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Trace Metal Quality of Meenachil River at Kottayam, Kerala (India) by Principal Component Analysis

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Abstract: A preliminary study on the water quality of the Meenachil river at Kottayam has been done with reference to pH, Electrical conductivity and trace metals for 8 stations during May 2009-September 2009. The metals analyzed included Zinc, Manganese, Iron, Lead, Copper and Cadmium. The pH was found in the range 6.23-6.94, Conductance in the range of 0.04-4.620 m.mhos/cm. The trace metal showed the range of Copper (0.03-0.35 mg/l), Iron (0.30-2.53 mg/l), Manganese (0.09-2.83), Lead (0.16-0.86 mg/l), Zinc (0.15-0.17 mg/l) and Cadmium (0.06-0.13 mg/l). Over all seasonal and locational variation was significant for Cu, Mn, Pb, Zn and Cd while all other showed non significant variation. The dominance of various trace metals in the surface water of the river Meenachil followed the sequence Fe > Pb > Mn > Cu > Cd > Zn. The metals did not showed any correlation with pH while Mn and Cd showed good correlation with EC. The Factor analysis revealed that Fe, Pb, Zn, Mn, Cd and EC were the most important parameters affecting the water quality of Meenachil river for both the seasons.

Key word: Meenachil river · Water quality · Trace metals · Pre-monsoon · Post monsoon

INTRODUCTION

With exploding population, increasing industrialization and urbanization, water pollution by agricultural, municipal, domestic and industrial sources has become a major concern for the welfare of mankind. Surface waters are most vulnerable to pollution due to their easy accessibility for disposal of waste waters [1]. Rivers play a major role in assimilating or carrying industrial and municipal waste water, runoff from agricultural fields, roadways and street which are major sources of pollution. Among various organic and inorganic water pollutants, metal ions are toxic, dangerous and harmful because of their carcinogenic nature. Trace metals and their toxicity is the concern of present day by virtue of their universal usage in all spheres of life [2]. Since rivers constitute the main inland water resource for domestic, industrial and irrigation purposes, the monitoring of toxic trace metal pollutants in river water has received great attention.

The studies conducted by several researchers on some of the important rivers around the world and in India revealed that, in recent years most of these rivers are polluted. Kar *et al.* studied the heavy metal pollution of river Ganga and found out that Fe, Mn, Zn, Ni, Cr and Pb were detected in more than 92 % of the samples in the range of 0.025-5.49, 0.025-2.72, 0.012-0.370, 0.012-0.375, 0.001-0.044 and 0.001-0.250 mg/l respectively [3] and Latimer *et al.* studied the metal pollution of the Pawtuxet river and found out that locations nearest to point source outfalls showed elevated metal concentrations [4]. Suratman *et al.* studied distribution of trace metals in Besut river, Malayasia and found that metal concentrations were higher during wet monsoon season [5]. Pollution potential of toxic metals in Yamuna river was studied by Ali and Jain [6] and the results showed that the river water is not safe due to high levels of toxic metals. Evaluation of heavy metals loading in river Ijana, Nigeria was done by Emoyan *et al.* [7] and found that the river is fairly polluted due to the presence of Cd, Cr, Cu, Fe, Ni, Pb and Zn. Tripathi *et al.* [8] studied the trace metal quality of river Gomti in Lucknow and found that except Fe, all other heavy metals such as Pb, Cu, Zn and Cr levels were within the limit. Trace metal pollution of Umtata river

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of South Africa was studied by Fatoki *et al*. [9] and observed high levels of Al, Cd, Pb, Zn and Cu in the river water.

