Assessment on factors controlling nutrient dynamics in a small tropical river using multivariate analysis

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Abstract- Water samples (N= 96) were collected from Meenachil river for 16 locations (S1-S16) in pre monsoon (PRM), monsoon (MON) and post monsoon (POM) seasons during 2013 and 2014. The nutrients like NO_3, PO_4 (<1 mg/L) and SiO_2 (<4 mg/L) are generally low in the river, and increases from upstream to downstream. The cations of abundance include Na> Ca> K> Mg> Fe for PRM, Ca> Na> Mg> K> Fe for MON and Na> Ca> Mg> K> Fe for POM. Anion abundance include $Cl>HCO_3>SO_4>SiO_2>NO_3>NO_2>PO_4$ during PRM, HCO_3> Cl> SO_4> SiO_2> NO_3> PO_4> NO_2 during MON and Cl> HCO_3> SO_4> NO_3> SiO_2> NO_2> PO_4 during POM. The factor analysis result illustrate F1 loading (TEMP, TH, SAL, Mg, Ca, SO_4, Na, K, Cl and HCO_3) of 69.85 % during PRM clearly indicating the role of tropical weathering process in the river system. From the F1 loading during MON, it is interpreted that positive loading of NO_2, PO_4, Na and K indicate role of agricultural runoff in determining the water quality of river system. During POM, F1 loading for TH, SAL, PO_4, Mg, Ca, SO_4, Na, K and Cl accounting 67.89 % variance depicts influence of agricultural as well as anthropogenic activity on the river system. Cluster analysis reveals that stations in the highland and a part of midland (S1-S10) is comparatively less polluted. During PRM, river mouth station S16 alone forms a separate cluster indicating dominance of saline water ingress in that station. While in POM the effect of liming of agricultural land in this watershed also has much influence in controlling the river water chemistry in the lowland stations especially S14, S15 and S16.

Index Terms- River nutrients, Tropical river, Pollution identification, Multivariate analysis

I. Introduction

Rivers constitute to the main water resources in inland areas for drinking, irrigation and industrial purposes; thus, it is a prerequisite for effective and efficient water management to have reliable information of water quality [1]. Livelihoods such as agriculture, fishing and animal husbandry are affected by poor water quality. Biodiversity, especially of freshwater ecosystems is under threat due to water pollution [2]. The water quality of a natural stream is determined by the concentration of different chemical variables of the water body. The change in the concentration of these different variables is the result of a number of random processes, including rainfall, runoff, anthropogenic activities, geology etc. Water quality can be affected when watersheds are modified by alterations in landuse pattern, sediment balance, or fertilizer use from industrialization, urbanization, or conversion of forests and grasslands to agriculture and silviculture [3]. Natural factors like geology, climate, hydrology and vegetation are usually first order controls of the amount and composition of dissolved and particulate substances transported by rivers. Now-a-days, human-induced environmental changes often go far beyond natural variations and therefore may lead to drastic change in the river input to estuaries and affect coastal ecosystems [4]. Increased nutrient input into the riverine system emphasizes the imbalances and alterations in terrestrial sources. Thus the quantity and quality of nutrient input to the rivers needs to be monitored to cope with the existing and future climatic and environmental changes [5].

The water quality assessment, however, does not focus on the instantaneous concentration as it is seldom that the instantaneous concentration has an impact on the water user. Rather the overall difference in the magnitude of the concentration and range of concentration over a period of time must be used as a measurement of the water quality status [6]. Due to spatial and temporal variations in water chemistry a stringent and scientific mode of continuous water quality monitoring pattern is necessary for surface waters especially for rivers. Thus, monitoring programs including frequent water samplings from specific sites and determination of its quality is of vital value.

Study area

The Meenachil river (Order= 7^{th}; Length= 78 km; Area= 1272 km^2), one of the important rivers in Central Kerala (Fig.1), is formed by several streams originating from the Western Ghats at Araikunnumudi (elevation=1097m above msl) and flows in the E-W direction and finally debouch into the Vembanad lake (a Ramsar site). The entire river basin area geographically lies between N latitude $9^0 25'$ to $9^0 55'$ and E longitude $76^0 30'$ to $77^0 00'$. Major part (41 km; 53%) of this river runs through midland terrain, 21 km (27%) through the highland and the rest (16 km; 20%) is seen to flow through the low land terrain. The river has 47 sub-watersheds and 114 micro-watersheds [7,8]. It has 38 tributaries including major and minor ones.

