Deciphering water quality using WQI and GIS in Tummalapalle Uranium Mining area, Cuddapah Basin, India

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ABSTRACT
This paper gives an insight into the assessment of water quality in and around the Tummalapalle Uranium deposit. A total of 19 groundwater samples were collected in the study area and the chemical parameters were analyzed by using ICP-MS. Data generated from ICP-MS were compared with the Bureau of Indian Standards (BIS) and noticed that some chemical elements viz., Na, Mg, Al, Ca, Mn, Fe, and U were present beyond the permissible limits. To know the inter-element relationship, the Correlation coefficient and T-Test were conducted to know the overall water quality at the respective stations. The Water Quality Index was computed. It is, thus observed that about 42% of the water samples fall under 'very poor water quality category' and require proper treatment to use the groundwater for domestic needs. The results of Factor analysis demonstrate three factors are responsible for the poor quality of water in the study area. The spatial variation maps were generated in GIS environment deciphers the uneven distribution of elemental concentrations in the study area.

INTRODUCTION
Due to its inherent properties by soil, groundwater (GW) is considered as freshwater for all domestic purposes. For the past couple of decades, the surface water bodies are unfortunately suffering from acute environmental stress. Even though underground water is naturally protected from pollution than surface water, anthropogenic activities may alter the underground water composition. Due to the alarming rate of industrialization, urbanization and uncontrolled exploitation of groundwater the bandwidth of the scarcity for freshwater is increasing day by day (Ramakrishanaiah, Sidashivaiah, & Ranganna, 2009). Water pollution is one of the significant threats to mankind. Apart from natural processes viz., erosion, weathering, etc., water resources are polluted by anthropogenic activities like mining, unscientific agricultural practices, disposal of waste material into the water bodies without any proper treatment, etc., hence it is key to determine the hydrochemistry properties of water in order to utilize it for various needs. The groundwater quality is the product of all processes and reactions that act on water from the moment of its precipitation to discharge through wells or springs. The present study was carried out to evaluate the quality of water in and around the Uranium deposit of Tummalapalle area, Andhra Pradesh, India. This is considered to be the second-largest low-grade uranium deposit in the world (Anjan, Purohit, & Mamallan, 2010). Mining is an important activity that boosts the economic face of a developing country in terms of employment creation, contribution to government revenue, significant growth in Gross Domestic Production (GDP), etc., (Phillips et al., 2001). Besides positive aspects, mining activity has also had negative aspects like the production of a large scale of pollutants, contamination of adjoining water, soil and atmosphere which affects adversely the ecological system. Leaching of mining waste and overburden dumps may reach groundwater and degrades the quality of groundwater (Khan, Israili, Ahmad, & Mohan, 2005; Prasad & Mondal, 2008) if once the groundwater is contaminated it causes adverse effects persistently and affects many generations to follow. Hence, assessment of the quality of the water serves as an important tool to monitor the health status of a water body. However, evaluating the Physico-chemical parameters, when laced with calculating water quality indices provides a realistic picture of the quality of the water (Cude, 2001; Kannel, Lee, Lee, Kanel, & Khan, 2007). Water Quality Index (WQI) is a mathematical tool, which provides a single number by integrating a set of water quality parameters that verbalize the overall quality of the water body (Stambuk Giljanovic, 1999).

The traditional approach to assess the quality of water is comparing the experimentally derived chemical parameter values to the local or international standard values. Even though the conventional procedure provides the levels of contamination but does not provide overall water quality at certain locations (Debel, Figueroa, Urrutia, Barra, & Niell, 2005). WQI is first proposed and introduced by Horton (1965) and later developed by Brown, McClelland,
Deininger, and Tozer (1970). As time passes by, many researchers have developed and adopted different approaches to calculate WQI (Bordalo, Nilsumranchit, & Chalermwat, 2001; Ott, 1978; Pesce & Wunderlin, 2000; Steinhart, Schierow, & Chesters, 1981; Rocchini & Swain, 1995; Said, Stevens, & Sehike, 2004; Zandbergen & Hall, 1998). In most approaches, the physicochemical properties were considered for calculating WQI but the difference exits in integrating statistical and interpretation strategies (Zagatto, Lorenzetti, Perez, Menegon, & Buratini, 1998). Bhargava (1983), extensively worked on WQI in India and he is considered a pioneer of the WQI work in India (Sharma & Arun, 2011). Factor Analysis (FA) is a multivariate technique, used to determine the number of significant factors contributing to chemical composition to the underground water (Purushotham, Mishra, Kavitha, & Naga Vinod, 2017). By using Geographical Information System (GIS) spatial variation maps were generated for each chemical element to realize the elemental distribution in the study area (Khan & Jhariya, 2017)

