Comprehensive assessment of groundwater quality using heavy metal pollution indices and geospatial technique: A case study from Wanaparthi watershed of upper Krishna River basin, Telangana, India.

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Research Article

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Abstract

The present study is to characterize groundwater quality using heavy metal pollution indices and geospatial variations. A total of 58 samples from hand pump/submersible bore wells were collected from the Wanaparthi watershed of the upper Krishna River basin according to the grid size (5*6 km²). The heavy metals concentration in groundwater samples are found in the order of Zn(38.67%)> B(32.67%)> Ba(13.59%)> As(8.49%)> Hg(3.71%)> Cr(1.28%)> Ni(0.52%)> Cd(0.47%). Among these heavy metals, arsenic (22.4%) and mercury (5.1%) were found above the permissible limits of WHO drinking water guideline values. A positive correlation between pH versus B/Ba/Hg, TH versus EC/TDS, and B versus Ba indicates the presence of metals due to chemical reaction (rock-water interaction). Arsenic correlation with EC/TDS/TH indicates artificial intervention. Drainage network analysis enumerates high concentration of parameters at near or joining to upper order of drainage system, which might be due to input of runoff water (interaction of variable rocks composition) and later stage infiltration to subsurface and reached to an aquifer. Heavy metal pollution index (HPI) showed 86.2% of samples are in the category of low class, whereas 12.1% of samples fall within medium class. According to metal index (MI) classification, 12.1% samples are in very pure, 24.14% samples are pure, while the remaining 63.8% samples are in the slightly to strongly affect category. This study suggested the main source of heavy metals in groundwater might be from the dominant granitoid rocks because the area is mostly devoid of industrialization.

1. Introduction

Renewable groundwater is found between layers of impermeable rock formations known as an aquifer. Aquifers are connected through joint, crack, fracture, or structurally deformed zone. It is essential to know the portability of groundwater and the amount of recharge and discharge ratio because the future generation depends on how we utilized and managed the aquifer system. In most parts of India, highly dependent on groundwater for drinking purposes, which gives rise to risk due to limited resources of surface water and a highly dense population. Heavy metals in groundwater are generally at low concentrations in the undisturbed environment due to natural chemical weathering and rock-water interaction (Tiwari et al., 2016; Karbassi et al., 2007). Groundwater pollution is not only influence water quality but also render chaos to a health problem, economic growth, and social life (Singh and Kamal 2017; Marcovecchio et al. 2007). Heavy metal concentrations in groundwater are very much concerned about the environmental pollution and wellbeing of humans. This is because of heavy metals are non-degradable and once it reaches into body system it accumulates and causes diseases at very low content, they are highly dangerous (Zakhem et al. 2015; Vinodhini and Narayanan 2008; Lohani et al. 2008; Marcovecchio et al. .2007; Momodu and Aayako 2010; Lee et al. 2007). Generally, heavy/trace metals can be defined as a group of elements with an atomic density above 4000 kg/m³ (Garbarino et al. 1995; Hutton and Symon 1986). Heavy metals in groundwater can be either from natural or anthropogenic processes; whereas natural processes include weathering, chemical reactions of elements, soil leaching, etc. while anthropogenic are from domestic waste, fertilizers, urbanization, mining, industrial waste, etc. (Agarwal et al. 2013; Zarazua et al. 2006, Reiners et al. 1975). Among the heavy metals, a few of them like Ni, Cr, and Zn are essential as micronutrients for biochemical activities in aquatic life though they become highly toxic in higher concentrations (Kumar et al., 2012; Nurnberg 1982). Arsenic is considered highly hazardous due to its toxic and carcinogenic to human health even at low concentrations (Selvam et al. 2015), and the mineral source is arsenopyrite (FeAsS). Other heavy metals B, Ba, Be, and Hg are known to less health importance, but still, their