Meenachil river which is one of the important rivers in Kerala, emerges from Western ghats, flows through the taluks of Meenachil, Vaikom and Kottayam and ending into Vembanad Lake. This river has a total length of 78 km and has a catchment area of 1272 sq.km. The entire Meenachil watershed area geographically lies between $9^{\circ}25'$ N to $9^{\circ}55'$ Nlatitudeand $76^{\circ}30'$ E to $77^{\circ}00'$ E longitude. The river has 38 tributaries including major and minor ones. The Meenachil river basin falls within the realm of tropical climate and the temperature of the area varies in between 24°C and 32°C throughout the year. The Meenachil river basin mainly comprises of Precambrian metamorphic rocks and the major rock types are quartzite, charnokite, garnetiferous biotite gneiss and pink/gray granite. The major soil type prevalent in the area is well drained laterite soils followed by riverine alluvium soils and forest soils [10]. The studies on Meenachil river water quality at Kottayam town area on pH, Electrical conductivity and some of the selected trace metal concentration during pre and post monsoon seasons of the year 2009 has been discussed in this paper.

MATERIALS AND METHOD

In order to prepare the location map of the study area, Survey of India toposheet (No. 58 C/6 and C/10) were used and the map was prepared with the help of Map info software. To carry out the present study of trace metal quality of Meenachil river at Kottayam town area, 8 sampling stations namely Nattasseri, Nagampadom, Chungam, Aimanam, Thazhathangadi, Kodimatha, Illickal and Kumarakom were selected. These sampling stations are shown in Fig. 1 and cover the upstream and