The present study intends to evaluate the water quality by the conventional approach and also by calculating WQI for the collected samples to determine the aptness of the water for various purposes. It also aims to study, the effect of mining activity on groundwater resources. This work is considered to be first of its kind in the present study area and the data generated from this study serve as a baseline for future groundwater studies. Further, the spatial distribution maps of polluted and non-polluted areas will help the decision or policymakers and stakeholders to take appropriate precautions to check the deleterious of mining effects in the unpolluted areas.

Methodology

Geology of the study area

The study was conducted in and around the Tummalapalle Uranium Mining area. This is the second-largest low-grade uranium deposit in the world (Anjan et al., 2010). It is located in the southwestern margin of Kadapa district, India. It lies between 14°18’00”N and 14° 20’30”N latitudes and 78°15’00” E and 78°18’00” E longitudes (Figure 1) and included in the Survey of India (SOI) toposheets no 57 J/7. The geology of the study area composed of purple shale, massive limestone, intraformational conglomerate, dolostone/dolomite, stromatolitic cherty limestone, Basic sills, and dikes. The discovered radioactive minerals in the ore body are pitchblende, coffinite and U – Ti complex. The mineralized rock body occurs in between purple shale and conglomerate beds above and below respectively which serves as the markers horizon (Basu, 2007).

Hydrogeology

The study area enjoys tropical wet and dry climatic conditions characterized by high temperatures, with an average temperature of 39.1°C in summer (March to May) and 23.6°C in winter (November to January). The average rainfall throughout the year is about 710 mm which ranges nil rainfall in January to 137 mm in October. A total of 56.7% of rainfall is contributed by Southwest Monsoon. The mean seasonal rainfall distribution is 402.4 mm and 239.1 mm in Southwest monsoon (June-September) and Northeast monsoon (October-December) respectively. The main recharge source of water is by precipitation (Central Ground Water Board, 2013). Groundwater in the study area occurs in the weathered zones of Chitravathi and Papagni group of rocks, the water table lies below the weathered zone, generally occurs at shallow depth. The quartzites and massive limestone serve as good aquifers with numerous joints, fractures, and fissures.

Materials and method

Methodology

The methodology adopted for the present study is shown in Figure 2. A systematic water sampling program was conducted for 19 samples (Figure 1), from the bore wells randomly in and around the Tummalapalle area on 15th, 16 December 2012. Samples were collected in 2 liters capacity double cap, pre-cleaned (with 10% nitric acid followed by repeated rinsing with bi-distilled water) and well-dried polyethylene bottles and added 5 ml of nitric acid in order to retain the elements in water samples from evaporation (American Public Health Association (APHA), 1995). The coordinates were noted against each sample using handheld GPS (GRAMIN, Exc. model). Then water samples were used to determine chemical parameters by using Inductive Coupled Plasma Mass Spectrometer (ICP-MS), Model ELAN DRC II, Perkin-Elmer Sciex instrument, at National Geophysical Research Institute, Hyderabad, India. The acidified groundwater samples were directly fed into the instrument by using a periplasmic pump with a solution uptake rate of about 1 ml/min. Subsequently, ascertained chemical parameters were evaluated to the BIS values for drinking purposes. Values that are above the permissible limits were considered for further analysis. Unstable parameter like hydrogen – ion concentration (pH) was measured in the field by using digital portable pH meter.