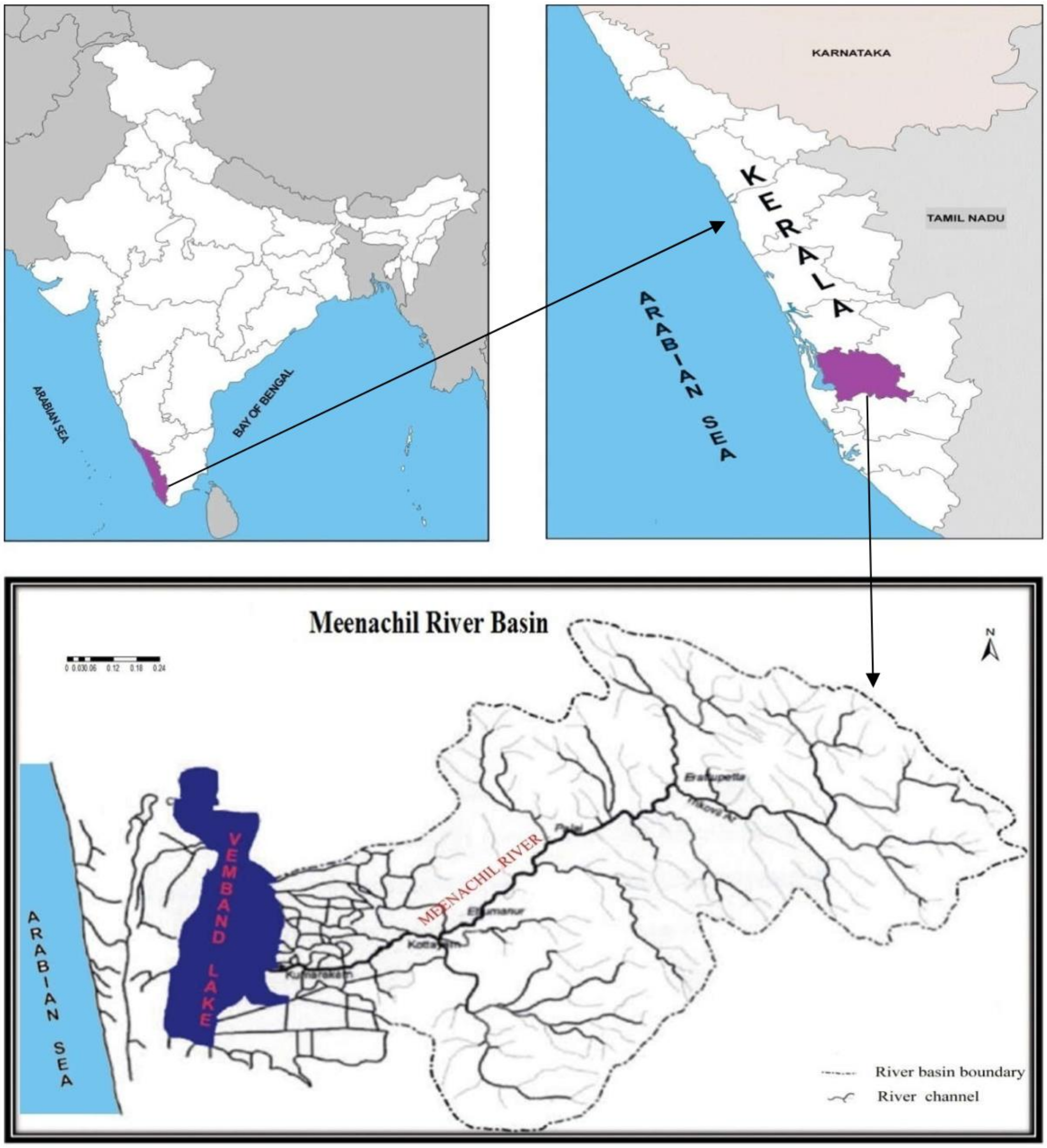


Figure 1. Location map of study area

The major tributaries are Kadapuzha, Kalathukadavu, Kurisumalai, Trikkoil, Punjar, Meenadom [9]. The river exhibits a dendritic drainage pattern and splits into a number of distributaries in the lowlands and finally merges with the Vembanad Lake at Kavanattinkara [10].

The basin primarily comprises of Precambrian metamorphic rock system. The major soil type prevalent in the area is well drained lateritic soils, while main rock types of the area belong to Charnockite/charnakite gneiss, Biotite gneiss (migmatite), cordierite gneiss, magnetite quartzite and pyroxene granulite. Quaternary formations of fluvial deposit, fluvio marine and paleo marine deposits were found in lower reaches of river [11].

The Meenachil river basin falls within the realm of tropical humid climate and high variations in relief from the west coast to the hilly region of the Western Ghats in the east and proximity to the sea influence the climatic parameters. During 2010 – 2014 period the mean annual temperature of the area is 32.5^0C, experiencing average annual rainfall of 3030 mm, while mean humidity is 88.6 percent. The basin experiences both south-west and north-east monsoons. The south-west monsoon sets during June and lasts till August. The north-east monsoon, which is uncertain strikes in October and continues till the end of November.

SAMPLING SCHEME AND METHODOLOGY

River water samples (total no.= 96) were collected in Meenachil river from upstream to downstream for 16 locations (S1-S16) The water samples were collected for pre monsoon (PRM), monsoon (MON) and post monsoon (POM) seasons during 2013 and 2014. The portrait of sampling locations was given in table 1 and figure 2.

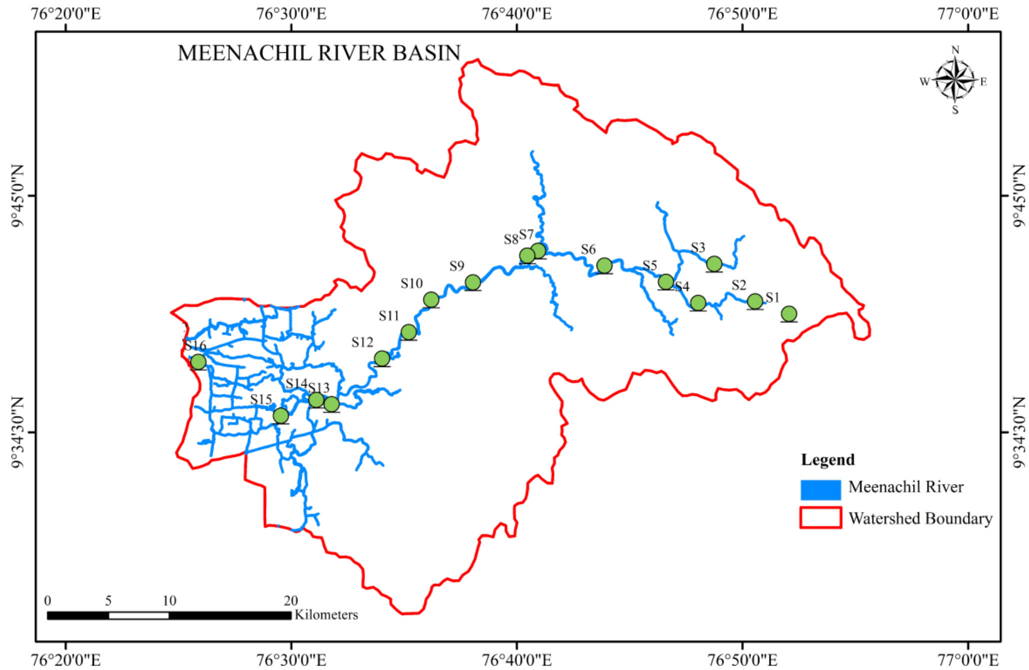


Figure 2. Portrait of Sampling locations

The samples were collected in clean polyethylene bottles kept under dark or below ambient temperature and were analysed using standard procedures [12,13]. The parameters identified include Temperature, pH (Systronics pH meter, 361), TDS, Conductivity (Systronics Conductivity-TDS meter, 308), Total Hardness (TH),Total Solids (TS), Salinity, HCO_3, Fe, PO_4, Si, DO, BOD, NO_2, NO_3, Mg, Ca, SO_4 and Cl. DO was estimated by Winkler's Iodometric method using $MnSO_4$ and alkai KI and titrating against thiosulphate using starch as indicator, while BOD is measured after incubating it for 5 days at 20^0C. All spectrophotometric analysis were done using Systronics UV-VIS, 118, spectrophotometer while Na and K were determined using Flame Photometer (Elico CL 361) after conducting standard calibration. Chloride concentrations were estimated by employing argentometric titration using standard silver nitrate solution having potassium chromate as indicator.