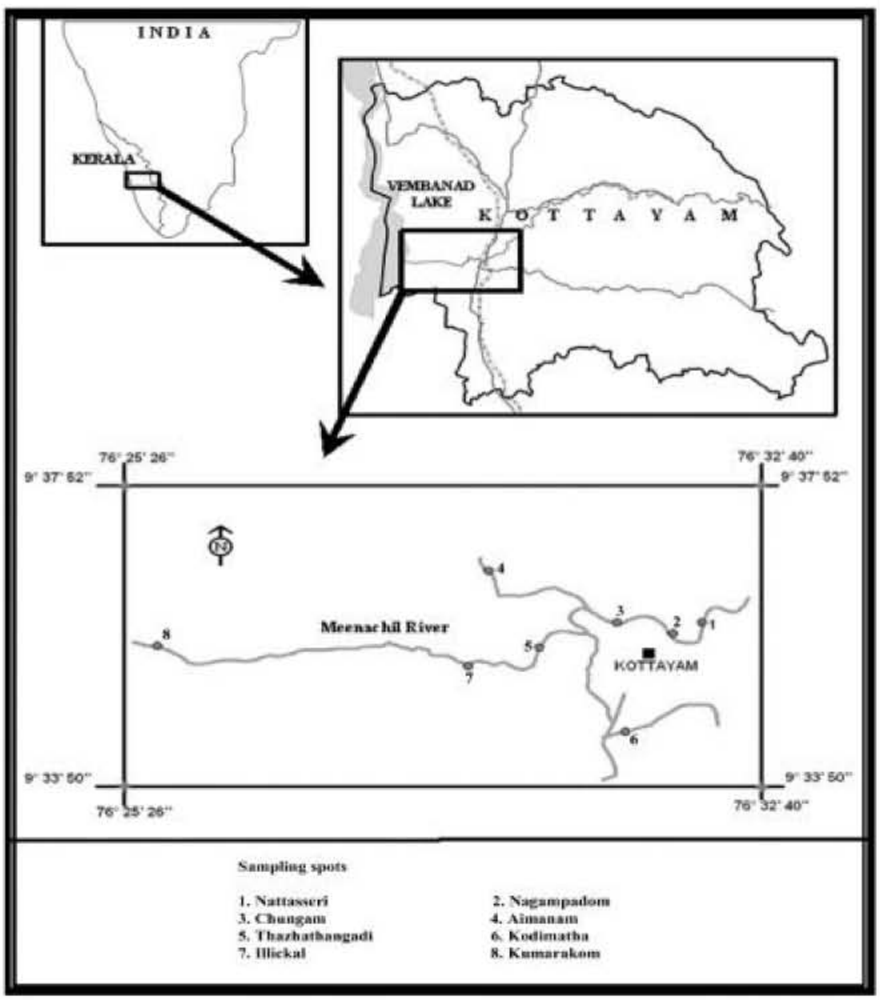

Fig. 1: Location map of the study area

downstream of the Meenachil river basin. Sampling was carried out during the pre-monsoon (May 2009) and post monsoon period (September 2009) of S-W monsoon. The water samples were collected in polythene bottles from the midstream of the river at 15 cm depth using a standard water sampler as prescribed by *Bureau of Indian Standards* [11]. The pH of the water samples was determined using pH meter (ELICO LI-127), conductivity was measured by conductivity meter (ELICO CM 180). For the analysis of trace metals, the samples were kept in polythene bottles at 4°C with the addition of 2 ml concentrated HNO_3 for one litre to avoid precipitation. Trace metals were determined after a digestion with nitric acid in an *Atomic Absorption Spectrophotometer (ELICO SL-176 with minimum detection limit of 0.003 mg/l)* [12]. The data obtained was subjected to statistical analysis to test the significance of difference of each parameters with season and location using t-Test, to do Factor analysis and to do correlation studies among all the parameters using SPSS statistical package.

RESULTS AND DISCUSSIONS

The analytical data obtained from the present study were compared with the drinking water standards of Bureau of Indian Standards (BIS) [13] and World Health Organization (WHO) [14] and (Table 1) to find out the suitability of this river water for drinking purpose.

Water samples exhibited pH values in the range of 6.24 to 6.94 with an overall mean of 6.62, with no significant difference between locations ($p>0.05$) in both periods (pre and post monsoon). However seasonal mean pH values significantly differed between both periods with means of 6.71 in pre-monsoon and 6.53 in post monsoon (Table 2). The possible reasons for the decrease in pH could be an outcome of sewage and disposal of domestic wastes [15]. Another reason may the runoff from agricultural sites as the entire study area is surrounded by agricultural land [16]. Although the observed values were well within the BIS permissible limit for drinking water (except for stations no. 3 and 8 for pre-monsoon and 5,6,7 and 8 for post monsoon), all the stations did not satisfied the drinking water standards for both seasons according to WHO. The observed values for electrical conductivity ranged from 0.042 to 4.620 with an overall mean value of 0.53 m.mhos/cm (Table 2). The mean seasonal values of conductivity ranged from 0.07 to 0.98 m.mhos/cm. According to WHO and BIS, during pre-monsoon, all the locations showed higher values than the permissible limits. The lowest conductivity during post monsoon period may be due to the dilution effect of rain water [3]. Regarding the highest conductivity (4.62) at station 8, the downstream station might be due to the intrusion of saline water from Vembanad lake during the tidal time [17]. With regard to other stations, the addition of domestic sewage and wastes into the river water might have increased the electrical conductivity [18]. In addition to that, the salt load can also be increased due to agricultural run off [19]. The test of significance revealed that EC change was significant between locations and it was insignificant between seasons.

The concentration of trace metals obtained for Meenachil river water during pre and post monsoon seasons in the 8 sampling stations are summarized in Table 3. From the present study, it was revealed that, a general tendency of increasing the iron content during post monsoon was observed throughout the entire study area. The iron content ranged from 0.3 to 2.53 mg/l with an over all mean of 1.32 mg/l. The seasonal mean values ranged from 0.79 to 1.85 mg/l. When compared with the BIS standards, the iron content was on the higher side for both pre and post monsoon in all the locations. According to WHO standards, post monsoon period showed higher iron content. The pre-monsoon period showed lower value with the exception of locations No. 6 and 8. Since there is no major industrial activity in the study area, during post monsoon, the major reason for the increase in Fe content might be due to the terrestrial runoff from the rocks present in the area. Charnockite groups of rocks are the prevalent rock type in the basin [20] which are rich in iron. They might have undergone weathering and erosion process during monsoon period. Another reason for the increase in Fe content might be due to the run off from domestic wastes and other urban wastes [21]. The t-Test showed that there existed a significant change in the iron content between locations and an insignificant change occurred between seasons.