Inverse Distance Weighted (IDW)

The study area was digitized from the SOI toposheet 57 J/7 using Arc GIS 9.3 software and location points were imported from GPS into the GIS environment. For the preparation of spatial distribution maps, the
Inverse Distance Weighted interpolation (IDW) technique was adopted. IDW interpolation technique is used to predict a value from the measured values to any unmeasured or un-sampled location. Weights are assigned to the measured location points in such a fashion that the measured values which are nearer to the prediction location have more impact on the anticipated value than those farther away locations.

Calculation of Water Quality Index (WQI)

Three consecutive steps have been employed to calculate WQI as in Lateef (2011) and Al-hadithi (2012). In the first step, according to each chemical element importance in the overall drinking water assign a weight to each individual chemical parameter ($w_i$). Then, Relative weights ($W_i$) for each parameter were computed in the second step given by Equation (1)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$  \hspace{1cm} (1)

Where $W_i$ is the relative weight, $w_i$ is the assigned weight of each parameter, $\sum_{i=1}^{n} w_i$ is the summation of ‘n’ number of assigned parameters. Later, figured out the Quality Rating Scale (QRS) for each parameter which is calculated by Equation (2)

$$QRS = 100+NPI$$  \hspace{1cm} (2)

Where, NPI is the Net Pollution Index (NPI) of each parameter, which is given by measured parameter value/permissible limit value of that chemical parameter.

Figure 1. Location map of the study area.
In the third step, the values of Wi and QRS of each parameter were used to compute \( W_n \) for each chemical parameter by Equation (3)

\[
W_n = \frac{W_i}{QRS}
\]  

(3)

Where \( W_n \) is the sub-index of each parameter, later, Water Quality Index at each station was given by the summation of the \( W_n \) (Equation (4))

\[
WQI = \sum_{i=1}^{n} W_n
\]  

(4)

Where \( n \) is the number of parameters, then the obtained values were categorized into five classes (Brown et al., 1970).

**Factor analysis (FA)**

Factor analysis is a well known multivariate technique, that signifies the important factors contributing to the chemical data and explicates interrelationships among the pairs of variables (Lall & Sharma, 1996). Furthermore, it throws a light on the genetic understanding of the environment. This was done as follows: The correlation coefficient matrix has been transformed into a diagonal matrix in order to obtain eigenvalue (principal components) by varimax with Kaiser normalization method. The highest Eigenvalue pertains to the so-called factor I, which explains that the highest amount of variance in the dataset and the second factor (uncorrelated pairs of elements to the first factor) explains most of the remaining variance.

