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Metal Pollution of Groundwater in the Vicinity of Valiathura Sewage Farm in Kerala, South India

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Abstract A comprehensive study was conducted to evaluate metal pollution of groundwater in the vicinity of Valiathura Sewage Farm in Thiruvananthapuram district, Kerala using the Heavy Metal Pollution Index (HPI). Forty two groundwater samples were collected during the summer season (April 2010) and the concentration of metals Fe, Cu, Zn, Cd and Pb were analyzed. Results showed that groundwater was contaminated mainly with Fe, Cu and Pb. Correlation analysis revealed that the sources of metals in groundwater in the study area are the same, and it may be due to the leachates from the nearby Sewage Farm, Parvathy Puthanar canal and solid wastes dumped in the residential area. Of the groundwater samples studied, 47.62 % were medium and 2.68 % were classified in HPI high category. HPI was highest (41.79) in DW29, which was adjacent to the polluted Parvathy Puthanar canal and Sewage Farm. The present study points out that the metal pollution causes the degradation of groundwater quality around the Sewage Farm during the study period.

Keywords Water quality · Correlation analysis · Parvathy Puthanar · Dug well · Solid waste

Groundwater is a major source of fresh drinking water in both rural and urban regions in the developing world. Groundwater quality is deteriorating due to different anthropogenic activities. Current urbanization, industrialization and mining developments release various pollutants to surface and groundwater bodies. Among these, metals are a major pollutant in water sources (Kumar et al. 2003). Metal pollution in water bodies may be from natural (geological) or possibly anthropogenic (from fertilizers, pesticides, untreated sewage and solid wastes) processes (Singh 2005). Groundwater with excess metals is an environmental concern because they are non-biodegradable. Metals tend to accumulate in plants and animals causing chronic adverse effects on human health (Shrivastava and Mishra 2011). Metal contamination of groundwater and its toxicity was studied by various authors (Ramesh et al. 1995; Karatas and Dursun 2006; Obri 2007; Venugopal et al. 2009; Thomas et al. 2011; Ghosh et al. 2012; Hussain and Sheriff 2013). The Heavy Metal Pollution Index (HPI) is an effective method to evaluate the metal pollution of surface and groundwater (Prasad and Sangita 2008; Kumar et al. 2012; Sheykhi and Moore 2012).

Valiathura Sewage Farm is situated in the coastal area of Thiruvananthapuram district and is comprised of 43.706 hectares. The Sewage Farm is maintained by the Dairy Development Department, Kerala state, where fodder grass cultivation is carried out. Sewage water from Thiruvananthapuram city is collected in the sewage pumping station at Kuriathy and then pumped to Valiathura Sewage Farm before being disposed for irrigation. 'Parvathy Puthanar', a man made canal is flowing adjacent to the Sewage Farm. After irrigation, the excess sewage water directly drains to the nearby Parvathy Puthanar offering the potential for pollution (Unnikrishnan 2004; Chithra and Jaya 2005). Since the study area is densely populated, people usually dispose their solid wastes to adjacent water sources and open yards.

The main groundwater abstraction structures for domestic and agricultural purposes are dug wells, bore wells and tube wells. In the crystalline and lateritic terrain the groundwater is developed through dug wells and bore

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wells, while along the coastal alluvium the groundwater is developed through dug wells, filter point wells and tube wells. Since the degree of geological weathering is low, the shallow bore wells vary in depth from 6 to 13 m. The most potential aquifer in the area has an average yield of 10–60 m^3 day^{-1} (CGWB 2008).

The people living around the Sewage Farm depend on various groundwater sources for their domestic needs. A literature review shows no previous studies conducted on the metal content of groundwater in Valiathura. Therefore the present study is an attempt to examine the metal pollution of potable groundwater sources in the vicinity of Valiathura Sewage Farm in Thiruvananthapuram district.