The lead content ranged from 0.16 to 0.86 mg/l with an overall mean value of 0.55 mg/l. The seasonal mean values ranged from 0.33 to 0.76 mg/l. The analytical data of Pb content showed that during post monsoon all the stations recorded higher values than the WHO and BIS permissible limits. While during pre-monsoon it was on the higher side for location no. 1, 7 and 8. The excess of Pb content in water might be due to terrestrial run off from sewage effluent and through seepage from waste sites in accordance with the studies done by [9]. The excess of Pb content is also due to the runoff from agricultural fields where phosphorous fertilizers are applied, in which lead is one of the impurity [22]. The t-Test data showed that

Table1: Drinking water quality standards

Parameters	Drinking water standards WHO	BIS
pH	7.0-8.5	6.5-8.5
Electrical conductivity (m.mhos/cm) (m.mhos/cm)	0.30	0.25
Total Dissolved Solids (mg/l)	500	500
Iron (mg/l)	0.5	0.3
Manganese (mg/l)	0.5	0.1
Copper (mg/l)	2.0	0.05
Zinc (mg/l)	3.0	5.0
Cadmium (mg/l)	0.003	0.01
Lead (mg/l)	0.01	0.05

Table 2: Chemical characteristics of Meenachil river water at Kottayam

	pH		Electrical Conductivity (m.mhos/cm)	
Location No.	PRM	PM	PRM	PM
1	6.92	6.77	0.394	0.042
2	6.94	6.78	0.340	0.049
3	6.45	6.77	0.402	0.075
4	6.92	6.55	0.892	0.060
5	6.88	6.23	0.434	0.051
6	6.77	6.28	0.404	0.048
7	6.55	6.34	0.375	0.049
8	6.24	6.49	4.620	0.167
Min	6.24	6.23	0.340	0.042
Max	6.94	6.78	4.620	0.167
Mean	6.71	6.53	0.98	0.07

PRM : Pre-monsoon PM: Post monsoon

Table 3: Trace metal content of Meenachil river water at Kottayam

	Iron (mg/l)		Lead (mg/l)		Cadmium (mg/l)		Zinc (mg/l)		Manganese (mg/l)		Copper (mg/l)	
Location No.	PRM	PM	PRM	PM	PRM	PM	PRM	PM	PRM	PM	PRM	PM
1	0.30	1.68	0.42	0.69	0.08	0.07	Nd	0.15	0.09	0.12	0.23	0.03
2	0.30	2.53	Nd	0.69	0.09	0.06	Nd	0.17	0.30	0.20	0.08	0.06
3	0.30	1.59	Nd	0.75	0.11	0.06	Nd	0.17	0.13	0.12	0.04	0.06
4	0.46	1.78	Nd	0.80	0.11	0.07	Nd	0.16	0.13	0.12	0.35	0.09
5	0.38	1.78	Nd	0.75	0.11	0.06	Nd	0.16	0.13	0.12	0.04	0.09
6	1.93	2.15	Nd	0.86	0.09	0.07	Nd	0.17	0.13	0.14	0.12	0.09
7	0.38	1.68	0.42	0.75	0.11	0.07	Nd	0.16	0.13	0.12	0.35	0.09
8	2.26	1.59	0.16	0.80	0.13	0.06	Nd	0.17	2.83	0.20	0.04	0.06
Min	0.30	1.59	0.16	0.69	0.08	0.06	--	0.15	0.09	0.12	0.04	0.03
Max	2.26	2.53	0.42	0.86	0.13	0.07	--	0.17	2.83	0.20	0.35	0.09
Mean	0.79	1.85	0.33	0.76	0.10	0.07	--	0.16	0.48	0.14	0.16	0.07

Nd : Not detected PRM: Pre-monsoon PM : Post monsoon

Table 4: KMO-Batlett's test of sphericity

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.593
Bartlett's Test of Sphericity	Approx. Chi-Square	133.300
	Df	28
	Sig.	.000

Table 5: Correlation matrix of different parameters of Meenachil river water

	pH	EC	Cu	Fe	Mn	Pb	Zn	Cd
pH	1.000							
EC	-.282	1.000						
Cu	.261	-.052	1.000					
Fe	-.481	.160	-.480	1.000				
Mn	-.375	.975	-.206	.306	1.000			
Pb	-.420	-.377	-.212	.587	-.225	1.000		
Zn	-.367	-.422	-.421	.679	-.260	.925	1.000	
Cd	.057	.662	.308	-.477	.522	-.822	-.870	1.000