presence in groundwater is considered toxic at low concentration. A review of the literature showed that many researchers had reported the groundwater quality assessment using heavy metal pollution index (HPI) and metal index (MI) to find out the additive result of heavy/trace metals in water for quick analyses of overall groundwater standard for drinking and effect on human health (Abbas et al. 2021; Wu et al. 2021; Panseriya et al. 2020; Singh and Kamal 2017; Tiwari et al. 2015; Zakhem and Hafez 2015; Goher et al. 2014; Protano et al. 2014; Yankey et al. 2013; Prasanna et al. 2012; Giri et al. 2010; Kikuchi et al. 2009; Zhang et al. 2009; Pandey et al. 2009; Prasad and Sangita 2008). This study is the continuation of an earlier investigation of major ions, hydrogeochemical process seasonal variation, and health risk assessment of groundwater (Vaiphei and Kurakalva, 2021; Vaiphei et al. 2020) in the Wanaparthy watershed. Since no report has been found on groundwater studies on heavy metals contamination in Wanaparthy watershed, Telangana, India, hence the present study has a major objective on understanding the groundwater quality with respect to heavy metals concentration and distribution. The methods to be followed are identifying individual heavy metal concentration, heavy metal pollution index (HPI), metal index (MI), and their spatial distribution in the study area.

2. Study Area

Wanaparthy watershed is located in the upper Krishna River basin between 16°19'1" to 16°49'53"N latitude and 77°49'21" to 78°12'55" E longitude of Telangana state in southern India (Fig. 1a), covering an area of 1600 km². The geomorphology of the area, North-west, and north-eastern region have higher topography, which gradually slopes down towards the south-west side (Fig. 1b); the elevation ranges from 309- 692m (AMSL) (ESM_Fig. 1). The dominant river system in the area is of dendritic pattern where the higher-order streams finally reach to major Krishna River. Krishna river originates from Western Ghats (Maharashtra) and passes through the southern part of Telangana, which reaches into the Bay of Bengal on the eastern coast (Andhra Pradesh). Krishna river serves as a significant water source for drinking, domestic purposes, and agriculture in the study area. Red soils, lateritic soils, and black cotton soils are the main dominant soil types. The major cultivation in the study is rice, maize, sugarcane, bajra, cotton, mango, grape, lemon, papaya, pomegranate, etc., whereas there is less predominant of mining and industries. The area comes under a tropical semi-arid climate with temperature ranging from between 16.9°C to 42°C. The dominant rock formation of the study area belongs to the peninsular gneissic complex and Dharwar group of Precambrian age consisting of grey biotite granite, migmatite, leucogranite, alkali feldspar granite, pink biotite granite, banded migmatite quartzite, amphibolite, etc. There is migmatite intrusion which cut across the massive peninsular gneissic complex in the north-west to north-east direction Fig. 2 (GSI).

3. Materials And Methods

Fifty-eight water samples were collected from hand pump/submersible bore wells as per the grid (5*6 km²) drawn for the study area during March 2019 from the Wanaparthy watershed. Sampling points were fixed to collect the samples preferably either from the center of the village or center of the prepared grid size (5*6 km²). Sampling points were fixed to collect the samples preferably either from the center of the village or center of the prepared grid size (5*6 km²). The groundwater samples were collected in high-density polyethylene (HDPE) bottles prewashed with 10% nitric acid followed by rinsing with double distilled water. Before collecting the samples, water is drawn out from the hand pump, or submersible bore wells for about 10 minutes to

confiscate out the stagnant water. Two sets of samples were collected separately in 500ml and 60ml HDPE bottles. The 500ml water samples were utilized for titrimetric measurement of total hardness using EDTA (ethylenediamine tetraacetic acid), ammonium chloride-ammonia buffer, Eriochrome Black-T (EBT), while the total alkalinity was measured using sulphuric acid, phenolphthalein indicator, and methyl orange following APHA (2005) standard procedure. The 60ml containers were acidified with 2-3ml of conc. HNO_3 to keep dissolved and to stabilize the heavy metals (Kumar et al. 2012). Water quality parameters like pH, TDS, and EC were measured *in-situ* using portable meters (Hanna, HI98130). Later, samples were transported to the Environmental Geochemistry Lab of CSIR-NGRI, Hyderabad. Heavy metals (As, Ba, Cd, Cr, Hg, Ni, and Zn) concentrations in groundwater were analyzed using ICP-OES (Optima 4300 DV, Perkin Elmer). A calibration curve is constructed using freshly prepared working standards and continued testing until the correlation coefficient (r^2) close to 1.