Materials and Methods

The study area is located between longitude 76°54′51″E–76°57′33″ E and latitude 8°26′26″N–8°29′29″N. The location of the study area is provided in Fig. 1. For this study, 42 groundwater bodies were selected which include dug wells (n = 29) and bore wells (n = 13), at an interval of 0.5–2 km in the northern, southern, eastern and western direction of the Sewage Farm during April 2010. Dug wells in the study area were shallow with a total depth ranging from 1.5 to 5.1 m, and the diameter ranged from 0.7 to 1.15 m. The depth of bore wells ranged between 7 and 25 m. Water samples were collected in pre-cleaned polyethylene bottles (1 L) and labeled appropriately. Water samples were carried to the laboratory within an hour and subjected to nitric acid digestion for metal analysis (APHA 1995). To 500 mL water sample, we added 5 mL concentrated nitric acid and digested the sample in a digestion chamber. Afterwards, the sample was made up to 50 mL volume and filtered using 0.45 μm membrane filter paper. Filtered water samples were analyzed for Cu, Zn, Cd, Pb and Fe using an Atomic Absorption Spectrophotometer (GBC 932 AA model, Dandenong, Victoria, Australia). The instrument is equipped with single element hollow cathode lamp and air-acetylene burner. The AAS was calibrated with different concentrations of standard solutions of the metals. Working standards were prepared from the standard stock solutions (Merck, Darmstadt, Germany) of Zn (HCO90983, 1,000 ± 2 mg L^{-1}), Cd (HCO86902, 1,000 ± 2 mg L^{-1}), Fe (HCO81154, 1,000 ± 2 mg L^{-1}), Pb (HCO95295, 1,000 ± 2 mg L^{-1}) and Cu (HCO96351, 1,001 ± 2 mg L^{-1}). Mean values of three replicates were taken for each metal determination. Limits of detection for Zn, Cd, Fe, Pb and Cu were 0.008, 0.009, 0.05, 0.06 and 0.025 μg mL^{-1}, respectively. Correlation analysis was performed using Statistical Package for Social Sciences (SPSS, Version 17). The HPI was calculated using the equation given by Mohan et al. (1996)

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

where Q_i is the sub index of the *i*th parameter, W_i is the unit weight of the *i*th parameter and n is the number of parameters considered. The sub index (Q_i) of the parameter is calculated by

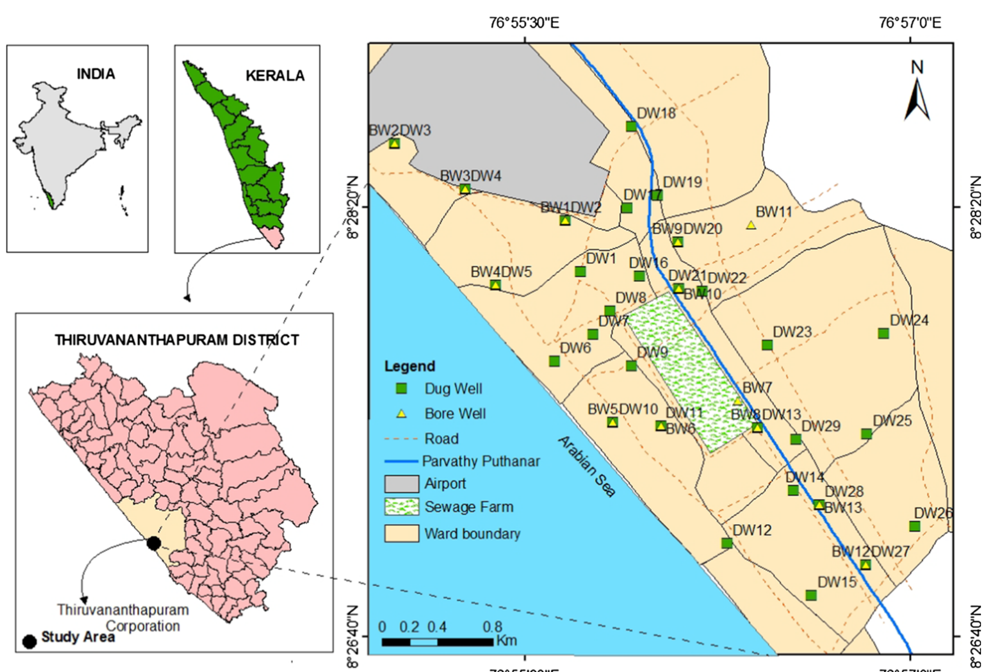

Fig. 1 Location map of study area showing Sewage Farm and sampling wells

Table 1 Metal concentration (mg L^{-1}) in groundwater sources around the Valiathura Sewage Farm

Metals	Dug well n = 29				Bore well n = 13			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Fe	0.03	0.94	0.29	0.22	0.08	2.38	0.47	0.62
Zn	0.03	0.26	0.11	0.07	0.02	0.19	0.11	0.06
Cd	0.001	0.003	0.001	0.001	0.001	0.002	0.001	0.000
Cu	0.01	0.33	0.10	0.10	0.03	0.30	0.12	0.11
Pb	0.01	0.06	0.03	0.01	0.02	0.06	0.04	0.02

