. Surface water quality indexes have been developed and introduced worldwide by researchers with various applications of the Nation Sanitation Foundation Water Quality Index (NSFWQI), the Water Quality Index (WQI) based on the database of water monitoring parameters. The indices are among the most effective ways to communicate information on water quality trends with general public or policy makers and in water quality managers.

Additionally, WQI also facilitate comparison between different sampling sites and/or events. Consequently, they are considered better for transmitting information to general audiences. When their specific characteristics and limitations are taken into consideration, WQI's can be very useful for the purpose of management and decision-making.

In Kerala, located on the southwestern part of Peninsular India, the quality of freshwater is adversely affected due to variegated reasons which include natural and anthopogenic. The rivers of southern Kerala (example: Neyyar, Karamana and Vamanapuram rivers), drains through important agricultural watersheds. Considerable amounts of water are being extracted for use in irrigation, agriculture and for the production of drinking water for the city of Trivandrum and the rural water supply projects.

In this paper, the water quality (in terms of physico-chemical attributes) of three rivers (like Neyyar, Karamana and Vamanapuram) of southern Kerala have been generated and an attempt was made to assess the water quality along individual rivers by developing WQI for each of the river systems.

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Study area

For the present study, about 10.0 km length from the river mouth towards upstream in each of the three rivers, *viz,* the Neyyar (order=6th; L=56 km; area=492 km2), the Karamana (order=6th; L=68 km; area=702 km2), and the Vamanapuram river (order=7th; L=81 km; area=787 km2) in southern Kerala, India, has been selected for assessing the water quality. Among these rivers, the portion of the channel reaches in the midland and lowland of Neyyar and Karamana river flow through urban areas before emptying in to the Arabian Sea at Poovar and Poonthura respectively. But, a major portion of the Vamanapuram River drains through rural area and joins the Arabian Sea at Mudalapozhi (Figure 1).

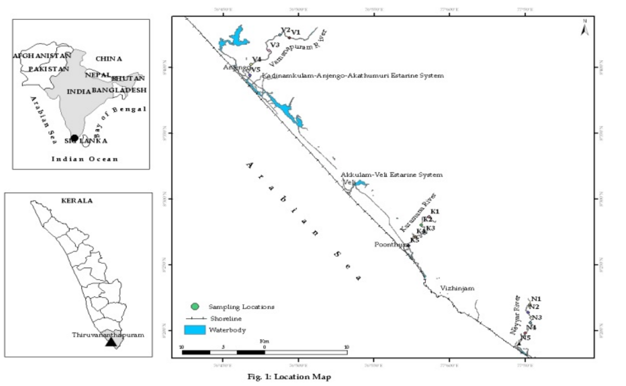

Figure1: The area enjoys a tropical humid climate with an average annual rainfall of about 2048 mm and the annual average temperature varies between 26.3 and 28.5.

Geology of the area: The rocks belonging to khondalite series, charnockites, granites gneiss, pegmatites and dikes are mainly exposed in this terrain. Khondalites and charnockites have undergone extensive migmatization. These ancient rocks, in turn, are overlained by mixed chemical and clastic sediments of the Quilon formation followed by the arkosic sediments and laterite of the Warkalli formation. Sedimentary formations ranging in age from Miocene (sub-surface occurrence) to Sub-Recent overlie the crystalline along the coastal tract.

MATERIALS AND METHODS

Five sampling stations (interval=2 km) were fixed for each of the above three rivers after taken into consideration of the tidal influence in these rivers. A total of 15 (3 × 5=15) surface water samples were collected in pre-washed polyethylene bottles from each of these three rivers covering the three prominent seasons, *viz,* Post-Monsoon POM (December), Pre-Monsoon PRM (March) and Monsoon MON (July).

The samples were analyzed immediately after collection for different parameters like pH, Total Dissolved Solids (TDS), Total Alkalinity (TA), Total Hardness (TH), Chloride, Sulphate, Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD). The conductivity and pH were determined at the time of sampling using a portable water-quality analyser (Multilane F/SET-3, WTW). DO was fixed at the field and estimated by the Winkler method with azide modification. An unseeded dilution technique and incubation for 5 days at 20 ± 1 were adopted to estimate BOD. Estimations of DO, BOD, Cl, SO4, TH, TA and TDS were carried out following standard analytical procedures (APHA, 1995).

Water quality index

In the calculation of WQI, eight physico-chemical attributes such as pH, TDS, TA, TH, chloride, sulphate, DO and BOD were used by following Weighted Arithmetic Index Method. It is a five step process. Quality of several water-bodies has been estimated and a classification with verbal and numerical limits as shown in Table 1.