3.1 Heavy metal pollution index (HPI) Zn, Ba, As, Hg, Cr, Ni, Cd)

HPI is a rating method of water quality utilizing determining individual heavy metal concentrations and their composite effects (Zakhem and Hafez 2015 and Sheykhi and Moore 2012). The rating or weights (W_i) is assigned between 0 and 1 for each heavy metal, which is based on the importance of individual quality considerations or by taking the inverse proportional value of approved standard to all metals considered (Mohan et al. 1996; Horton 1965). According to Tiwari et al. (2015) and Prasad and Bose (2001), different researchers/scholars set their limit values for HPI, and the critical limit value of HPI for drinking water is 100. Edet and Offiong (2002) categorized HPI into three distinct classes; low ($\text{HPI} < 15$), medium , and high ($\text{HPI} > 30$). However, this study followed the classification of HPI based on the description of Kumar et al. (2012). These were explained as low ($\text{HPI} < 19$), medium , and high ($\text{HPI} > 38$). The concentration limits (i.e., the maximum permissible value S_i and maximum desirable value I_i for every parameter) are based on the international standard (WHO 2011). Maximum permissible value S_i can be defined as beyond this limit it is not advisable to drinking water while maximum desirable value I_i is one way of relaxation limit set by the individual organization where it gives the best water to drink purpose (like every country will have different maximum desirable value I_i it depends on the economy of the state). The HPI is calculated using the following equations below (Mohan et al., 1996).

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad \text{eq. 1}$$

where,

Q_i is the sub-index of i^{th} parameter

W_i is the unit weight of i^{th} parameter, and n is the number of parameters used

The unit weight (W_i) is obtained by using the formula

$$W_i = K/S_i$$

where K is proportional constant (1) and S_i is the standard permissible value of i^{th} parameter

The sub-index (Q_i) of the parameter is given by

$$Q_i = \sum_{i=1}^n \frac{|M_i(-)I_i|}{S_i - I_i} * 100 \quad \text{eq. 2}$$

where,

M_i is the monitor value of the metal in i^{th} parameter

I_i is the ideal value of the metal in i^{th} parameter

S_i is the standard value of the metal in i^{th} parameter and

(-) sign is to have the absolute value of the two numbers

3.2 Metal Index

MI is also an important factor in determining groundwater quality for public concern. Metal Index is classified as follows; very pure ($MI < 0.3$), pure, slightly affected, moderately affected, strongly affected and seriously affected ($MI \geq 6$). MI value is considered a sign of warning when it is greater than 1 (Goher et al., 2014; Bakan et al., 2010). Metal Index (Tamasi and Cini 2004) is calculated as:

$$MI = \sum [C_i / (MAC)_i] \quad \text{eq. 3}$$

where C_i is the measure concentration of each metal, MAC is the maximum permissible limit

2.3 Geographical information

system (GIS) analysis

Geographical information system (GIS) helps in collecting and manipulation of a diverse range of spatial data and generates the spatial distribution phenomena of all individual values (Gupta and Srivastava 2010). GIS manipulates all water quality parameters, gives an overall idea, provides easy understanding to the people and policymakers (Singh et al. 2013). The inverse distance weighted interpolation method of ArcGIS- 10.7 software (GIS Lab, CSIR-NGRI, Hyderabad, India) was used to generate a spatial distribution map of all parameters.

4. Results And Discussion

4.1 Physicochemical analysis

Table. 1 describes the overall statistical arrangement of all water quality parameters investigated in the study area. All considered parameters permissible limits are following WHO (2011) standards. The spatial distribution maps of physicochemical parameters for temperature, pH, EC, TDS, TH, and TA were shown in ESM_Fig. 2 (a) to (f). Temperature and pH: The water temperature in the study ranged between 29°C - 30°C. Temperature is critical due to its tendency to cause a chemical reaction and control oxygen levels in the water. pH values obtained in this work are between 7.28 -8.43, which is between desirable limits of WHO (2011) drinking water guideline values. The value of pH in the study is not corrosive. pH has a positive correlation with EC and Alkalinity. For instance, pH 7 is the neutral value of water. Suppose pH value is low than high corrosive properties and vice versa. Electrical conductivity (EC) values range from 640 μ S/cm to 5890 μ S/cm, whereas 18.97% of samples are above the permissible limit of 1500 μ S/cm. Total dissolved solids (TDS) are found high in the area as most of the samples (81.03%) are above the permissible limit of 1000mg/l.