Table 1. Description of sampling stations

Station No.	Stations	Lat. (N)	Long. (E)	Location remarks
S1	Adivaram	$9^0$39'44.8"	$76^0$52'3.8"	Forest and plantation
S2	Perumkulam	$9^0$40'17.9"	$76^0$50'33.7"	Forest and plantation
S3	Tikkoi	$9^0$41'57.8"	$76^0$48'45.1"	Plantation and Mixed vegetation
S4	Punjar	$9^0$40'13.8"	$76^0$48'2.1"	Plantation and Mixed vegetation
S5	Erattupetta	$9^0$41'9.8"	$76^0$46'36.4"	Plantation and Mixed vegetation
S6	Baranamghanam	$9^0$41'53.2"	$76^0$43'52.9"	Plantation and Mixed vegetation
S7	Pala	$9^0$42'32.5"	$76^0$40'56.3"	Plantation and Mixed vegetation
S8	Kadapattoor	$9^0$42'19.7"	$76^0$40'27.6"	Plantation and Mixed vegetation
S9	Cherpungal	$9^0$41'8.6"	$76^0$38'3.2"	Plantation and Mixed vegetation
S10	Kidangoor	$9^0$40'22.4"	$76^0$36'12.3"	Plantation and Mixed vegetation
S11	Pattarmadom	$9^0$38'56.1"	$76^0$35'12.5"	Plantation and Mixed vegetation
S12	Perror	$9^0$37'45.8"	$76^0$34'1.5"	Plantation and Mixed vegetation
S13	Kottayam Railway Bridge	$9^0$35'44.2"	$76^0$31'47.3"	Plantation,Mixed vegetation and minor industrial area
S14	Chungam	$9^0$35'55.5"	$76^0$31'6.6"	Paddy and Mixed vegetation
S15	Illickal	$9^0$35'13.5"	$76^0$29'32.2"	Paddy and Mixed vegetation
S16	Kavanattinkara	$9^0$37'36.9"	$76^0$25'52.9"	Paddy, river lake interface area

II. RESULTS AND DISCUSSION

a. Spatio-temporal nutrient variability

The water quality analysis of river water conducted for PRM, MON and POM of 2013 and 2014. For the convenience of study, the season wise averaged data for 2013 and 2014 are presented in Figure 3-4 . What follows is a brief summary of the season wise averaged results.

Temperature, TEMP

During PRM, the TEMP ranged from 19.1 to 20.0^{o}C having an averaged value of 19.42^{o}C. But in MON the average TEMP dropped to 19.18^{o}C and then increased to 19.7^{o}C during POM. The mean TEMP values of river water during PRM, MON and POM are 19.42, 19.18 and 19.35 respectively. It was well noted that the narrow range of temperature difference found in the river system might be due to the high runoff phenomenon seen in many tropical rivers.

pH

During PRM, pH values ranged from 6.67 to 7.13, while in MON values ranged from 7.12 to 7.99. However, during POM it ranged between 6.75 and 7.37. The mean pH values of river water during PRM, MON and POM are 6.89, 7.56 and 7.05 respectively. pH is important for acid-base neutralisation, water softening, precipitation, coagulation, disinfections and corrosion control It tends to increase during day largely due to the photosynthetic activity (consumption of carbon dioxide) and decreases during night due to respiratory activity.

Total Dissolved Solids, TDS

During PRM, TDS values ranged from 32.66 to 682.11 mg/L , while in MON values ranged from 40.45 to 52.83 mg/L. However, during POM it ranged between 44.35 and 326.90 mg/L. The mean TDS values of river water during PRM, MON and POM are 168.18, 47.52 and 91.14 respectively. It has an overall effect on the living creatures like humans, aquatic and terrestrial organisms. Hence, the influence of temperature in weathering process could aid in uplifting TDS values.

Conductivity, COND

During PRM, COND values ranged from 51.02 to 1065.80 µS/cm, while in MON values ranged from 63.20 to 82.55 µS/cm. However, during POM it ranged between 69.30 and 510.78 µS/cm. The mean COND values of river water during PRM, MON and POM are 262.7, 74.2 and 142.4 respectively.

Total Hardness, TH

During PRM, TH ranged from 9.04 to 206.79 mg $CaCO_3$, with a mean value of 53.45. The maximum concentrations were observed at S16 (Kavanattinkara) However, during MON, TH has mean value of 18.36, with maximum concentration of 23.49 at S16 station. During POM, TH ranged from 19.49 to 78.61 mg $CaCO_3$, having a mean value of 32.3. The maximum value were noted at S16. From these results it was evident that seasonal factors has got much influence in controlling the TH in the river.

Total Solids, TS

During PRM, TS ranged from 0.05 to 0.41 mg/L having a mean value of 0.13. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, TS has mean value of 0.16, with maximum concentration of 0.41 mg/L at S16 station (Kavanattinkkara). During POM, TS ranged from 0.03 to 0.31 mg/L, having a mean value of 0.1. The maximum value was noted at S16. It was observed that TS show highest values in downstream stations, with maximum concentrations were observed during MON, followed by PRM and POM. Results show that monsoon effect could be a factor which aids in elevating TS concentrations in the river.

Salinity, SAL

During PRM, SAL ranged from 0.02 to 0.58 ppt with a mean value of 0.15. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, SAL has mean value of 0.02, with maximum concentration of 0.03 ppt at S15 (Chungam) and S16 (Kavanattinkkara) stations. During POM, SAL ranged from 0.01 to 0.27 ppt (mean= 0.06). The maximum value was noted at S16. It was observed that SAL show highest values in downstream stations, while maximum concentrations were observed during PRM, followed by POM and MON. Results shows that monsoon factor has got vital influence in modifying the SAL concentrations in the river.

Dissolved Oxygen, DO

During PRM, the DO ranged from 6.35 to 7.7 mg/L with a mean value of 7.01. The maximum concentration was observed at S1 (Adivaram). However, during MON, the DO has mean value of 7.19, with maximum concentration of 7.7 mg/L at S1 (Adivaram) and S2 (Perumkulam) stations. During POM, the DO ranged from 6.5 to 7.4 mg/L, having a mean value of 6.98. The maximum value was noted at S1. It was observed that DO show highest values in upstream stations, while maximum concentrations were observed during MON, followed by PRM and POM. Results show that monsoon effect could be a factor which aids in elevating DO concentrations in the river.

Biological Oxygen Demand, BOD

During PRM, the BOD ranged from 0.45 to 1.45 mg/L with a mean value of 0.90. The maximum concentration was observed at S13 (Kottayam Railway bridge) and S16 (Kavanattinkkara) stations. However, during MON, BOD has a mean value of 0.58, with maximum concentration of 0.95 mg/L at S16 (Kavanattinkkara) station. During POM, the BOD ranged from 0.5 to 1.55 mg/L, having a mean value of 0.85. The maximum value was noted at S13 (Kottayam Railway bridge). It was observed that BOD show highest values in downstream stations, while maximum concentrations were observed during PRM, followed by POM and MON. Results show that monsoon dilution effect could be a factor which helped in lowering BOD concentrations in the river.