Bold values indicates strong correlation

Table 6: Variance explained by two principal components for Meenachil river water

	Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %
1	3.342	41.777	41.777
2	3.012	37.655	79.432

Table 7: Factor loading (rotated using varimax method) for water quality data of Meenachil river

	Component	
	VF1	VF2
pH	-.667	
EC		.972
Cu	-.605	
Fe	.886	
Mn		.943
Pb	.785	
Zn	.840	-.503
Cd	-.604	.749

Bold values indicate strong loadings

there existed a significant change between the seasons and locations under study. In the case of Cadmium, the analytical data was much above the permissible limit of WHO and BIS for both the seasons. The entire area recorded a minimum value of 0.06 mg/l and a maximum values of 0.13 mg/l with an overall mean value of 0.09 mg/l. The seasonal mean values ranged from 0.07 to 0.10 mg/l. The possible sources of contamination of Cd might be due to the runoff from agricultural soil. The entire study area is covered by agricultural land where rock phosphate is used as phosphorous fertilizers. Cadmium is found to be an important impurity in the phosphorous fertilizers as supported by [23] and [24]. The test of significance showed that there existed a significant seasonal and locational change for cadmium.

The Zn, Mn and Cu contents ranged from non-detectable limit to 0.17, 0.09 to 2.83 and 0.03 to 0.35 mg/l respectively. The seasonal mean values for Zn, Mn and Cu were 0.16, 0.14 to 0.48, 0.07 to 0.16 respectively. The study shows that, the Zn content was well within the WHO and BIS permissible values invariably among all the stations for both the seasons. A minor increase of Zn level was observed from pre-monsoon to post-monsoon which might be due to agricultural runoff from the surrounding areas as recorded by [8]. In the case of Mn, a major increase was observed at station 10 during pre-monsoon as per WHO standard. According to BIS, almost all the locations showed higher concentration for both seasons. The Cu content was within the WHO permissible limits for all the locations. But according to BIS, except location 5, 7 and 10, all other locations showed higher levels during pre-monsoon and during post-monsoon except location 1 and 3, all other locations showed higher concentrations. The higher Mn and Cu concentrations might be due to the addition of sewage and domestic wastes in the river [21]. The t-Test data showed that the seasonal and locational change for Zn, Mn and Cu was significant.

Kaiser Meyer Olkin (KMO) and Bartlett's test was initially performed on the water quality data set to measure the sampling adequacy that indicates the proportion of variance which is common variance, i.e. which might be caused by underlying factors. The KMO measure of sampling adequacy value close to 1.0 and > 0.50 generally indicate that a factor analysis may be useful [1] and [25] which is the case in this study KMO = 0.593. The KMO and Bartlett's test of sphericity indicates the suitability of water quality data for Factor Analysis (FA) and shows that the correlation matrix is an identity matrix which would indicate that variables are unrelated [26]. The significance level which is zero in this study (less than 0.05) indicates that there are significant relationship among variables. The results of KMO and Bartlett's test are shown in Table 4.

Factor Analysis was applied on the water quality data set to evolve the correlation matrix for different parameters. Only those with correlation values higher than 0.50 were considered [27]. The correlation among the physico-chemical properties (pH, electrical conductivity) of water and different heavy metal concentrations were also studied and the results are presented in Table 5. The pH of the water did not show any correlation with other parameters. EC showed significant positive correlation with Mn (.975) and Cd (0.662). Among the trace metals themselves, Iron showed a very good positive correlation with Pb (0.587) and Zn (0.679). Mn showed a significant positive correlation with Cd (0.522) only while Pb showed significant positive correlation with Zn (0.925) and negative correlation with Cd (-0.822). In the case of Zn, the significant negative correlation existed with Cd (-0.870). Cu did not show any correlation between metals. The correlation study among trace metals will help to understand the nature of these metals and their species speciation in the aquatic environment [3].