Total Hardness (TH) ranges between 58.5-1480.5mg/l, where 46.55% of samples are beyond the permissible limit (500mg/L) as prescribed by WHO. The average concentration of TH was found to be 526.57mg/L. Total Alkalinity (TA) is due to the contribution of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in water and the main controlling factor. Alkalinity in the study area was found to be in the range of 60-580 mg/l, which is within the permissible limit.

Heavy metals concentration in groundwater samples found descending order are as Zn(38.67%) >Ba(13.59%)>As(8.49%)>Hg(3.71%)>Cr(1.28%)>Ni(0.52%)>Cd(0.47%). Zn has the maximum concentration of all analyzed heavy metals in groundwater from the study area. According to the WHO limit, none of the samples found is above 3000 μ g/L permissible. The concentration of Zn is within the limit, i.e., between 11.69-130.2 μ g/L, as shown in Fig.3(a). Though Zn is harmful in higher concentrations, it is also one of our essential heavy metals as they are consumed as organic compounds and salts in food, medicine, and drinking water. Zn gives good health through proper diet. Rusting of pipes that concentrate with water through the household tap is one major cause of high Zn in drinking water and affecting human health. Generally, zinc is associated with lead and cadmium in groundwater. Barium (Ba) is in the third spot regarding the amount of percentage present in groundwater. It constitutes about 8.49% of the total content of metals. Though Ba is second, the concentration found is within the permissible limit, i.e., 0.033-26.71 μ g/L (Fig. 3b), where the maximum allowable is up to 700 μ g/L. Generally, Barium is high in regions where pH is low and associate with granite rocks, alkaline igneous rock, volcanic rocks, and sedimentary (Mn-rich) rocks. Arsenic (As) is a dangerous heavy metal because they are toxic even at trace concentration. It ranks fourth highest in order of composition in groundwater samples, contributing 8.49%. Many samples (22.41%) found to be is above the permissible limit of 10 μ g/L. The minimum and maximum range of As between 0.308-38.38 μ g/L, as shown in Fig. 3(c). The natural source of arsenic is arsenopyrite (FeAsS); its association minerals are Fe and sulphide. Anthropogenic sources are chemical pesticides, industrial waste, coal burning, lead, and gold mining.

In contrast, mining and industrial activity in the study area are not prominent, so it imparts the idea of contamination through geogenic processes. Therefore, the chances of anthropogenic dominancy in the study area were found to be of using pesticides for agriculture activities. Mercury (Hg) constitutes 3.71% of samples and is found in the range of 0.412-8.988 μ g/L (Fig. 3d). The permissible limit of Hg is 6 μ g/L, where 3(5.17%) samples exceed the limit. Natural sources are volcanoes, hot springs, serpentinite changes to silica-carbonate in the presence of carbonate-rich water (Adolph, 1906 and White, 1957). At the same time, natural processes are

hydroelectric plants, mine, paper industry wastes, etc. Chromium (Cr) concentration is found between 0.123-2.496µg/L, as shown in Fig. 3(e), and constitutes 1.28%. No samples exceed the permissible limit 50µg/L. Chromium in water is due to waste products from electroplating, leather tanning, and textile factories (Fetter 1993), while leaching of soils and rocks are the major sources. Nickel (Ni) concentration ranges from 0.012-0.865µg/L (Fig. 3f), where no sample exceeds the permissible limit, i.e., 70µg/L. Generally, nickel is contaminating water bodies due to iron leaching. Sources of nickel are steel factories, non-ferrous alloys (aluminum, copper, zinc, tin, lead, brass, etc.), and superalloy (having high melting, less corrosion, strength, etc.). Cadmium (Cd) is a minor concentration among all heavy metals ranging from 0.277-0.544µg/L (Fig. 3g), constituting 0.47%. None of the samples exceed the permissible limit 3µg/L. Cadmium is a trace metal present widely in nature (Xie et al. 2021) in crust and water. It is used for rusting resistance as well as to stabilized plastics. Cadmium is known for its uses in making batteries. Majorly environment contaminant medium is through water and air (release fossil fuels combustion). Cadmium is released to water from galvanized plumbing (coated with zinc), water pipes, domestic wastes, and fertilizer factories. Cadmium is generally associated with ores of zinc, copper, lead. When the groundwater is highly acidic, a chemical reaction occurs, resulting in a high Cd concentration in groundwater. Krishna et al. (2009) reported that heavy metals like Ba, Ni, Cr in water were controlled and associated by mixed origin from both natural and anthropogenic inputs, while, As, Zn, Mn, Fe, Pb, and Co were due to anthropogenic sources. The study region also has similar lithology and peninsular region of South India, i.e., granitoid terrain of Medak district, Andhra Pradesh (presently under Telangana State, India).