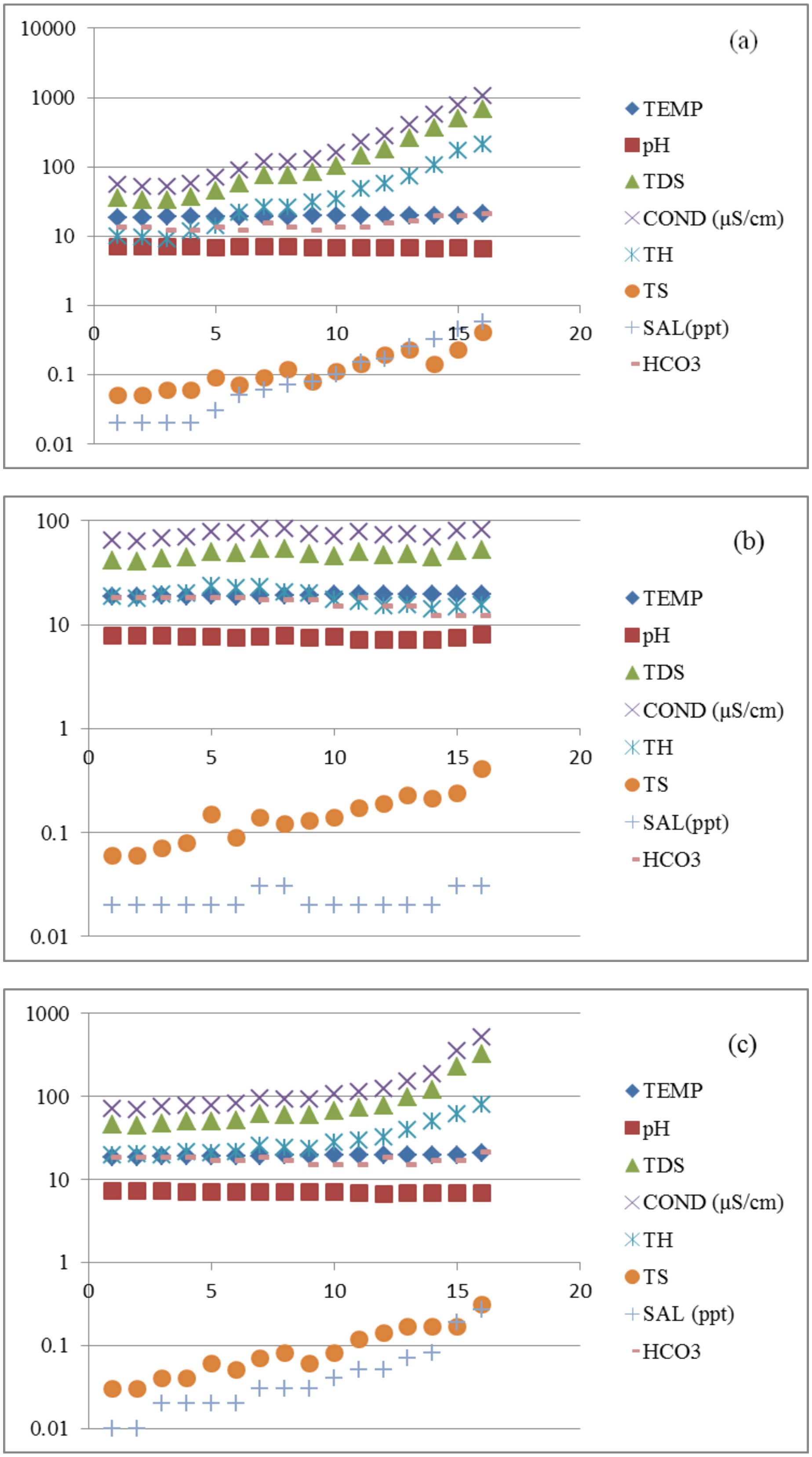


Figure 3. Mean values of River water parameters during (a) PRM (b) MON and (c) POM

Bicarbonate, HCO_3^-

During PRM, HCO_3^- ranged from 12.20 to 21.35 mg/L with a mean value of 14.97. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, HCO_3^- has a mean value of 16.44, with maximum concentration of 18.3 mg/L in upstream stations (S1-S6). During POM, HCO_3^- ranged from 15.25 to 21.35 mg/L, with a mean value of 17.25. The maximum value was noted at S16. It was observed that HCO_3^- show an erratic trend from upstream to downstream, while maximum concentrations were observed during MON, followed by POM and PRM. Results show that monsoon effect could be a factor which aids in elevating HCO_3^- concentrations in the river.

Phosphate, PO_4

During PRM, PO_4 ranged from 0.01 to 0.12 mg/L and having a mean value of 0.04. The maximum concentration was observed at S16 (Kavanattinkkara), the river mouth station. It was noted that PO_4 show an erratic trend from upstream to downstream with more fluctuations were evident in downstream stations. This could be due to the extensive agricultural practices prevailing in the downstream reaches of river basin. However, during MON, PO_4 has a mean value of 0.06, with maximum concentration of 0.18 mg/L at S16 station. It was observed that MON showed maximum concentrations of PO_4 in most stations. Runoff from agricultural lands and rubber plantation area could be the prominent source for this phenomenon. POM also show a similar pattern as that of PRM with a mean PO_4 value of 0.04 and a maximum concentration of 0.15 mg/L at S16.

Silicate, SiO_2

During PRM, SiO_2 ranged from 0.95 to 3.99 mg/L with a mean value of 1.84. The maximum concentrations were observed at S12 (Peroor). However, during MON, SiO_2 has mean value of 1.94, with maximum concentration of 3.75 mg/L at S12 station. During POM, SiO_2 ranged from 0.07 to 0.54 mg/L, having a mean value of 0.17. The maximum value were noted at S12. It was noted that maximum availability of SiO_2 was observed in midstream stations during PRM and MON. From these results it was evident that seasonal factors has got much influence in controlling the silica concentrations in the river.

Nitrite, NO_2

During PRM, NO_2 ranged from 0.02 to 0.08 mg/L with a mean value of 0.05. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, NO_2 has a mean value of 0.04, with maximum concentration of 0.09 mg/L at S16 station. During POM, NO_2 ranged from 0.03 to 0.06 mg/L, with a mean value of 0.05. The maximum value was noted at S5, S7, S11, S13 and S16. It was observed that NO_2 show an erratic trend from upstream to downstream and maximum concentrations were noted during PRM and POM. Results show that monsoon factor has got much influence in regulating the NO_2 concentrations in the river.

Nitrate, NO_3

During PRM, NO_3 ranged from 0.03 to 0.93 mg/L having a mean value of 0.21. The maximum concentration was at S16 (Kavanattinkkara). However, during MON, NO_3 has mean value of 0.09, with maximum concentration of 0.29 mg/L at S16 station. During POM, NO_3 ranged from 0.08 to 0.73 mg/L, having a mean value of 0.40. The maximum value was noted at S14 (Chungam). It was observed that NO_3 show an erratic trend, while downstream stations show maximum concentrations during PRM and POM. Results show that monsoon factor has got much influence in regulating the NO_3 concentrations in the river. The change in landuse and land cover particularly the increase in Rubber plantation in the highland and midland did not increase the NO_3 in water. However, in the lowland region, the mixed crops, paddy and coconut can contribute NO_3 into the river .