Factor Analysis was also applied on the water quality data set by varimax rotation mode to identify the imperative seasonal water quality parameters. Eigen values gives a measure of the significance of the each factors. The factor with highest eigen values are considered as the most significant one and eigen values of 1.0 or greater are considered significant [24]. Factor loading is classified as strong, moderate and weak corresponding to absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30 respectively [25]. Factor Analysis of the entire data set evolved Two Principal Components (PCs) with eigen values > 1.0 explaining about 79.43 % of the total variance in the water quality data set (Table 6). The first factor (VF1) accounting for 41.77 % of total variance and has strong positive loading with Fe, Pb, Zn and moderate negative loading with pH, Cu and Cd indicating the metal group (Table 7). The main source of this group comprises of both natural (rock weathering) and organic pollution (domestic wastes disposal, agricultural and sewage run off). The second factor VF2 accounting for 37.65 % of the total variance and has strong positive loading with EC, Mn and Cd and moderate negative loading with Zn which again indicates natural (saline water intrusion) and organic sources of pollution. The results from Factor Analysis suggested that, it did not result in any significant data reduction. The variations in water quality are explained by all the 8 parameters to explain 79.43 % of total variance. However, the analysis helped to identify the most important parameter contributing in Meenachil river quality during the study period and also to know the source of pollution. In this study, water quality parameter with a strong factor loading (> 0.75) was considered to be a significant parameter contributing to seasonal variations of the water quality in Meenachil river [27]. Table 7 revealed that, Fe, Pb, Zn, EC, Mn and Cd are the most important parameters affecting the water quality of Meenachil river water for both the seasons.

CONCLUSIONS

In the present study, the Meenachil river water was analyzed for its pH, EC and trace metal concentrations. The overall water quality data indicated that, Kumarakom location was the most polluted area. All the studied parameters of this location did not satisfy the drinking water standards (WHO / BIS). Considering the status of heavy metal concentrations in water, it may be concluded that the river water from the entire study area as such is not suitable for drinking purpose due to the excess concentration of Fe, Pb and Cd since these metal ions are extremely toxic and the consumption of this river water may cause serious health problems as Meenachil river is one of the major source of drinking water in Kottayam town area. Since there is no major industrial activity in the study area, the excess heavy metal load of river water can be attributed to the discharge of domestic wastes, sewage from urban areas, agricultural run off and the rock type of the river basin. This study reveals that, the assessment of trace metals for one particular season is not sufficiently representative for any assumption. The data evolved through this present study provides some indicative trend for further future studies.

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Notations:

Al	Aluminium
BIS	Bureau of Indian Standards
°C	Degree Celsius
Cd	Cadmium
Cr	Chromium
Cu	Copper
EC	Electrical Conductivity
Fe	Iron
KMO	Kaiser Meyer Olkin
mg/l	Milligram per litre
Mn	Manganese
Ni	Nickel
Pb	Lead
PC	Principal Component
pH	Potential Hydrogen
Zn	Zinc