4.2 Pollution indices

4.2.1 Heavy metal pollution index (HPI)

Seven heavy metals such as Zn, Ba, As, Hg, Cr, Ni, Cd were considered to determine the heavy metal pollution index of groundwater. Statistical calculation of HPI for heavy metals shown in Table 2 for groundwater samples. According to Kumar et al. (2012), three main classes are defined as low (HPI<19), medium, and high (HPI>38) were followed respectively, as shown in Table 3. From the HPI values, it is clear that 29 samples fall under the low category, which means less contamination, and it contributes 50% of the total area. 27(46.55%) samples fall within a medium group while only 2 (3.45%) sample is found to have a high concentration of metals in the area. For a better understanding of heavy metals in the study, a scatter plot and spatial distribution map of HPI is generated, as shown in Fig. 4 and 5. Two samples (PRM-35 and 41) with high HPI values are found to be fall within the migmatite body, as shown in Fig.2, which suggests that migmatite rock might be the source of origin. Since the area is dominant with granitoid composition, it can play a vital role as a source of heavy metals in groundwater through natural processes because the study region is devoid of industrialization. This data will help the future investigation find the geochemical study of rocks and the extent of contamination in groundwater for better management.

4.2.2 Metal Index (MI)

The metal index is another way to check water quality by determining the concentration of heavy metals. Metal index help in classifying groundwater quality and is considered to be hazardous for drinking and aquatic life when MI>1 (Goher et al., 2014). The metal index has grouped into six types based on their concentration such as very pure (MI<0.3), pure, slightly affected, moderately affected, strongly affected and seriously affected

(MI $\geq$ 6) as shown in Table 4. Accordingly, it is found that 7(12.07%) samples are in very pure category, 14(24.14%) samples are in pure category while the remaining 37(63.79%) samples contribute slightly affected to the strongly affected category. A spatial distribution map of the metal index is shown in Fig. 6. Though one sample collected from Chegunta village falls within the seriously affected category of MI, it is clear that most of the groundwater in the area followed the trend to be affected. Therefore, it is the right time to take up control measurements so that groundwater can be saved and used in the long run.

4.3 Correlation coefficient analysis

The correlation coefficient index defines the relation of two variables which describe the sufficiently of a variable to relate to the other (Davis, 1986), such that high correlation coefficient values show good relation and vice versa. Determination of variables, i.e., the dependent (x) is solely control by independent (y) and vice versa (Voudouris et al., 2000). Also, if the correlation coefficient value is close to zero, then it does not correlate. A high positive value (r) means a good relationship, but if it is negative, it is an inverse correlation. A statistical calculation was done to better understand the source of pollution, either anthropogenic or natural, according to Pearson's correlation matrix. The correlation coefficient of all parameters (physicochemical parameters and heavy metals) has shown in Table 5. Positive relation between pH with Ba/Hg; TH with EC/TDS shows the chemical reaction through the natural process; As with EC/TDS/TH indicates the source of chemical fertilizers from agricultural infiltration, domestic waste, and industrial discharge. While parameters that show negative or no relation indicates the source of heavy metals in groundwater is not an individual contribution of natural or anthropogenic sources.