Iron, Fe

During PRM, the content of Fe ranged from 0.04 to 0.22 mg/L with a mean value of 0.07. The maximum concentration was observed at S5 (Erattupetta). However, during MON, Fe has a mean value of 0.03, with maximum concentration of 0.06 mg/L at S5 station. During POM, Fe ranged from 0.02 to 0.08 mg/L (mean = 0.04). The maximum value was noted at S5. It was observed that Fe show highest values in a particular station especially at S5 Erratupetta which is supposed to be of geogenic source. Results show that Fe is not supposed to be a contamination factor in the Meenachil river .

Magnesium, Mg

During PRM, Mg ranged from 0.38 to 34.80 mg/L having a mean value of 6.6. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, Mg has a mean value of 1.09, with maximum concentration of 1.80 mg/L at S16 station. During POM, Mg ranged from 0.79 to 11.92 mg/L, having a mean value of 3.18. The maximum value was noted at S16. It was observed that Mg show highest values in downstream stations, while maximum concentrations were observed during PRM, followed by POM and MON. Results shows that monsoon factor has got vital influence in modifying the Mg concentrations in the river.

Calcium, Ca

During PRM, Ca ranged from 3.00 to 25.43 mg/L having a mean value of 10.52. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, Ca has a mean value of 5.56, with maximum concentration of 7.35 mg/L at S5 (Erattupetta). During POM, Ca ranged from 6.31 to 11.83 mg/L, with a mean value of 7.68. The maximum value was noted at S16. It was observed that Ca show an erratic trend, while maximum concentrations were noted during PRM and POM. Results highlight that Ca show maximum availability during PRM, followed by POM and MON.

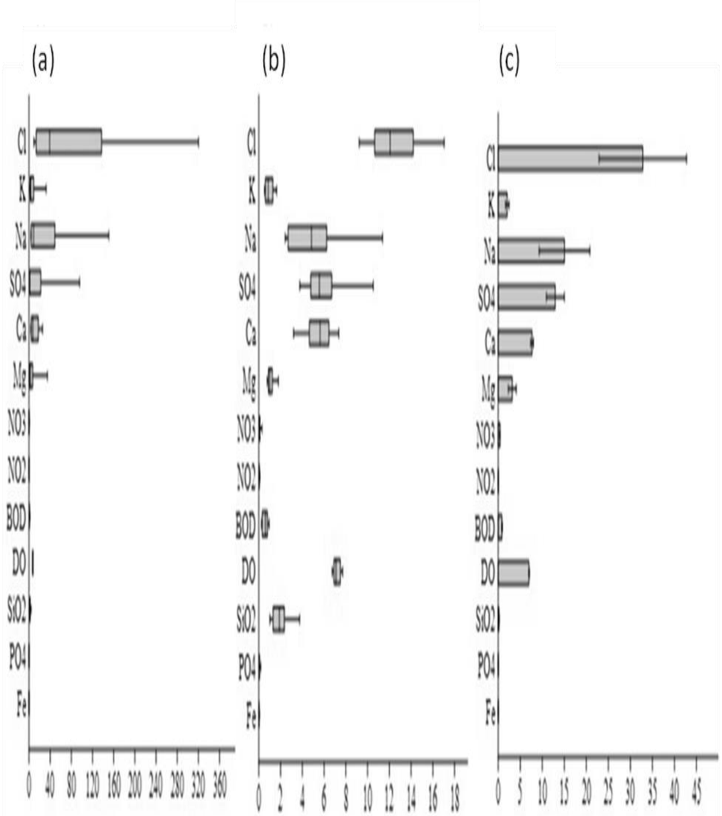
Sulphate, SO_4

During PRM, SO_4 ranged from 0.81 to 95.53 mg/L with a mean value of 14.87. The maximum concentration was at S16 (Kavanattinkkara). However, during MON, SO_4 has mean value of 6.10, with maximum concentration of 10.52 mg/L S16. During POM, SO_4 ranged from 7.33 to 36.21 mg/L, having a mean value of 12.96. The maximum value were noted at S16. It was noted that maximum availability of SO_4 was observed in downstream stations during PRM and POM. From these results it was evident that seasonal factors have got much influence in controlling the SO_4 concentrations in the river.

Sodium, Na

During PRM, the Na ranged from 3.21 to 150.70 mg/L with a mean value of 29.01. The maximum concentration was observed at S16 (Kavanattinkkara). However, during MON, Na has mean value of 5.24, with maximum concentration of 11.38 mg/L at S16. During POM, it ranged from 3.25 to 87.78 mg/L (mean= 15.04). The maximum value was noted at S16. It was noted that maximum availability of Na was observed in downstream stations during PRM and POM. From these results it was evident that dominance of lake water has got much influence in controlling the Na concentrations in the river water in downstream stations especially at S14, S15 and 16.

Figure 4. Mean values of River water nutrients during (a) PRM (b) MON and (c) POM



Potassium, K

During PRM, the content of K ranged from 1.40 to 32.26 mg/L having a mean value of 7.39. The maximum concentration was at S16 (i.e, Kavanattinkkara). However, during MON, the K has mean value of 0.97, with maximum concentration of 1.63 mg/L at S16. During POM, it ranged from 0.80 to 6.44 mg/L, having a mean value of 2.04. Again, the maximum value was noted at S16. It was noted that maximum availability of K was observed in downstream stations during PRM and POM. From these results it was evident that similar to Na, the dominance of lake water has got much influence in controlling the K concentrations in the river water especially in downstream stations.

Chloride, Cl

During PRM, Cl ranged from 9.23 to 320.21 mg/L having a mean value of 82.98. The maximum concentration was registered at S16 (i.e., Kavanattinkkara). However, during MON, Cl has a mean value of 12.68, with maximum concentration of 17.04 mg/L at S7 (Pala). During POM, Cl ranged from 7.10 to 151.23 mg/L, having a mean value of 32.82. The maximum value were noted at S16. It was noted that maximum availability of Cl was observed in downstream stations during PRM and POM. From these results, it was evident that dominance of lake water has got much influence in controlling the Cl concentrations in the river water in downstream station during PRM.

b. Correlation Analysis

During PRM (Table 2), it was noted that temperature (TEMP) plays an important role in defining the water quality structure of Meenachil river mainly owing to its good correlation with various hydrochemical parameters. Significant positive correlation was observed between TEMP and other parameters like TDS (0.86), conductivity-COND (0.86), total hardness-TH (0.85), TS (0.87), salinity-SAL (0.89), HCO_3 (0.81), Ca (0.95), Na (0.82), Cl (0.89). Meanwhile, negative correlation of TEMP with pH and DO is also of vital importance. TDS, COND, TH and TS show good positive correlations with various cations and anions like Mg, Ca, Na, K, SO_4 and Cl. However, parameters like Fe and DO do not show significant positive correlation with other ionic groups. Significant correlation among Mg, Ca, Na, K, SO_4 and Cl were noticed during this PRM season.