**Results and discussion**

A total of 20 elements were determined by using ICP-MS, out of which Silicon (Si), Potassium (K), Chromium (Cr), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Selenium (Se), Rubidium Rb, Strontium (Sr), Barium (Ba), Lead (Pb) were found to be within the permissible limits of BIS. And Elements like Sodium (Na) Magnesium (Mg), Aluminum (Al), Calcium (Ca), and Manganese (Mn), Iron (Fe) and Uranium (U) were present beyond the permissible limits in collected water samples. The results of the chemical elements of the 19 water samples are shown in Table 1. Statistical analysis and interpretation have been carried out to the elements which were present beyond the acceptable limit of BIS. Spatial distribution maps were prepared for the chemical element which exits beyond the permissible limits of BIS values using Inverse Distance Weighted (I.D.W) interpolation method in Arc GIS 9.3 (Figure 3).
| Element | pH  | Na  | Mg  | Al  | Si  | K   | Ca  | Cr  | Mn  | Fe  | Co  | Cu  | Zn  | As  | Se  | Rb  | Sr  | Ba  | Pb  | U   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| S1      | 8.33| 57.8| 57.1| 0.02| 8.8 | 3.6 | 67.4| 0.02| 0.001| 0.1 | 0.005| 0.005| 0.006| 0.006| 0.003| 0.7 | 0.2 | 0   | 0.005|
| S2      | 8.08| 39.7| 53.8| 0.01| 17.8| 3.88| 110.2| 0.01| 0.006| 0.2 | 0.006| 0.002| 0.3  | 0.001| 0.005| 0.003| 0.4 | 0   | 0.006|
| S3      | 7.72| 35.9| 68.2| 1.9 | 25.9| 7.2 | 122.3| 0.01| 0.006| 2.8 | 0.01 | 0.02 | 0.2  | 0.03 | 0.004| 0.006| 0.5 | 0.5 | 0.2 | 0.2 |
| S4      | 7.36| 60.7| 70.6| 1.2 | 15.9| 7.6 | 124.2| 0.01| 0.5  | 1.3 | 0.01 | 0.01 | 0.007| 0.03 | 0.01 | 0.01 | 0.6 | 0.1 | 0.02| 2.0 |
| S5      | 8.61| 66.5| 61.9| 0.8 | 16.3| 7.6 | 107.6| 0.01| 0.3  | 1.2 | 0.01 | 0.01 | 0.03 | 0.03 | 0.01 | 0.01 | 0.6 | 0.1 | 0.01| 1.9 |
| S6      | 7.87| 38.0| 42.8| 0.004| 17.7| 3.95| 66.3 | 0.01| 0.004| 0.007| 0.1 | 0.002| 0.001| 0.001| 0.003| 0.003| 0.2 | 0.5 | 0.0 | 0.02|
| S7      | 7.57| 28.7| 57.9| 1.2 | 20.1| 6.0 | 128.6| 0.01| 0.5  | 2.0 | 0.01 | 0.01 | 0.02 | 0.004| 0.005| 0.4  | 0.1 | 0.02| 0.2 |
| S8      | 7.28| 38.0| 43.1| 0.005| 18.8| 3.44| 68.3 | 0.01| 0.006| 0.1  | 0.004| 0.002| 0.001| 0.001| 0.004| 0.002| 0.2 | 0.1 | 0   | 0.0 |
| S9      | 8.03| 29.8| 43.2| 0.007| 19.1| 3.3 | 69.9 | 0.01| 0.007| 0.1  | 0.005| 0.005| 0.004| 0.001| 0.003| 0.002| 0.1 | 0.1 | 0   | 0.0 |
| S10     | 7.4 | 24.1| 45.8| 0.003| 18.4| 3.1 | 71.7 | 0.01| 0.003| 0.1  | 0.004| 0.002| 0.001| 0.003| 0.002| 0.01 | 0.1 | 0   | 0.01|
| S11     | 7.91| 26.1| 48.9| 0.001| 17.3| 3.5 | 91.9 | 0.01| 0.006| 0.2  | 0.004| 0.001| 0.001| 0.006| 0.002| 0.2  | 0.1 | 0   | 0.0 |
| S12     | 8.02| 17.2| 40.6| 0.008| 14.3| 6.5 | 73.2 | 0.01| 0.003| 0.2  | 0.004| 0.001| 0.001| 0.002| 0.004| 0.2  | 0.1 | 0   | 0.0 |
| S13     | 7.59| 53.4| 55.2| 0.01 | 20.1| 15.1| 89.4 | 0.01| 0.003| 0.2  | 0.004| 0.001| 0.001| 0.002| 0.005| 0.004| 0.2 | 0.8 | 0   | 0.03|
| S14     | 8.06| 40.2| 63.6| 0.004| 15.7| 3.8 | 88.5 | 0.01| 0.0  | 0.2  | 0.005| 0.003| 0.003| 0.001| 0.004| 0.004| 0.1 | 0.2 | 0   | 0.02|
| S15     | 7.9 | 33.3| 63.2| 0.02 | 14.7| 3.8 | 83.9 | 0.01| 0.001| 0.2  | 0.005| 0.004| 0.003| 0.0 | 0.006| 0.007| 0.1 | 0.5 | 0   | 0.01|
| S16     | 7.89| 28.2| 46.6| 0.01 | 11.5| 3.0 | 79.6 | 0.01| 0.002| 0.2  | 0.004| 0.0 | 0.01 | 0.0 | 0.01 | 0.003| 0.1 | 0.7 | 0   | 0.05|
| S17     | 7.93| 34.8| 56.5| 0.04 | 8.9 | 4.5 | 74.4 | 0.02| 0.006| 0.4  | 0.007| 0.04 | 0.2  | 0.001| 0.03 | 0.004| 0.2  | 0.2 | 0.1 | 0.1 |
| S18     | 8.16| 42.3| 59.6| 0.004| 12.6| 3.2 | 84.1 | 0.01| 0.005| 0.2  | 0.005| 0.001| 0.009| 0.001| 0.04 | 0.03 | 0.3 | 0.1 | 0   | 0.0 |
| S19     | 8.39| 35.9| 68.2| 1.9 | 25.9| 7.2 | 122.3| 0.01| 0.06 | 2.8  | 0.01 | 0.2  | 0.2  | 0.03 | 0.004| 0.006| 0.5 | 0.5 | 0.02| 0.2 |