WQI	Status
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
101 and above	Unsuitable for drinking

Table 1: Classification of water based on WQI.

Step 1: When there are 'n' water quality parameters, then quality rating or sub-index (Qn) corresponding to 'n'th parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. Qn is calculated using the following expression.

Qn=100[(Vn-Vio)/(Sn-Vio)]... (1)

Where

Qn=Quality rating for nth water quality parameter.

Vn=Estimated value of nth parameter at a given sampling station.

Sn=Standard permissible value of nth parameter.

Vio=Ideal value of nth parameter in pure water.

All the ideal values (Vio) are taken as zero for drinking water except for pH=7.0 and DO=14.6 mg/L. Quality rating for pH and DO are calculated separately for various stations using (2) and (3).

Step 2: Quality rating for pH

For pH, ideal value is 7.0 (for neutral water) and permissible value is 8.5 (for polluted water), then quality rating for pH is calculated as below:

QpH=100[(VpH-7.0)/(7.0- 8.5)]... (2)

Where, VpH=Observed value of pH.

Step 3: Quality rating for DO

Ideal value (VDO) for DO is 14.6 mg/L and permissible standard value for drinking water is 5 mg/L. So, quality rating

Q_{DO}=100[(VDO-14.6)/(5-14.6).. (3)

Where

V_{DO}=Measured value of DO.

Step 4: Unit weights (Wn) for various water quality parameters are inversely proportional to recommended standards for the corresponding parameters and is given in Table 2.

Wn= K/Sn... (4)

Where

Wn=Unit weight for nth parameters

Sn=Standard value for nth parameters

K=Constant of proportionality.

Step 5: WQI is calculated from the following equation:

WQI=∑QnWn/∑Wn... (5)

Parameters	Standards (Sn)	Recommending agency	Unit weights (Wn)
pH	7.0 to 8.5	ICMR	0.218176
TDS	500	WHO	0.003708
TA	120	ICMR	0.01545
TH	300	ICMR	0.0061816
Chloride	250	ICMR	0.0074179
Sulphate	250	WHO	0.0074179
DO	5	ICMR	0.37089
BOD	5	ICMR	0.37089

Note: ICMR: Indian Council of Medical Research; WHO: World Health Organization; TDS: Total Dissolved Solids; TA: Total Alkalinity; TH: Total Hardness; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand. (All values except pH are in mg/L).

Table 2: Drinking water standards and unit weights based on recommending agencies.

RESULTS AND DISCUSSION

The results (in terms of ranges and averages) of the physico-chemical attributes of water from the lower reaches of three rivers (*viz,* Neyyar, Karamana and Vamanapuram) of the study area for the different seasons. Higher pH in the POM of all rivers can be attributed to high growth rate of algal population which utilizes CO_2 through photosynthetic activity [1]. However, pH slightly declines during PRM and MON. Lower value during PRM was due to enhanced decomposition of organic matter at high temperature liberating CO_2. The decline of pH during MON was due to the dilution of alkaline substances. It is generally known that pH of water does not cause any severe health hazard. However, high pH induces the formation of trihalomethanes, which are toxic. According to pH between 6.7 and 8.4 are suitable for drinking, while below 5.0 and above 8.3 are detrimental. Acceptable limits for pH variation should be consistent with that required for "normal" biological life (pH=6.5-8) [2]. The observed TDS in Neyyar ranges from 63 to 1510.0 mg/L. The averages for PRM, MON and POM are 835, 309.1 and 296.0 mg/L respectively. In Karamana, it ranges between 33 and 516 mg/L, and the averages for the above seasons are 223.4, 106.2 and 50.4 mg/L. In Vamanapuram the ranges are 11.14 and 7140 mg/L. The season wise averages are 2148.5, 1632.2 and 1504 mg/L respectively. Further, the seasonal average for Neyyar, Karamana and Vamanapuram are 480.05, 126.66 and 1761.56 mg/L respectively.

In general, the TDS shows lower values during MON and POM owing to the influx of more water from the catchment areas and subsequent dilution of the dissolved salts. However, relatively high TDS contents (above the permissible limits) are recorded for all seasons at certain stations of Vamanapuram (eg, V3, V4 and V5). This may be due to the salt water intrusion from the Kadinamkulam-Akathumuri estuarine system in the coastal land, which was once a seasonal estuary and is now converted into a perennial one. In the other two riverine systems, the seasonal estuarine mixing and the sewage mixing contribute to the TDS [3].