Conclusion

This study integrated the heavy metals, physicochemical parameters, multivariant statistical methods, and ArcGIS to evaluate the groundwater quality and sources of pollution. Concentration of heavy metals related to abundance in groundwater samples are in order; Zn(38.67%) >Ba(13.59%)>As(8.49%)>Hg(3.71%)>Cr(1.28%)>Ni(0.52%)>Cd(0.47%). Though Zn has the maximum concentration among all the heavy metals in the groundwater of the study area, none of the samples are above the permissible limit of 3000 μ g/L (observed values are between 11.69-130.2 μ g/L). Except for two heavy metals, namely As with 22.41% of samples and Hg with 5.17%, samples are above WHO permissible limits for drinking water. According to HPI classification, most of the samples (86.21%) fall under the low category of HPI (<19) revealed no significant health issue due to heavy metals. Correlation coefficient analyses suggest that the contribution of heavy metals in groundwater is due to natural (chemical reactions) and anthropogenic sources. From spatial distribution maps, HPI and MI have a higher concentration in small patches of the northeast side of Wanaparthi watershed. Considering the overall view of the spatial variation of the parameters investigated, a higher concentration of heavy metals is found near or joining to upper order drainage system. The higher concentrations of heavy metals might be due to the input of runoff water (interaction of variable rocks composition) from a higher elevation and later get infiltration (low lying/depression areas) to subsurface and reach the aquifer. Heavy metal pollution indices (HPI and MI) suggested that the main source of heavy metals in groundwater might be from the dominant granitoid rocks because the area is mostly devoid of industrialization. The present work suggested the MI value in 63.79% of the samples in Wanaparthi watershed is slightly affected to the strongly affected category, which means most groundwater samples need proper treatment before used for drinking purposes.

Declarations

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Tables

Table 1. Statistical summary of water quality data and comparison with WHO (2011) drinking water guidelines

Parameters	Min	Max	Ave	Median	SD	Desire limit (WHO 2011)	No. of samples above desire limit
Chemical Parameters							
Temp °C	29	30	29.64	29.7	0.282	---	---
pH	7.28	8.43	7.876	7.875	0.256	7-8.5	Nil
EC µS/cm	640	5890	1757.93	1540	965.48	750-1500	11
TDS mg/l	409.6	3769.6	1125.07	985.6	617.91	500-1000	47
TH mg/l	58.5	1480.5	526.57	474.75	303.03	300-500	27
TA mg/l	60	580	251.55	230	107.29	---	Nil
Heavy/ Toxic Elements							
As µg/L	0.308	38.38	8.809	6.654	7.594	10	13
Ba µg/L	0.033	26.71	9.487	8.4	6.839	700	Nil
Cd µg/L	0.277	0.544	0.3245	0.314	0.045	3	Nil
Cr µg/L	0.123	2.496	0.907	0.818	0.519	50	Nil
Hg µg/L	0.412	8.988	4.287	4.681	2.783	6	3
Ni µg/L	0.012	0.865	0.37025	0.388	0.186	70	Nil
Zn µg/L	11.69	130.2	27.047	25.28	16.061	3000	Nil

Table 2. Calculation of HPI for groundwater sample in Wanaparthy watershed

Heavy metals (µg/L)	Mean concentration (Mi)	Standard permissible value (Si)	Highest desirable value (Li)	Unit Weight (Wi)	Sub Index (Qi)	Wi * Qi
As	8.809	10	1.5	0.1	144.9412	14.49412
Ba	9.487	700	50	0.001429	5.083077	0.007264
Cd	0.3245	3	0.5	0.333333	7.16	2.386664
Cr	0.907	50	1	0.02	0.85102	0.01702
Hg	4.287	6	0.25	0.166667	4.347826	0.724639
Ni	0.37025	70	10	0.014286	16.37833	0.233981
Zn	27.047	3000	---	0.000333	0.736667	0.000245
$\Sigma W_i = 0.63605$; $\Sigma W_{i*} * Q_i = 179.4981$; $HPI = 17.86839$						

Table 3. HPI classification showing numbers and % of samples within the HPI range (Kumar et al. 2012)

HPI Range	Description of conc.	No. of samples	% of samples
<19	Low	29	50
19 - 38	Medium	27	46.55
>38	High	2	3.45
	Total	58	100

Table 4. Details on MI classes including numbers and % of samples in the study area