**Acceptable Limit (mg/L)**

6.5–8.5 | 50  | 30  | 0.03 | 25  | 10  | 75  | 0.05 | 0.1  | 0.3 | NA  | 0.05 | 5   | 0.05 | 0.01 | 0 NA  | 0.7 | 0.1 | 1.4 |

*NA- Not Available.*
Groundwater quality

pH

pH is an estimate of hydrogen ion concentration value in water which is measured on a logarithmic scale, suggesting whether the solution is acidic or alkaline in nature. The pH value in the study area varies from 7.28 to 8.61 with an average of 8 indicating the basic (alkaline) nature of the groundwater (Table 2). The spatial distribution map of pH also depicts the alkaline nature.

Table 2. Summary of chemical elements concentrations in collected water samples.

| Element | Minimum | Maximum | Average | Median | Standard deviation | Coefficient of variation | Acceptable Limit* |
|---------|---------|---------|---------|--------|-------------------|------------------------|-------------------|
| pH      | 7.28    | 8.61    | 8       | 7.91   | 0.4               | 5                      | 6.5–8.5           |
| Na      | 17.2    | 66.5    | 38.8    | 35.9   | 0.3               | 5                      | 50                |
| Mg      | 40.6    | 70.6    | 55.2    | 56.5   | 0.9               | 5                      | 30                |
| Al      | 0.001   | 1.9     | 0.5     | 0.01   | 0.7               | 5                      | 0.03              |
| Ca      | 66.3    | 128.6   | 91.4    | 84.1   | 0.7               | 5                      | 75                |
| Mn      | 0       | 0.5     | 0.1     | 0.006  | 0.2               | 5                      | 0.3               |
| Fe      | 0.007   | 2.8     | 0.8     | 0.2    | 0.7               | 5                      | 0.3               |
| U       | 0       | 2       | 0.4     | 0.8    | 0.7               | 5                      | 1.4               |

*Acceptable limit concentrations (mg/L) as defined by Bureau of Indian Standard (BIS) (2009)
of water in most of the study area including Tummalapalle village (Figure 3(a)). The alkaline nature of water is attributed to the presence of bicarbonate, carbonate-rich rock beds (Limestone and dolomite) (Ranjana, 2009; Rasheed, Lakshmi, Patil, & Dayal, 2011).

**Sodium (Na)**

The minimum and maximum concentration of Sodium in the study area varies from 17.2 to 66.5 mg/L, respectively with an average of Na 38.8 mg/L, but the stations like S1, S4, S5, and S13 exceeds the threshold limit (50 mg/L). The concentration of Na is higher in the north, central and southern portions of the investigation area (Figure 3(b)) might have resulted from the excess usage of fertilizers in the farmland and by the leaching action of water while percolating through the sedimentary rocks (Central Ground Water Board, 2013).

**Magnesium (Mg)**

Magnesium is a crucial element for human being which is instrumental in normal bone structure along with calcium in the body. The presence of higher concentrations of Mg and Ca is regarded as hard water which is undesirable for domestic purposes (Selvam, Venkatramanan, Sivasubramanian, Chung, & Singaraja, 2017). The Mg concentration in the groundwater varies from 40.6 to 70.6 mg/L with an average of 55.2 mg/L (Table 2). Mg content in all water samples exceeds the permissible limit of BIS (Table 1). The spatial distribution map shows the predominance Mg concentration in the Central, southeast regions of the study area (Figure 3(c)). The higher concentration of the Mg element in groundwater plausibly by the circulation of water creates a condition for the dissolution of Mg element from the host rocks like dolomite and shale.

