Groundwater Quality Assessment in hard rock terrain of part of Ranchi district, Jharkhand, India: An integrated approach
Bindu Kumari, Saumitra Mukherjee, Neha Singh
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India.
binduses@gmail.com
doi:10.6088/ijes.2014050100070

ABSTRACT
The physico-chemical parameters of groundwater in the hard rock terrain largely depend upon geological setup of the area. However, anthropogenic activities adversely affected the quality of groundwater. Groundwater Quality Index (GWQI) was calculated by considering various physico-chemical parameters (pH, EC, TDS, Bicarbonate, Chloride, Fluoride, Nitrate, Sulfate, Calcium, Sodium, Magnesium, Iron, Zinc, and Manganese) of the groundwater samples, to assess overall quality of groundwater for drinking purposes. Groundwater with poor and very poor quality was observed in the sites contaminated by Fe$^{2+}$, Mn$^{2+}$, F$^-$, and Zn$^{2+}$, as these ions were given more weightage due to their greater influence in water quality even in very low concentration. Inverse distance weighted (IDW) raster interpolation technique of Spatial Analyst Module was used to generate the spatial distribution maps of various groundwater quality parameters. Good to very good quality of groundwater (GWQI <50) was reported in approximately 33% of the study area while Poor to very poor quality of groundwater (GWQI >75) was reported in around 35% of the study area, which needs immediate management.

Keywords: Groundwater Quality Index (GWQI), Ranchi, Physico-chemical parameters, Groundwater, Interpolation.

1. Introduction
Groundwater resources are dynamic in nature and affected by various natural and anthropogenic factors. Though value of groundwater lies in its wide spread occurrence and availability, the consistent good water supply for drinking purpose is also very important. Monitoring the groundwater quality in a regular basis is very important because once it gets contaminated, it is very difficult to restore due to its high persistence (Ramakrishnaiah et al., 2009, Kumar et al., 2010). The severity of groundwater contamination depends upon various factors such as porosity of top soil layer, aquifer characteristics, climate and land use pattern (Bishnoi and Malik, 2008, Mukherjee and Das, 2007, Udayalaxmi et al., 2010). Due to the rapid growth of urbanization and industrialization, there is an increasing pressure on land, water and environment, thus the overexploitation of groundwater and improper waste disposal practices leads to severe groundwater pollution (Rajankar et al., 2009, Swarna et al., 2010). The district Ranchi is underlain by crystalline and sedimentary rocks belonging to Precambrian and permo-carboniferous age wherein groundwater is restricted to weathered residuum as well within the consolidated rocks due to secondary porosity (Mukherjee, 1989, Naik, 1998). Groundwater Quality Index (GWQI) can be used to assess groundwater quality for its suitability in drinking purposes (Tiwari and Mishra, 1985, Pradhan et al., 2001, Sinha and Saxena, 2006, Naik and Purohit, 2001, Avvannavar and Shrihari, 2008). Current study is...
to delineate the areas having groundwater suitable for drinking purpose by integrating various physico-chemical parameters using Geographic Information System (GIS).

2. Methodology

2.1 Groundwater sampling and analysis

The study area includes Namkum, Ratu and Kanke blocks of Ranchi district extended between the latitude 23°22’N and 23°64’N and longitude between 85°10’E and 85°54’E and covering an area of 1164 sq.km (Figure 1). Groundwater samples (n=52) were collected from dug wells, tube wells and hand pumps during May, 2009 and locations were marked using GPS (Global Positioning System) (Figure 2). Care was taken during collection of water samples from hand pump by discarding initial water in order to minimize the impacts of iron pipes. Groundwater samples were collected in the acid washed polythene bottles and samples were stored at suitable conditions till analysis in the laboratory. Various parameters such as pH, EC and TDS were analyzed in the field condition during sample collection by using probes. The groundwater samples for cation and heavy metal analysis were acidified and collected separately. The samples were filtered using vacuum filtration unit and analyzed by using standard procedures (APHA, 2005). Na⁺ and K⁺ ions were analyzed by flame photometer method (AIMIL Flame Photometer). Other metals were analyzed by using Atomic Absorption Spectrophotometer (Thermo Fisher Scientific).