SD standard deviation

Table 2 Correlation matrix of metals in groundwater around the Valiathura Sewage Farm

Metals	Fe	Zn	Cd	Cu	Pb
Fe	1.000	0.342*	0.011	0.454**	0.460**
Zn		1.000	0.342*	0.425**	0.594**
Cd			1.000	0.558**	0.655**
Cu				1.000	0.830**
Pb					1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \times 100 \quad (2)$$

where M_i is the monitored value of metal of the *i*th parameter, I_i is the ideal value of the *i*th parameter, S_i is the standard value of the *i*th parameter. The sign (−) indicates the numerical difference of the two values, ignoring the algebraic sign.

HPI was developed by assigning unit weightage (W_i) for each metal. The rating is based on the value between 0 and 1 which reflect the importance of the individual water quality considerations and defined as inversely proportional to the recommended standards for each metal (Mohan et al. 1996; Kumar et al. 2012). For HPI calculation, Indian drinking water standards (BIS 1991) were selected.

Results and Discussion

Results of the metal concentrations in dug wells and bore wells are presented in Table 1. Samples were compared with regional (BIS 1991) and International (WHO 2011) drinking water standards. The Fe content in about 27.5 % dug wells and 38.4 % bore wells were above the desirable limit (0.3 mg L^{-1}) prescribed by BIS (1991). Among the dug well and bore well samples, high Fe concentration was recorded at BW7, which was adjacent to the Sewage Farm and Parvathy Puthanar canal. This may be due to either the leaching of wastewater from the Sewage Farm, houses and Parvathy Puthanar canal or from the geology associated with the groundwater in the study area. Hussain and Sheriff (2013) conducted a study on groundwater samples around the Cooum River at Chennai and reported the concentration of Fe in bore well water samples ranged from 0.55 to 2.74 mg L^{-1}. They concluded the high Fe content in water was due to the discharge of domestic waste water. Effects of exposure to high Fe concentrations include abdominal discomfort, lethargy and fatigue. Excess Fe deposition leads to shrinkage of the liver, followed by fibrosis and cirrhosis. Ingestion accounts for most of the toxic effect of Fe, since Fe is rapidly absorbed in the gastrointestinal tract (Thomas et al. 2011).

According to WHO (2011), the permissible limit of Pb in drinking water is 0.01 mg L^{-1}. Current results show that most of the bore well samples and dug well samples (except DW23, DW24, DW25) exceeded the permissible

Table 3 HPI calculations for groundwater compared with BIS permissible limits (1991)

Metals	Mean value (M_i) (μg L^{-1})	Standard permissible value (S_i) (μg L^{-1})	Highest desirable value (I_i) (μg L^{-1})	Unit weightage (W_i)	Sub index (Q_i)	$Q_i \times W_i$
Fe	342.33	1,000	300	0.001	30.68	0.03068
Zn	106.53	15,000	5,000	0.00006	48.93	0.00294
Cd	1.32	10	–	0.1	13.19	1.319
Cu	105.39	1,500	50	0.0006	5.43	0.00326
Pb	33.52	50	–	0.02	67.04	1.3408

$\sum Q_iW_i = 2.69$; $\sum W_i = 0.1217$; HPI = 22.11

Table 4 Heavy metal Pollution Index (HPI) of sampling wells around the Valiathura Sewage Farm