Metal Index	Characteristics base on concentration	Class types	No. of samples	% of samples
<0.3	Very pure	I	7	12.07
0.3-1.0	Pure	II	14	24.14
1 .01-2.0	Slightly affected	III	33	56.90
2.01-4.0	Moderately affected	IV	3	5.17
4.01-6.0	Strongly affected	V	1	1.72
>6.0	Seriously affected	VI	Nil	Nil
		Total	58	100

Table 5. Correlation matrix of physico-chemical parameters and heavy metals of groundwater

Parameters	Temp	pH	EC	TDS	TH	Alk	As	Ba	Cd	Cr	Hg	Ni	Zn
	1.00												
	0.03	1.00											
	-0.07	-0.59	1.00										
	-0.07	-0.59	1.00	1.00									
	0.11	-0.78	0.81	0.81	1.00								
	0.03	0.44	-0.07	-0.07	-0.40	1.00							
	0.17	-0.40	0.36	0.36	0.39	-0.10	1.00						
	-0.16	-0.47	0.36	0.36	0.39	-0.25	0.18	1.00					
	-0.11	0.01	-0.07	-0.07	-0.07	-0.01	-0.06	0.10	1.00				
	0.06	-0.59	0.83	0.83	0.89	-0.21	0.26	0.37	0.00	1.00			
	0.14	0.35	-0.40	-0.40	-0.43	0.20	-0.20	-0.32	0.39	-0.49	1.00		
	0.09	0.24	-0.05	-0.05	-0.22	0.29	-0.11	-0.29	-0.02	-0.12	0.11	1.00	
	0.23	0.18	-0.14	-0.14	-0.03	-0.08	-0.12	-0.24	0.15	-0.14	0.31	0.14	1.00

Table 6. Details summary of groundwater from all samples in the study area with respect to HPI and MI

Sample ID	Villages name	GPS points		Source	Drinking	Colour	HPI	MI
		Latitude	Longitude				range	
PRM-01	Yenugonda	16.75528	78.03532	submersible	Yes	clear	17.86	1.55
PRM-02	Parvathapuram	16.81101	77.99579	submersible	Yes	clear	8.78	0.41
PRM-03	Kenipally	16.77956	77.99104	submersible	Yes	clear	5.24	0.15
PRM-04	Chowderpally	16.70595	77.94411	submersible	Yes	clear	21.33	1.13
PRM-05	Rajunaiktanda	16.74044	77.86519	submersible	Yes	clear	29.26	1.95
PRM-06	Ramchandrapur	16.70007	77.89989	handpump	No	Pale Yellow	21.28	1.13
PRM-07	Hajalipur	16.62681	77.88467	handpump	Yes	clear	4.47	0.15
PRM-08	Vemula	16.6011	77.93636	submersible	Yes	clear	8.66	0.40
PRM-09	Komireddipally	16.57083	77.96155	handpump	Yes	clear	21.44	1.65
PRM-10	Shakapur	16.54493	77.95014	handpump	No	clear	21.74	1.60
PRM-11	Veltoor	16.46915	77.93751	submersible	Yes	clear	12.50	1.08
PRM-12	Kanimetta	16.43407	77.93734	handpump	Yes	clear	3.72	0.32
PRM-13	Palem	16.40845	77.94205	submersible	Yes	clear	21.09	1.71
PRM-14	Mojerla	16.44628	77.97057	handpump	No	Pale Yellow	16.95	1.57
PRM-15	Peddamandaddi	16.42804	78.02144	handpump	Yes	clear	5.31	0.22
PRM-16	Manigilla	16.41078	78.00547	submersible	Yes	clear	9.73	0.49
PRM-17	Vaddeda	16.3711	78.03926	handpump	Yes	clear	7.11	0.33
PRM-18	Srinivaspur	16.3451	78.05638	submersible	Yes	clear	21.85	1.87
PRM-19	Appaipally	16.3676	78.1065	handpump	No	Pale Yellow	27.50	1.54
PRM-20	Munнанur	16.35967	78.11681	handpump	Yes	clear	20.68	1.74
PRM-21	Buddaram	16.43918	78.14085	submersible	Yes	clear	16.91	1.44
PRM-22	Chityala	16.39324	78.07317	submersible	Yes	clear	12.60	1.08
PRM-23	Aloor	16.44307	78.09299	submersible	Yes	clear	11.74	1.06
PRM-24	Chinamandaddi	16.46157	78.04445	submersible	Yes	clear	5.67	0.14
PRM-25	Awal	16.44603	78.01681	submersible	Yes	clear	5.21	0.16