REFERENCES

1. Singh, K.P., A. Malik, D. Mohan and S. Sinha, 2004. Multivariate statistical techniques for the evaluation of spatial and temporal variation in water quality of Gomti river (India)-a case study. Water Research, 38: 3980-3992.
2. Sinha, D.K. and Navneet, Kumar, 2006. Monitoring of trace metals in Gagan river water at Moradabad. Indian J. Environ. Protection, 26(6): 516-520.
3. Kar, D., P. Sur, S.K. Mandal, T. Saha and R.K. Kole, 2008. Assessment of heavy metal pollution in surface water. Int. J. Environ. Sci. Tech., 5(1): 119-124.
4. Latimer, J.S., C.G. Carey, E.J. Hoffman and J.G. Quinn, 1988. Water quality in Pawtuxet river: Metal monitoring and geochemistry. Water Resources Bulletin, pp: 791-800.
5. Suratman, S., H.C. Hang, N.A.M. Shazili and N. Mohd Tahir, 2009. A preliminary study of the distribution of selected trace metals in the Besut river basin, Terengganu, Malaysia. Bull. Environ. Contam Toxicol., 82: 16-19.
6. Ali, I. and C.K. Jain, 2001. Pollution potential of toxic metals in the Yamuna river at Delhi, India. J. Environ. Hydrol., 9(12): 1-9.
7. Emoyan, O.O., F.E. Ogban and E. Akarah, 2006. Evaluation of heavy metals loading of river Ijana in Ekpan-Warri, Nigeria. J. Appl. Sci. Environ. Mgt., 10(2): 121-127.
8. Tripathi, C.P., N.K. Singh and D.S. Bhargava, 2006. Qualitative assessment of river Gomti in Lucknow emphasizing the trace metals. J. Instn Engrs India. Pt En., 87(9): 27-34.
9. Fatoki, O.S., N. Lujiza and A.O. Ogunfowokan, 2002. Trace metal pollution in Umtata river. Water SA., 28(2): 183-189.
10. Watershed Atlas, 1998. Kerala State Land Use board. Govt. of Kerala Publications, Kerala, India.
11. Bureau of Indian Standards, 1987. IS: 3025. Methods of sampling and test (physical and chemical) for water and waste water: Part I, Sampling. Bureau of Indian Standards, New Delhi, India.
12. APHA, 1998. Standard methods for examination of water and waste water (19th Edn). American Public Health Association, Washington. D.C. 2005.U.S.A.
13. Bureau of Indian Standards, 2003. IS: 10500: Indian standard-Drinking water specification. Bureau of Indian Standards, New Delhi, India.
14. World Health Organization, 1993. Guidelines for Drinking Water Quality. World Health Organization, Geneva, Switzerland.
15. Chaudhary, S., Anuradha and K.V. Sastry, 2004. Pollution of river Yamuna at Faridabad (Haryana). Polln. Res., 23(4): 749-756.
16. Vijith, H. and R. Satheesh, 2007. Geographical information system based assessment of spatio-temporal characteristics of groundwater quality of upland sub-watershed of Meenachil river, parts of Western Ghats, Kottayam District, Kerala, India. Environ. Geol., 53: 1-9.
17. Gupta, B.K. and R.R. Gupta, 1999. Physico-chemical and biological study of drinking water in Satna, Madhya Pradesh. Polln. Res., 18: 523-525.

18. Mahdieh, Eisakhani and Amirhossein Malakahmad, 2009. Water Quality Assessment of Bertam River and its Tributaries in Cameron Highlands, Malaysia. World Appl. Sci. J., 7(6): 769-776.
19. Vikram, Bhardwaj, Dhruv Sen Singh and A.K. Singh, 2010. Water quality of the Chhoti Gandak river using principal component analysis, Ganga plain, India. J. Earth Syst. Sci., 119(1): 117-127.
20. Geological Survey of India, 2002. District Resource Map (Geology and minerals) of Kottayam District, Kerala. Geological Survey of India, Kolkata.
21. Neal, C., H.P. Jarvie, B.A. Whitton and J. Gemmell, 2000. The water quality of the river Wear, north-east England. Sci. Total Environ., 251/252: 153-172. doi: 10,1016/S0048-9697 (00) 00408-3.
22. Ramachandra, T.V., 2006. Soil and groundwater pollution from agricultural activities. Central publishing company, New Delhi.
23. Cherian, M.G. and A.A. Goyer, 1989. Cadmium toxicity. Comments Toxicol., 3: 191-206.
24. Shrestha, S. and F. Kazama, 2007. Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. Environ. Modeling and Software, 22: 464-475.
25. Liu, C.W., K.H. Lin and Y.M. Kuo, 2003. Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. Sci. Tot. Environ., 313: 77-89.
26. Chen, K., J.J. Jiao, J. Huang and R. Huang, 2006. Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China. Environmental Pollution. Doi: 10.1016/j. envpol. 2006.09.02.
27. Pejman, A.H., G.R. Nabi Bidhendi, A.R. Karbassi, N. Mehrdadi and M. Esmaeil, Bidhendi, 2009. Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. J. Environ. Sci. Tech., 6(3): 467-476.