![Figure 1: Showing study area](image)
2.2 Groundwater Quality Index (GWQI)

Overall quality (suitability for drinking purpose) of groundwater samples can be represented by estimating GWQI through assigning weighted average to the parameters. On the basis of values of GWQI, groundwater suitability for drinking has been categorized into five groups viz. Excellent (0-25), Good (26-50), Moderate (51-75), Poor (76-100) and very poor (>100). GWQI has been calculated by following steps (Tiwari and Mishra, 1985, Asadi et al., 2007, Kavitha and Elangovan, 2010, Chatterjee et al., 2010):

\[
GWQI = \text{Antilog} \left[ \sum_{n=1}^{n} W_n \log_{10} Q_n \right]
\]

Where, \( W_n \), Weightage factor is computed using the following equation (table 1),

\[
W_n = \frac{K}{S_n}
\]

Where, \( K \), Proportionality constant is derived from,

\[
K = [1/(\sum_{n=1}^{n} 1/S_n)]
\]

\( S_n \) is the Indian standard values of the water quality parameter.

Quality rating (q) is calculated using the formula,
Groundwater Quality Assessment in hard rock terrain of part of Ranchi district, Jharkhand, India: An integrated approach

\[ Q_{ni} = \left( \frac{V_{actual} - V_{ideal}}{V_{standard} - V_{ideal}} \right) \times 100 \]

Where,

- \( Q_{ni} \) = Quality rating of \( i^{th} \) parameter for a total of \( n \) water quality parameters.
- \( V_{actual} \) = Value of the water quality parameter obtained from laboratory analysis.
- \( V_{ideal} \) = Value of that water quality parameter can be obtained from the standard tables.
- \( V_{ideal} \) for pH = 7 and for other parameters it is equivalent to zero.
- \( V_{standard} \) = Indian standard of the water quality parameter.

2.3 Application of GIS

The groundwater quality data were used to create geo-database for present study. Groundwater quality parameters of particular location were added to the attribute table of corresponding sampling point using Arc 9.1 software. Inverse distance weighted (IDW) raster interpolation technique of Spatial Analyst Module was used to generate the spatial distribution maps of various groundwater quality parameters. This method used a defined set of sample points for estimating the output grid cell value. The cell values are determined using a linearly weighted combination of a set of sample points. Weights are computed by taking inverse of the distance from an observation’s location to the location of the point being estimated (Asadi et al., 2007, Burrough et al., 1998). The Brief methodology of current study is given as a flow chart (Figure 3).

![Flow chart showing brief methodology of current study.](image)

Figure 3: Flow chart showing brief methodology of current study.