**Aluminum (Al)**

Aluminum varies from 0.001 to 1.9 mg/L with mean value 0.5 mg/L (Table 1). Only five water samples (S3, S4, S5, S7, and S19) exceed the threshold values of Aluminum. The higher concentration of Al was observed in the central portion and southern regions of the study area (Figure 3(d)). Aluminum occurs naturally in feldspars and mine tailings. The higher concentration of Al causes dementia (Alzheimer’s disease).

**Calcium (Ca)**

Calcium plays a vital role in physiology and biochemistry of the cell and organisms. Consumption of water which is higher in the concentration of the Ca shows adverse effects on human health viz. formation of stones in kidneys, bone weakness, and hypercalcemia, etc. In the study area, Calcium varied from 66.3 to 128.6 mg/L with an average of 91.4 mg/L. The maximum permissible limit of Ca in groundwater is 75 mg/L. The spatial map shows a higher concentration of Ca mostly in the central and southern portions of the study area (Figure 3(e)). Higher concentrations of Ca ion in the water samples might have resulted in the carbonate weathering of country rocks like dolomite and massive limestone besides agricultural waste runoff.

**Manganese (Mn)**

The concentration of Mn in the groundwater varies from 0 to 0.5 mg/L with an average value of 0.1 mg/L. Only two water samples exceeded the permissible level i.e. 0.3 mg/L (Table 1). But the spatial distribution map shows the higher concentration of Mn in the southwestern portions of the study area (Figure 3(f)). Higher Mn concentration levels in groundwater may be due to the presence of interspersed of clay material in shale that exits near the water table.

**Iron (Fe)**

The concentration of Fe in the groundwater varies from 0.007 to 2.8 mg/L with average value 0.8 mg/L (Table 1) only five samples of Fe exceeded the permissible level i.e. 0.3 mg/L. The higher concentration of Fe observed as patches in the central portion and southern portions of the study area (Figure 3(g)). The occurrence of a higher concentration of Fe in groundwater might have resulted from the natural weathering of Fe content in conglomerate and purple shale. The presence of a higher concentration of Fe element in the groundwater may increase the growth of pathogenic organisms (Andrews et al., 2003).

**Uranium (U)**

Uranium varies from 0.0 to 2.0 mg/L in the study area with an average value 0.4 mg/L which is present within the permissible limit of BIS (1.4 mg/L) (Table 1) but only two samples of uranium (S4 and S5) stations were located in the ore body regions) are found beyond the acceptable limits. The abnormal values may be due to the presence of the ore zone (Figure 3(h)). The ore zone consists of radioactive minerals like U-Ti complex, pitchblende, and coffinite (Basu, 2007).

**Correlation analysis of water samples**

To know the degree of linear affiliation in the water quality parameters, the correlation coefficient (r) has been calculated (Table 3). A T-Test was conducted to determine the p-value that indicates how likely the water quality parameters are correlated (Table 4). For 19 samples the standard value of the t-test is 2.1 with 95% of the confidence level. The values which are above the standard value i.e. 2.1 [from t table] (degree of freedom value is 17, the cumulative probability is
Table 3. Correlation coefficients among chemical elements.

|   | pH  | Na  | Mg  | Al  | Ca  | Mn  | Fe  | U  |
|---|-----|-----|-----|-----|-----|-----|-----|----|
| pH| 1   |     |     |     |     |     |     |    |
| Na| 0.23196| 1   |     |     |     |     |     |    |
| Mg| 0.19632| 0.529521| 1   |     |     |     |     |    |
| Al| 0.028235| 0.176838| 0.669137| 1   |     |     |     |    |
| Ca| 0.014313| 0.24726 | 0.72658 | 0.833074| 1   |     |     |    |
| Mn| −0.19689| 0.369391| 0.442027| 0.564887| 0.668196| 1   |     |    |
| Fe| 0.06561| 0.109766| 0.658974| 0.987452| 0.831121| 0.514053| 1   |    |
| U | 0.069222| 0.66762 | 0.475041| 0.439384| 0.501824| 0.749041| 0.342939| 1  |