A completely varied water quality scenario with respect to PRM was noticed from correlation matrix of MON (Table 3). No significant positive correlation was observed here owing to the monsoon impact mainly due to dilution effect occurring in the riverine system. However, some fundamental correlations were noted between TDS and SAL (0.75), Mg (0.62), and Cl (0.93). Existence of positive correlation between Na with TS (0.89), PO_4 (0.90), SO_4 (0.91) and K (0.89) were also noted.

During POM, correlation matrix (Table 4) depicts the existence of positive correlation between TDS and TH (0.97), TS (0.90), SAL (0.99), PO_4 (0.97), Mg (0.95), SO4 (0.98), Na (0.99), K (0.96) and Cl (0.99). Similarly significant correlation of TS with PO_4 (0.90), NO_3 (0.81), Mg (0.93), SO_4 (0.94), K (0.89) and Cl (0.90) were also noted. Significant positive correlation among Mg, Ca, Na, K, SO_4 and Cl which were prevalent in PRM was also observed in POM season.

Table 2. Correlation matrix of water quality parameters during Pre Monsoon

	TEMP	pH	TDS	COND	TH	TS	SAL	HCO_3	Fe	PO_4	Si	DO	BOD	NO_2	NO_3	Mg	Ca	SO_4	Na	K	Cl
TEMP	1																				
pH	-.919**	1																			
TDS	.856**	-.821**	1																		
COND	.856**	-.821**	.996**	1																	
TH	.853**	-.818**	.995**	.995**	1																
TS	.869**	-.793**	.925**	.925**	.908**	1															
SAL	.886**	-.846**	.997**	.997**	.995**	.925**	1														
HCO_3	.808**	-.801**	.938**	.938**	.927**	.826**	.935**	1													
Fe	.022	-.114	-.126	-.126	-.149	.006	-.110	-.097	1												
PO_4	.659**	-.675**	.758**	.758**	.714**	.867**	.741**	.660**	.238	1											
Si	.666**	-.613*	.297	.297	.291	.489	.345	.331	.224	.358	1										
DO	-.608*	.751**	-.484	-.484	-.478	-.506*	-.516*	-.462	-.654**	-.569*	-.541*	1									
BOD	.758**	-.721**	.665**	.665**	.638**	.767**	.685**	.603*	.379	.705**	.532*	-.621*	1								
NO_2	.503*	-.399	.521*	.521*	.475	.607*	.517*	.501*	.270	.533*	.181	-.334	.535*	1							
NO_3	.623**	-.542*	.663**	.663**	.631**	.799**	.660**	.539*	.268	.748**	.358	-.465	.842**	.715**	1						
Mg	.782**	-.746**	.982**	.982**	.990**	.884**	.973**	.905**	-.181	.702**	.185	-.407	.577*	.449	.609*	1					
Ca	.950**	-.918**	.949**	.949**	.947**	.892**	.968**	.908**	-.065	.687**	.508*	-.602*	.727**	.497*	.633**	.892**	1				
SO_4	.759**	-.728**	.984**	.984**	.976**	.898**	.968**	.913**	-.155	.767**	.154	-.399	.598*	.511*	.644**	.986**	.878**	1			
Na	.822**	-.782**	.993**	.993**	.979**	.933**	.982**	.924**	-.122	.801**	.256	-.449	.661**	.559*	.696**	.973**	.917**	.991**	1		
K	.793**	-.775**	.988**	.988**	.990**	.874**	.980**	.926**	-.165	.714**	.175	-.434	.587*	.468	.597*	.994**	.907**	.990**	.980**	1	
Cl	.887**	-.850**	.997**	.997**	.995**	.924**	1.000**	.937**	-.114	.738**	.349	-.516*	.683**	.513*	.657**	.973**	.969**	.966**	.981**	.979**	1

Table 3. Correlation matrix of water quality parameters during Monsoon

	TEMP	pH	TDS	COND	TH	TS	SAL	HCO_3	Fe	PO_4	Si	DO	BOD	NO_2	NO_3	Mg	Ca	SO_4	Na	K	Cl
TEMP	1																				
pH	-.667**	1																			
TDS	.445	.003	1																		
COND	.445	.003	.996**	1																	
TH	-.627**	.479	.210	.210	1																
TS	.684**	-.173	.533*	.533*	-.569*	1															
SAL	.216	.330	.748**	.747**	-.001	.480	1														
HCO_3	-.652**	.298	-.234	-.234	.750**	-.819**	-.395	1													
Fe	.196	-.215	.144	.144	.050	.224	-.118	-.135	1												
PO_4	.483	.112	.482	.482	-.496	.895**	.612*	-.797**	-.068	1											
Si	.701**	-.519*	.519*	.519*	-.225	.418	.215	-.233	.387	.156	1										
DO	-.968**	.695**	-.532*	-.532*	.546*	-.663**	-.271	.654**	-.209	-.480	-.736**	1									
BOD	.929**	-.486	.560*	.560*	-.554*	.807**	.319	-.639**	.165	.650**	.571*	-.888**	1								
NO_2	.462	-.109	.227	.227	-.515*	.780**	.152	-.524*	.154	.669**	.151	-.378	.690**	1							
NO_3	.217	.201	.435	.435	-.196	.759**	.462	-.455	.193	.712**	.258	-.191	.408	.676**	1						
Mg	.061	.353	.616*	.616*	-.002	.630**	.766**	-.526*	.048	.767**	-.029	-.143	.246	.304	.638**	1					
Ca	-.605*	.316	-.032	-.032	.930**	-.761**	-.283	.890**	.028	-.742**	-.199	.560*	-.606*	-.591*	-.417	-.369	1				
SO_4	.476	-.079	.534*	.534*	-.397	.844**	.558*	-.845**	.177	.872**	.190	-.544*	.570*	.473	.572*	.840**	-.677**	1			
Na	.691**	-.235	.470	.471	-.663**	.898**	.566*	-.939**	.049	.902**	.282	-.708**	.756**	.593*	.527*	.669**	-.862**	.912**	1		
K	.851**	-.410	.503*	.503*	-.689**	.875**	.482	-.820**	.077	.770**	.504*	-.815**	.890**	.691**	.563*	.417	-.794**	.697**	.886**	1	
Cl	.539*	-.043	.932**	.932**	.066	.528*	.796**	-.317	.071	.462	.512*	-.586*	.617*	.269	.393	.498*	-.123	.450	.504*	.604*	1