Alkalinity values lowers during MON. This is attributed to the influx of fresh water into the river. The downstream stretches of the rivers are affected by tidal incursion and show comparatively higher values of HCO_3. The hardness values spans between 4.24 and 136 mg/L in Neyyar; 22.10 and 165.24 in Karamana and 35 to 200 mg/L in Vamanapuram. The seasonal averages for Neyyar, Karamana and Vamanapuram are 54, 90 and 77 respectively.

Chloride is one of the indicators of water pollution. Content of chloride is found to vary between 24.80 and 312.70 mg/L for Neyyar; 14.78 and 270 mg/L for Karamana, 2.27 and 2664 mg/L for Vamanapuram river respectively. The averages for PRM, MON and POM are 130.87, 67.92 and 98.14 mg/L for Neyyar, whereas for Karamana the averages are 88.82, 22.45 and 79.64 mg/L, while in Vamanapuram the average values are 965.44, 218.40 and 495.75 respectively. The seasonal average for the Neyyar, Karamana and Vamanapuram are 98.97, 63.43 and 559.8 mg/L respectively. The value of sulphate ranges between 1.38 and 7.28 mg/L in Neyyar, whereas in Karamana it is higher and varies from 8.08 to 17.21 mg/L and in Vamanapuram between 2.20 and 25.46. The seasonal averages for the three rivers are 5.2, 12.7 and 3.6 respectively [4].

The content of DO spreads between 4.98 and 6.60 mg/L in Neyyar; 5.17 to 7.02 in Karamana and 3.48 and 5.14 mg/L in Vamanapuram respectively. The season wise average during the PRM, MON and POM are 5.43, 5.65 and 5.85 for Neyyar, whereas for Karamana the averages are 5.98, 6.13 and 6.33, and 4.30, 4.55 and 4.62 for Vamanapuram river. The seasonal average for the Neyyar, Karamana and Vamanapuram are 5.64, 6.14 and 4.49 mg/L respectively. BOD values were found to vary between 3.12 and 5.87 mg/L for Neyyar; 2.24 and 5.73 for Karamana and 1.64 to 4.14 for Vamanapuram respectively. The averages during PRM, MON and POM are 4.72, 3.68 and 3.42 mg/L for Neyyar, 3.98, 3.73 and 3.36 for Karamana; and 3.44, 3.23, and 3.04 for Vamanapuram respectively. The seasonal averages for the rivers are 3.94. 3.69 and 3.23 mg/L respectively.

The water quality of the rivers is the net result of the natural (hydrological cycles) and man-made processes operating in the basin. Almost all chemical constituents in the three rivers exhibit wide spatial and seasonal variations. The increased concentration of some attributes (for example, pH, TDS, TA, BOD, HCO_3 and chloride) during PRM is due to a multitude of reasons, such as less dilution of chemical contaminants due to the absence of free flow of water resulting greater contact time between water and soil in the river, high temperature, and greater use of river water for bathing and laundry purpose etc [5]. The direct and indirect influx of solid and liquid wastes from the many urban and townships deteriorate the water chemically particularly under the conditions of less water flow and high temperature prevailing during PRM period. The midlands and lowlands are occupied by agricultural lands and settlements, and hence anthropogenic impact is more pronounced at the lower reaches of the rivers. Furthermore, during PRM, the lower stretches of these rivers are affected by seawater ingression up to a distance of ~ 10 km in the inland. The increased rate of weathering of rocks and subsequent leaching under favourable conditions can also cause elevated levels of many of the hydrochemical parameters. The lack of sufficient base water flow due to damming of water can hinder the dilution and natural cleansing operations especially during this lean period.

The SO_4 were increased by 2 to 3 times during MON compared to that of PRM values. The high concentration in MON originates from geological weathering, agricultural practices together with the heavy flow of monsoon water that washed through the agricultural/polluted lands of the drainage basin. The river water derives its chemical constituents through weathering (mainly HCO_3), chloride by precipitation and human addition [6]. The dissolved salts in aquatic systems are controlled by precipitation, rock characteristics/weathering and evaporation. In Indian subcontinent true weathering processes is hindered by deforestation, urbanization and excess withdrawal of water for irrigation and hence rivers do not have any well-defined composition.

High flow in the MON induces marked changes in water quality in the three rivers. The pH and DO decrease markedly during MON, due to the influence of acidic rainwater and the presence of oxygen-demanding organic substances. Since parts of the uplands and midlands of the river basins are mainly used for agricultural purposes, the heavy monsoon flows carry residual nutrients from the soil into the rivers and hence lead to high values during the season.