Table 4. Correlation coefficients T – Test Matrix.

|   | pH  | Na  | Mg  | Al  | Ca  | Mn  | Fe  | U  |
|---|-----|-----|-----|-----|-----|-----|-----|----|
| pH| 1   |     |     |     |     |     |     |    |
| Na| 1   | 1   |     |     |     |     |     |    |
| Mg| 0.9 | 2.6 | 1   |     |     |     |     |    |
| Al| 0.2 | 0.8 | 3.8 | 1   |     |     |     |    |
| Ca| 0.1 | 1.1 | 4.4 | 6.3 | 1   |     |     |    |
| Mn| −0.9| 1.7 | 2.1 | 2.9 | 4.1 |     |     |    |
| Fe| 0.3 | 0.5 | 3.7 | 12.0| 6.2 | 2.5 | 1   |    |
| U | 0.3 | 3.7 | 2.3 | 2.1 | 2.4 | 4.7 | 1.6 | 1 |

Table 5. Water quality status classification according to WQI by Brown et al. (1970).

| WQI | Water quality status | Possible usage |
|-----|----------------------|----------------|
| 0–25| Excellent            | Drinking, Irrigation, Industrial |
| 26–30| Good                 | Drinking, Irrigation and Industrial |
| 31–75| Poor                 | Irrigation and Industrial |
| 76–100| Very Poor           | Irrigation |
| Above| Unstable for drinking| Proper treatment required before use |
| 100 |                     | Unstable for drinking |

L<sub>0.025</sub>, one tail) show a significant correlation among the chemical elements.

From Table 4, considerable correlation can be seen between Na-Mg (2.6), and Na-U (3.7). A significant correlation exists between Mg to all other elements except with manganese and the same as well with the Aluminum (Al) to the other elements, a very significant association can be observed between Al-Fe (12.0). It may be inferred that the noteworthy association between Al-Fe is attributed to the dissolution of Al and Fe from the shales by the predominate water-rock interaction which occurred in the aquifer. Considerable correlation can be seen between Ca and other elements but very significant association exists between Ca-Al (6.3), Ca-Fe (6.2). This indicates a common source due to the geochemical process for these elements (Stallard & Edmond, 1983). Further, Mn shows significant affiliation with Iron (2.5), and Uranium (4.7).

To gain a better insight on overall water quality over the respective stations, WQI was computed to the parameters of the water samples. The parameters used for the computing WQI were pH, Sodium (Na), Magnesium (Mg), Aluminum (Al), Calcium (Ca), Manganese (Mn), Iron (Fe) and Uranium (U). Calculation of WQI was carried out by Weighted Arithmetic Index Method (Brown et al., 1970; Ramakrishanaiah et al., 2009). Water Quality Status (WQS) according to WQI is shown (Table 5).

The minimum and maximum WQI values for the groundwater samples have been found to be 71 and 110, respectively which falls under “poor quality status” to “unstable for drinking purpose” categories (Table 6). It is observed from Table 7 that the majority (42%) of the groundwater samples fall under very poor water quality category which can be used for irrigation purposes (Brown et al., 1970) and requires special treatment ‘infiltration and disinfection’ to use the groundwater for domestic purposes. And about 32% of the samples fall under ‘unstable for drinking’ which requires proper treatment to use the water for drinking and for other domestic purposes. About 26% of the samples fall under poor water quality category which can be used for Irrigation and Industrial purposes. It is believed that abnormal values of the Uranium element from sites S4 and S5 are due to the presence of uranium deposit/ore body.