Sample ID	Source	HPI	% Deviation
DW1	Dug well	24.83	13.32
DW2	Dug well	33.41	52.51
DW3	Dug well	13.47	−38.54
DW4	Dug well	20.68	−5.60
DW5	Dug well	30.45	38.97
DW6	Dug well	35.91	63.90
DW7	Dug well	29.79	35.97
DW8	Dug well	9.48	−56.72
DW9	Dug well	24.26	10.73
DW10	Dug well	33.91	54.76
DW11	Dug well	17.50	−20.13
DW12	Dug well	18.28	−16.56
DW13	Dug well	27.45	25.30
DW14	Dug well	24.87	13.50
DW15	Dug well	32.46	48.14
DW16	Dug well	17.23	−21.37
DW17	Dug well	17.80	−18.78
DW18	Dug well	17.41	−20.53
DW19	Dug well	12.59	−42.52
DW20	Dug well	12.30	−43.84
DW21	Dug well	20.70	−5.51
DW22	Dug well	15.80	−27.88
DW23	Dug well	12.30	−43.85
DW24	Dug well	9.47	−56.79
DW25	Dug well	10.65	−51.38
DW26	Dug well	13.58	−38.00
DW27	Dug well	21.01	−4.12
DW28	Dug well	33.60	53.37
DW29	Dug well	41.79	90.75
BW1	Bore well	17.52	−20.04
BW2	Bore well	12.11	−44.72
BW3	Bore well	28.86	31.73
BW4	Bore well	21.76	−0.68
BW5	Bore well	30.76	40.41
BW6	Bore well	35.83	63.55
BW7	Bore well	30.96	41.30
BW8	Bore well	18.71	−14.62
BW9	Bore well	13.69	−37.54
BW10	Bore well	16.96	−22.59
BW11	Bore well	15.44	−29.53
BW12	Bore well	17.89	−18.34
BW13	Bore well	26.63	21.55

limit of drinking water quality standards. This may be due to the leaching of wastewater from the Sewage Farm and solid waste materials like batteries and pipes dumped near the well in the residential area. Hem (1985) showed sources of Pb contamination in groundwater are from gasoline, pipes, pigments and batteries. Pb has serious cumulative effects and can accumulate in bones, causing nausea, nervous and reproductive disorders and kidney damage in humans (Ramakrishnan 1998; Anonymous 2002). It is harmful to developing brains of fetuses and young children and also pregnant woman (WHO 2011). In the present study, the mean concentration of Cu in dug wells (0.10 mg L^{-1}) and bore wells (0.12 mg L^{-1}) exceeded the desirable limit (0.05 mg L^{-1}) prescribed by BIS (1991). Elevated levels of Cu in drinking water results from corrosion of pipes and fittings (Sonon et al. 2006). Excess Cu in the human body is toxic and causes hypertension, produces pathological changes in brain tissues (Rajappa et al. 2010), and gastrointestinal disorders (Shrivastava 2009). All dug well and bore well samples in the study area were within the guideline value for drinking water quality standards prescribed by WHO (2011) for Zn and Cd.

Pearson's correlation analysis was applied to study the interrelationship among the metals in groundwater samples in the study area (Table 2). A high positive correlation between Cu and Pb ($p < 0.01$) implied the corrosion of pipes in the study area as a likely source of Cu and Pb in groundwater. Fe had a strong, positive correlation with Cu and Pb ($p < 0.01$). The relationship among metals in groundwater samples implied sources of these metals were due to anthropogenic activities such as wastewater from the Sewage Farm, Parvathy Puthanar canal and leaching of solid wastes dumped in the residential area. The sandy aquifer in the study area may facilitate the mobility of metals to the groundwater. The sandy aquifer increases the possibility of interaction between groundwater and polluted surface water (Kumar et al. 2012).

Heavy Metal Pollution Index (HPI) gives the composite influence of metals on the total quality of water (Sheykhi and Moore 2012). The result of the HPI calculations of groundwater and HPI of various sampling wells were presented in Tables 3 and 4. HPI can be classified into three categories: low (<19); medium (19–38); and high (>38) (Kumar et al. 2012). Based on current study HPI values, about 21 samples fall in the low category, 20 in the medium category and only one in the high category (41.79). The maximum HPI value of 41.79 was observed at DW29 which is adjacent to the polluted Parvathy Puthanar canal and Sewage Farm. The lowest HPI value (9.47) was recorded at DW24 (Table 4). This area is 1.9 km from the Sewage Farm and unaffected by anthropogenic activities. The percentage deviation for each sampling wells were calculated from the mean HPI value. The deviation shows the quality of groundwater in the study area. Negative deviation indicates better quality and positive deviation indicates poor quality of groundwater. The study revealed that about 41.4 % dug wells and 38.5 % bore wells show positive deviation which indicates that the quality of water is deteriorated.

The study concluded that the majority of groundwater samples in the study area are contaminated with metals like Fe, Pb and Cu, and this may be due to the leachates entering into the water bodies from the Sewage Farm, Parvathy Puthanar canal and solid wastes dumped in the residential areas. The consumption of this water by people without prior treatment may cause different health problems. The study recommends that the groundwater sources in the study area need regular water quality monitoring, and should further monitoring result in continued exceedances, appropriate action should be taken.

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