WQI of riverine systems

WQI, a useful index of water quality based on particular sampling stations, determines the suitability of water for various beneficial uses. Spatial and seasonal distribution of WQI for Neyyar, Karamana and Vamanapuram, and the standards for WQI are given in Table 3.

Station no	PRM	MON	POM
N1	74.7	58.34	70.51
N2	72.3	66.11	56.96
N3	69.55	60	57.2
N4	68.8	64.12	64.07
N5	82.36	69.65	59.59
Average	73.54	63.65	61.66
Note: Seasonal avg=66.2			

Table 3: Water Quality Index (WQI) of Neyyar for different seasons.

WQI of river water samples show wide variations (range=45.7-83.7) and are a consequence of spatial variations in the rivers with respect to utilization of river resources and impacts thereof. Spatial and temporal distribution of WQI shows that in Neyyar during PRM, the WQI shows highest value at station N5 (=82.36), and based on the water quality rating it is under very poor category, whereas, the other four stations of Neyyar fall in the poor status. Similarly, during MON and POM all the stations fall under poor status in Table 4.

Station no	PRM	MON	POM
K1	61.38	61.52	45.97
K2	60.18	60.13	53.6
K3	70.62	76.3	65.43
K4	77.27	67.03	59.93
K5	72.81	61.37	74.54
Average	68.39	65.27	59.89
Note: Seasonal avg=64.5			

Table 4: Water quality index (WQI) of Karamana river.

In Karamana, during PRM station K5 (WQI=77.27) and during MON station K3 (=76.30) fall in the very poor category, whereas, all other stations for all periods (except K1 of POM) fall in the poor category (Table 5). Untreated waste (specifically urban waste), bathing and washing, sand mining, salinity intrusions, low flow rate and feacal contamination due to sewage are the major environmental problems causing deterioration in the quality of water (poor category) in both the Neyyar and Karamana rivers.

Station no	PRM	MON	POM
V1	68.75	53.9	49.57
V2	75.66	59.1	66.36
V3	64.08	55.35	56.49
V4	79.9	66.26	65.26
V5	83.77	76.91	68.09
Average	74.43	62.3	61.15
Note: Seasonal avg=65.9			

Table 5: Water quality index (WQI) of Vamanapuram river.

In Vamanapuram, station V5 during MON (=83.77) and PRM (=79.9) falls in the very poor category, whereas the station V1 (=49.57) during POM belongs to good category. But, the remainders fall in the very poor category and indicating that the riverine system is under stress from pollution. Salinity intrusion and sand mining are major environmental problems faced by the Vamanapuram river [7]. Season-wise WQI of PRM of all rivers shows higher numerical values and is ascribed due to the lean base flow and influx of sewage and extreme human interferences. Seasonal averages of WQI for the three rivers, Neyyar, Karamana and Vamanapuram are 66.28, 64.52 and 65.96 respectively. Based on the seasonal averages of WQI, water from the three rivers for all seasons belongs to 'poor' category.

River management strategies

Avoid the dumping of solid waste into the river system. In order to reduce the contamination on surface water (river), the effluent from the factories and other point sources should be properly treated or diluted before discharging into the adjacent land or water body. Encourage the farmers to use biofertilizers and biopesticides particularly in the buffer zone on the banks of the rivers to avoid the soil, surface water and groundwater contamination [8-10]. To avoid over-fertilization, the rate of nitrogen fertilizer to be applied needs to be calculated on the basis of the "crop nitrogen balance". This takes into account plant needs and amount of nitrogen in the soil.

The acidic surface water in some regions of rivers should be neutralized by adding lime or bleaching powder periodically. River sand mining should be prohibited particularly from the ecologically fragile zones of the rivers and encourage people to use other alternative sources like crusher sands etc. Awareness and training programmers should be conducted for the NGO's and the local people for the sustainable use and management of the surface water of the region and for the need for rainwater harvesting. A short term and long term management action plan should be formulated for the efficient use of the surface water resources and other natural resources after taking into account the population distribution, industrial activities, agricultural activities etc.

CONCLUSION

While comparing the various physico-chemical constituents of three rivers of southern Kerala, (*viz*, Neyyar, Karamana and Vamanapuram) with that of Indian (ICMR) and international (WHO) standards and the water quality index (WQI) in the lower reaches (L=10 km) of the rivers revealed that the rivers in the study area fall in the "poor to very poor" category. The salinity intrusion, sand mining, fecal contamination and direct and indirect influx of solid and liquid wastes from Thiruvananthapuram city (in the case of Neyyar and Karamana River) and adjoining townships (in case of Vamanapuram River) mainly deteriorate the water chemically.

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