Table 6. Water quality index values of ground water samples.

| Station No | Station Name | WQI | Status |
|------------|--------------|-----|--------|
| S1         | Tummalapalli 1| 91  | Very Poor Water Quality |
| S2         | Tummalapalli 2| 99  | Very Poor Water Quality |
| S3         | Tummalapalli 3| 110 | Unstable for drinking |
| S4         | Tummalapalli 4| 105 | Unstable for drinking |
| S5         | Tummalapalli 5| 101 | Unstable for drinking |
| S6         | Tummalapalli 6| 71  | Poor Water Quality |
| S7         | Somala vandla palli 1 | 108 | Unstable for drinking |
| S8         | Somala vandla palli 2 | 74  | Poor Water Quality |
| S9         | Mabbuchinta Palli 1 | 75  | Poor Water Quality |
| S10        | Mabbuchinta Palli 2 | 73  | Poor Water Quality |
| S11        | Mabbuchinta Palli 3 | 86  | Very Poor Water Quality |
| S12        | AMD camp       | 71  | Poor Water Quality |
| S13        | Bestavaripalli | 96  | Very Poor Water Quality |
| S14        | Velpula        | 96  | Very Poor Water Quality |
| S15        | Becchagaripalli 1 | 95  | Very Poor Water Quality |
| S16        | Becchagaripalli 2 | 82  | Very Poor Water Quality |
| S17        | Bunuyisgaripalli | 102 | Unstable for drinking |
| S18        | Rachakunta Palli 1 | 94  | Very Poor Water Quality |
| S19        | Rachakunta Palli 2 | 109 | Unstable for drinking |

Table 7. Factor analysis results of trace elements.

| Parameters | Factors |
|------------|---------|
| pH         | 0.062   | −0.130 | 0.434 |
| Na         | 0.489   | −0.758 | 0.276 |
| Mg         | 0.775   | −0.963 | 0.332 |
| Al         | 0.887   | 0.376  | 0.080 |
| Ca         | 0.882   | 0.201  | −0.025 |
| Mn         | 0.789   | −0.194 | −0.587 |
| Fe         | 0.863   | 0.473  | 0.139 |
| U          | 0.689   | −0.489 | −0.163 |

Total | 4.255 | 1.278 | 0.770 |
% of variance | 53.190 | 15.973 | 9.623 |
Cumulative % | 53.190 | 69.163 | 78.786 |
Factor analysis (FA)

Factor analysis shows a total of three factors loading with a total variance of 78.786% (Table 7). Factor 1 displays a total variance of 53.190% with substantial loading on is attributed to the presence of dolomite, shale as host rock and presence of ore body/discharge of mining material contributes large amounts of Mg, Al, Ca, Mn and U, thus natural activity is one of the most important factors controlling the groundwater quality in the study area. Factor 2 shows a total variance of 15.973% with factor loading of Al, this is due to the influence of anthropogenic activities like domestic agricultural runoff, etc., and factor 3 shows a total variance of 9.623% with factor loading of pH, which may be attributed to the dissolution of carbonates by the water-rock interaction in the aquifer. Based on this factor analysis, both geogenic and anthropogenic activities play a vital role in the underground water chemistry.

Conclusion

The present paper aims to evaluate the assessment of water quality in and around the world’s largest Uranium deposit i.e. TummalaPalle uranium which is located in Kadapa district, India. Over 19 groundwater samples were analyzed for chemical evaluation, conventional methods and by T-Test results, showed significant contamination in the levels of Na, Mg, Al, Ca, Mn, Fe, and U. To know the spatial dispersion of chemical elements in the study area spatial distribution maps were prepared in GIS environ by using IDW interpolation technique. To ascertain the overall water quality at the respective stations, WQI was computed. Results showed that about 42% of the groundwater samples in and around TummalaPalle areas fall under “very poor water quality category”, 32% of the samples showed “unstable for drinking” which requires proper treatment to use the groundwater for drinking and other domestic purposes. From factor analysis host rocks, dolomite and shale contribute majorly for groundwater chemistry. Hence it is inferred that the groundwater in around the TummalaPalle area is not safe at present for domestic use. This study recommends periodic monitoring of groundwater quality in and around the TummalaPalle area in order to mitigate and manage the health and environment of the mining area.

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