Table 4. Correlation matrix of water quality parameters during Post Monsoon

	TEMP	pH	TDS	COND	TH	TS	SAL	HCO_3	Fe	PO_4	Si	DO	BOD	NO_2	NO_3	Mg	Ca	SO_4	Na	K	Cl
TEMP	1																				
pH	-.632**	1																			
TDS	.535*	-.478	1																		
COND	.535*	-.478	.996**	1																	
TH	.575*	-.603*	.971**	.971**	1																
TS	.623**	-.734**	.904**	.904**	.950**	1															
SAL	.561*	-.512*	.998**	.998**	.973**	.909**	1														
HCO_3	-.122	.176	.442	.442	.327	.282	.405	1													
Fe	-.185	-.048	-.049	-.049	-.040	.026	-.058	.120	1												
PO_4	.610*	-.504*	.966**	.966**	.928**	.904**	.964**	.386	-.093	1											
Si	.400	-.746**	.225	.225	.344	.423	.251	-.010	.114	.168	1										
DO	-.508*	.871**	-.661**	-.661**	-.771**	-.793**	-.688**	.071	-.167	-.618*	-.574*	1									
BOD	.435	-.874**	.398	.398	.540*	.708**	.426	-.184	.189	.388	.663**	-.762**	1								
NO_2	.363	-.644**	.447	.447	.518*	.636**	.466	.025	.470	.409	.320	-.733**	.663**	1							
NO_3	.488	-.820**	.580*	.580*	.704**	.813**	.595*	.102	.198	.546*	.558*	-.857**	.835**	.806**	1						
Mg	.537*	-.601*	.953**	.953**	.993**	.927**	.955**	.306	-.041	.894**	.379	-.792**	.542*	.491	.709**	1					
Ca	.649**	-.502*	.881**	.881**	.850**	.883**	.880**	.363	-.033	.916**	.120	-.538*	.433	.548*	.557*	.784**	1				
SO_4	.527*	-.540*	.979**	.979**	.990**	.939**	.975**	.383	-.020	.942**	.247	-.729**	.498*	.505*	.675**	.979**	.863**	1			
Na	.500*	-.400	.993**	.993**	.938**	.861**	.989**	.494	-.053	.965**	.157	-.590*	.311	.397	.505*	.915**	.876**	.954**	1		
K	.563*	-.532*	.981**	.981**	.980**	.899**	.981**	.353	-.048	.944**	.265	-.739**	.419	.477	.625**	.974**	.832**	.981**	.963**	1	
Cl	.556*	-.501*	.999**	.999**	.974**	.908**	.999**	.402	-.059	.965**	.245	-.679**	.419	.454	.587*	.957**	.880**	.976**	.989**	.982**	1

c. Factor Analysis (FA)

The FA result of combined data set for PRM reveals the principal component factors determining the quality of water in the river. The result (Table 5) illustrate three principal components viz., factor 1 (F1) explaining a % variance of 69.85, factor 2 (F2) (12.99) and factor 3 (F3) (6.73) respectively. From the loading chart it was quiet evident that F1 comprise of different parameters mainly TEMP, TH, SAL, Mg, Ca, SO_4, Na, K, Cl and HCO_3, signifying weathering and saline water ingress, while F2 include mainly due to TEMP and Si indicating strong influence of weathering process, and F3 highlights anthropogenic pollution mainly due to strong positive loading of Fe, PO_4, BOD, NO_2 and NO_3 along with negative loading for pH and DO.

The FA analysis for MON reveals the principal component factors determining the quality of water in the river. The result (Table 6) illustrate four principal components, viz., F1 explaining a % variance of 53.20, F2 (15.07), F3 (11.04) and F4 (7.37) respectively. From the F1 loading it is interpreted that negative loading for pH, TH, HCO_3, DO, Ca and positive loading of NO_2, PO_4, Na and K indicate role of agricultural runoff in determining the water quality of river system. The F2 explained 15.07% of variance indicate minor role of weathering process with positive loading of Si, BOD and Cl. The F3 factor explains the combined effect of SAL, Mg, and Cl, while F4 explain the effect of Fe and NO_3 in modifying the riverine environment.

During POM (Table 7), F1 loading for TH, SAL, PO_4, Mg, Ca, SO_4, Na, K and Cl explaining 67.89% variance depicts influence of agricultural as well as anthropogenic activity on the river system. F2 which explained 12.30% of variance mainly attribute to TEMP, Si, and BOD indicating role of weathering process in modifying the water quality. F3 explaining 7.78 % of variance is mainly from Fe and NO_2 and negative loading of PO_4 along with DO indicating role of instream biological process in riverine processes.

Table 5. Principal Component factors using PCA during Pre Monsoon

Rotated Component Matrix[a]			
	Component		
	1	2	3
TEMP	0.734	0.592	0.192
pH	-0.682	-0.66	-0.175
TH	0.951	0.214	0.191
SAL	0.934	0.265	0.229
Fe	-0.42	0.413	0.7
PO_4	0.597	0.258	0.57
Si	0.12	0.885	0.049
DO	-0.216	-0.736	-0.452
BOD	0.448	0.494	0.601
NO_2	0.378	-0.01	0.744
NO_3	0.481	0.178	0.747
Mg	0.961	0.102	0.188

Ca	0.859	0.453	0.181
SO_4	0.953	0.055	0.267
Na	0.939	0.142	0.3
K	0.963	0.115	0.198
Cl	0.935	0.27	0.223
HCO_3	0.891	0.249	0.173
Total	**12.57**	**2.34**	**1.21**
% of Variance	**69.85**	**12.99**	**6.73**

Table 6. Principal Component factors using PCA during Monsoon

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
TEMP	0.529	0.767	0.003	0.017
pH	-0.372	-0.55	0.554	-0.106
TH	-0.914	-0.181	0.223	-0.022
SAL	0.108	0.24	0.888	-0.045
HCO_3	-0.86	-0.258	-0.288	-0.141
Fe	-0.094	0.352	-0.057	0.767
PO_4	0.689	0.36	0.539	0.083
Si	0.009	0.835	0.071	0.301
DO	-0.427	-0.885	-0.004	-0.079
BOD	0.455	0.818	0.159	0.181
NO_2	0.563	0.192	0.02	0.548
NO_3	0.301	-0.005	0.307	0.778
Mg	0.22	-0.091	0.894	0.241
Ca	-0.939	-0.124	-0.185	-0.084
SO_4	0.551	0.305	0.588	0.283
Na	0.72	0.555	0.37	0.145
K	0.641	0.645	0.205	0.22
Cl	-0.034	0.752	0.608	0.062
Total	**9.576**	**2.712**	**1.987**	**1.326**
% of Variance	**53.202**	**15.069**	**11.037**	**7.366**

Table 7. Principal Component factors using PCA during Post Monsoon

Rotated Component Matrix[a]			
	Component		
	1	2	3
TEMP	0.299	0.856	0.151
pH	-0.514	-0.8	-0.196
TH	0.935	0.275	0.156
SAL	0.913	0.38	0.091
HCO_3	0.305	-0.628	0.375
Fe	-0.101	0.074	0.891
PO_4	0.889	0.312	-0.061
Si	0.354	0.77	0.17
DO	-0.672	-0.578	-0.305
BOD	0.459	0.778	0.305
NO_2	0.403	0.425	0.694
NO_3	0.495	0.529	0.478
Mg	0.875	0.414	0.133
Ca	0.869	0.07	0.186
SO_4	0.948	0.179	0.184
Na	0.975	0.179	0.067
K	0.941	0.235	0.132
Cl	0.927	0.35	0.076
Total	**12.219**	**2.214**	**1.401**
% of Variance	**67.885**	**12.301**	**7.783**

d. Cluster Analysis (CA)

Cluster analysis conducted for PRM (Fig.5) reveals the influence of topography and climatic influence which affect the water quality of river system. It was noted that during PRM stations 1-10 forms a cluster while 11- 15 forms another separate cluster strictly depicting a separation for stations between pollution sources . Similarly river mouth station 16 forms separate cluster indicating dominance of saline water ingress in that station. From the factor analysis it was inferred that influence of Mg, SO_4 and Cl plays a vital role in making a vast separate cluster pattern in low land stations.