PRM-26	Veeraipally	16.48442	78.04633	handpump	Yes	clear	7.31	0.31
PRM-27	Gatlakhanapur	16.48215	77.991	handpump	No	clear	7.02	0.60
PRM-28	Solapur thande	16.53892	78.06507	handpump	No	clear	10.80	0.63
PRM-29	Khillaghanpur	16.5728	78.04807	submersible	Yes	clear	23.39	1.51
PRM-30	Salikelapur	16.57476	78.10114	submersible	Yes	clear	27.87	2.12
PRM-31	Manganuru	16.57252	78.15792	submersible	No	clear	28.00	1.97
PRM-32	Latupalle	16.54469	78.14442	submersible	Yes	clear	32.44	2.30
PRM-33	Mahabubnagar	16.7493	77.99107	handpump	No	Pale Yellow	5.18	0.21
PRM-34	Tadparti	16.72281	78.09795	handpump	No	clear	4.72	0.24
PRM-35	Amistapur	16.70395	78.03834	submersible	No	clear	49.44	3.89
PRM-36	Botlagaddatanda	16.68746	78.07915	submersible	Yes	clear	22.30	1.54
PRM-37	Karivena	16.67464	78.10463	submersible	Yes	clear	20.37	1.39
PRM-38	Pullagirithanda	16.67046	78.14429	submersible	Yes	clear	15.06	1.05
PRM-39	Pullagiri village	16.678	78.15674	handpump	Yes	clear	25.91	1.41
PRM-40	Gorita	16.62217	78.16042	submersible	Yes	clear	12.51	1.03
PRM-41	Chegunta	16.61715	78.14438	submersible	No	clear	47.01	4.01
PRM-42	Yelkicharla	16.62718	78.11251	submersible	Yes	clear	3.40	0.31
PRM-43	Kothamolgara	16.66103	78.07117	submersible	Yes	clear	30.30	1.96
PRM-44	Roadside	16.63596	78.06586	handpump	Yes	clear	19.46	1.45
PRM-45	Kadur	16.67941	77.92212	submersible	Yes	clear	5.74	0.3
PRM-46	Oblaipalle	16.66376	77.87949	submersible	Yes	clear	23.62	1.25
PRM-47	Gaddeguda	16.67193	77.84102	submersible	Yes	clear	7.33	0.74
PRM-48	Janampet	16.62767	77.98649	submersible	No	clear	4.84	0.37
PRM-49	Gopalapet	16.39119	78.14268	submersible	Yes	clear	14.27	1.09
PRM-50	Chennur	16.4089	78.11878	handpump	No	clear	5.37	0.46
PRM-51	Khandoor	16.54557	77.97745	submersible	Yes	clear	20.76	1.75
PRM-52	Madanapur	16.383724	77.888394	handpump	Yes	clear	17.17	1.06
PRM-53	Dwarakanagar	16.437511	77.879964	submersible	No	clear	14.45	1.31
PRM-54	Perur	16.484203	77.876751	submersible	No	clear	19.17	1.62
PRM-55	Isrampally	16.5157	77.87473	handpump	No	clear	18.36	1.29
PRM-56	Ponnakal	16.56661	77.93799	submersible	Yes	clear	19.10	1.59
PRM-57	Jeenugurala	16.582491	77.875398	handpump	No	clear	22.58	1.94
PRM-58	Alipur	16.70156	77.9847	submersible	No	clear	8.16	0.70

Figures

Figure 1

a) Location map along with samples point and b)3D view Wanaparthy watershed

Figure 2

Geological map of Wanaparthy watershed

Figure 3

a-g). Spatial distribution map of heavy metals (Zn, Ba, As, Hg, Cr, Ni and Cd) in groundwater.

Figure 4

Classification of groundwater based on HPI value

Figure 5

Spatial distribution map of HPI in groundwater of the study area.

Figure 6

Spatial distribution map of MI in groundwater of the study area.

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