While during MON cluster formation (Fig.6) strictly showed diverse patterns mainly owing to SW monsoon effect. Here small sub clusters were evident mainly due to point and non point source of pollution. Cluster formation at upland stations 1-6 indicate less pollution as compared with other clustered stations. Dominance of monsoon water in river mouth station was also highlighted here owing to the cluster formation (station 15 and 16).

Here in POM (Fig.7) also similar cluster formation as that of MON period was noticed and the availability of NE monsoon was also evident from the result. In the downstream stations (15 and 16) apart from this the closure of Thanneermukkom bund also has enormous impact in controlling the saline water intrusion. Similarly the effect of liming of agricultural land in this season also has much influence in controlling the river water chemistry in the lowland stations.

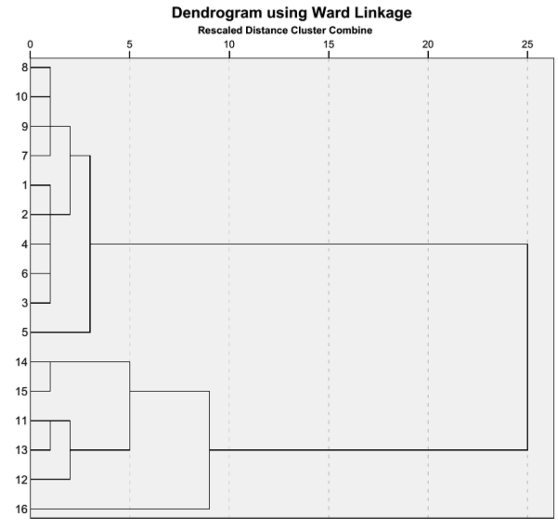


Figure 5. Dendrogram of HCA for different stations during PRM

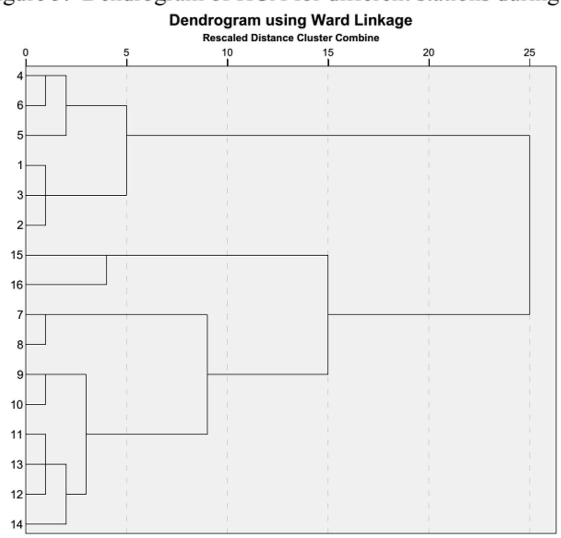


Figure 6. Dendrogram of HCA for different stations during MON

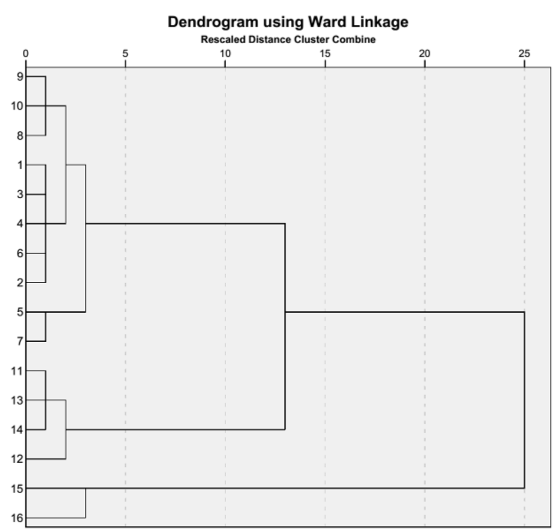


Figure 7. Dendrogram of HCA for different stations during POM

III. SUMMARY

From the study, it has been found that irrespective of seasons most of the parameters in most of the stations (except downstream S15, S16) are within permissible range for drinking purpose. River water parameters like BOD, DO, NO_2, NO_3, HCO_3, PO_4, SiO_2, and Ca, show an erratic trend with maximum contents towards the downstream side. The nutrients like NO_3, PO_4 (<1 mg/L) and SiO_2 (<4 mg/L) are generally low in the river, and increases from upstream to downstream due to the input from the agricultural field and from other sources.

The cations in the decreasing order of abundance include Na> Ca> K> Mg> Fe for PRM, Ca> Na> Mg> K> Fe for MON and Na> Ca> Mg> K> Fe for POM. Similarly, the anions in the decreasing order of abundance include Cl>HCO_3>SO_4>SiO_2>NO_3>NO_2>PO_4 during PRM, HCO_3> Cl> SO_4> SiO_2> NO_3> PO_4> NO_2 during MON and Cl> HCO_3> SO_4> NO_3> SiO_2> NO_2> PO_4 during POM.

The factor analysis result during PRM clearly indicating the role of temperature in weathering process and hence the water quality in the river system. F1 loading during MON indicate role of agricultural runoff in determining the water quality of river system. During POM, F1 loading depicts influence of agricultural as well as anthropogenic activity on the river system. Similarly, in cluster analysis , three separate clusters were getting for each of the three seasons. Generally, the stations in the highland and a part of midland (e.g., S1-S10) form one cluster, the stations from midland to lowland (e.g., S11-S14) another cluster and the stations in the downstream side (S15 & 16) form a third cluster in different seasons. However, during PRM, river mouth station S16 alone forms a separate cluster indicating dominance of saline water ingress in that station. While in POM the effect of liming of agricultural land in this watershed also has much influence in controlling the river water chemistry in the lowland stations especially S14, S15 and S16.

IV. CONCLUSION

A comprehensive river basin management strategy should be implemented in Meenachil river, especially toward downstream locations where rampant low land agricultural system prevails. Liming of agricultural lands and application of fertilisers should be in accordance with best agricultural management practices. Scientific execution regarding closure and opening of Thanneermukkom barrier has got pronounced effect in controlling salt water ingress in lower reaches of river basin.

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