3. Results and discussion

3.1 Statistical analysis

The average values of Fe\(^{2+}\) and Mn\(^{2+}\) concentration were exceeding the prescribed limit of the Indian standard of the drinking water (Table 1). Zn\(^{2+}\) concentration was found exceptionally high in some localized portion of the study area. A strong positive correlation was observed
between EC with Ca\(^{2+}\), Mg\(^{2+}\) and HCO\(_3^-\) \((r = 0.83, 0.62\) and 0.83, respectively\) (Table 2). A moderately positive correlation between Ca\(^{2+}\) and Mg\(^{2+}\) with Na\(^+\) and K\(^+\) indicates the dominance of weathering and subsequent ion-exchange processes in the groundwater aquifer system (Mahlknecht, 2003). There are no significant correlations among the metals which indicate its different sources in the groundwater. In the scattered plots of (Ca\(^{2+}\)+Mg\(^{2+}\)) vs. TZ\(^+\) (total cationic load) and (Na\(^+\)+K\(^+\)) vs. TZ\(^+\) (Figure 4a & 4b) the points were below 1:1 equiline, suggesting the enrichment of groundwater with alkali and alkaline earth metals, may results of both silicate and carbonate weathering in the study area (Srinivasamoorthy et al., 2008). The prevalence of alkali metals over bicarbonate (Figure 4c) observed only in few samples; however alkaline earth metals prevailed over bicarbonates in a significant number of samples (Figure 4d) which were collected from shallow aquifers. Na\(^+\) and K\(^+\) in groundwater in the study area largely derived from igneous and metamorphic rocks in which mica and orthoclase are common parent minerals (Mukherjee, 1989, Mahadevan, 2002, Saha et al., 2013). The relatively higher contribution of (Ca\(^{2+}\)+Mg\(^{2+}\)) to the total cations with high \((\text{Ca}^{2+}\text{+Mg}^{2+})/(\text{Na}^+\text{+K}^+)\) ratio (1.7±1.4) as well as plot of Ca\(^{2+}\)+Mg\(^{2+}\) versus \((\text{SO}_4^{2-} + \text{HCO}_3^-)\) (Figure 4e) indicates excess calcium and magnesium in groundwater exchanged with alkali metal ions from aquifer materials (Lakshmanan et al., 2003). Plot of (Ca\(^{2+}\)+Mg\(^{2+}\)) vs. SO\(_4^{2-}\) (Figure 4f) shows not very significant correlation indicates the possibility of some other sources of SO\(_4^{2-}\) along with MgCO\(_3\) and CaCO\(_3\). Thus, various correlations as discussed indicate that rock-water interactions have a major role controlling hydro-geochemistry of study area along with anthropogenic activities (Jayaprakash et al., 2008).

### Table 1: Water quality parameters, Indian standards and their weightage factor.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean±SD</th>
<th>Range</th>
<th>Indian standard (S)</th>
<th>Weightage Factor (Wn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.7 ±0.43</td>
<td>5.4 - 7.9</td>
<td>8.5</td>
<td>0.00798</td>
</tr>
<tr>
<td>EC</td>
<td>373.0 ±204.9</td>
<td>90 - 810</td>
<td>1400</td>
<td>0.00005</td>
</tr>
<tr>
<td>TDS</td>
<td>316.0 ±189.2</td>
<td>60 - 780</td>
<td>500</td>
<td>0.00014</td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>9.97 ±5.54</td>
<td>0.64 - 25.18</td>
<td>30</td>
<td>0.00226</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>24.90 ±15.97</td>
<td>2.0 - 89.0</td>
<td>75</td>
<td>0.00091</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>25.88 ±15.81</td>
<td>3.93 - 80.66</td>
<td>200</td>
<td>0.00034</td>
</tr>
<tr>
<td>K(^+)</td>
<td>5.7± 1.99</td>
<td>2.98-12.65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fe(^{2+})</td>
<td>1.0 ±1.30</td>
<td>0.06 - 6.3</td>
<td>0.3</td>
<td>0.226</td>
</tr>
<tr>
<td>Zn(^{2+})</td>
<td>2.3 ±5.39</td>
<td>0.01-21.3</td>
<td>5</td>
<td>0.01356</td>
</tr>
<tr>
<td>Mn(^{2+})</td>
<td>0.13 ±0.21</td>
<td>0.01 – 0.81</td>
<td>0.1</td>
<td>0.678</td>
</tr>
<tr>
<td>HCO(_3^-)</td>
<td>149 ±55.5</td>
<td>20 - 179</td>
<td>300</td>
<td>0.00023</td>
</tr>
<tr>
<td>F(^-)</td>
<td>0.906 ±0.529</td>
<td>0.27 – 2.22</td>
<td>1</td>
<td>0.0678</td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>44.68 ± 27.84</td>
<td>12.0 - 115.9</td>
<td>250</td>
<td>0.00027</td>
</tr>
<tr>
<td>NO(_3^-)</td>
<td>28.23 ±15.82</td>
<td>3.55 - 84.35</td>
<td>45</td>
<td>0.00151</td>
</tr>
<tr>
<td>SO(_4^{2-})</td>
<td>22.58 ±12.97</td>
<td>6.80 - 55.08</td>
<td>200</td>
<td>0.00034</td>
</tr>
</tbody>
</table>

Unit: All units in ppm except pH and EC (µs/cm).

### 3.2 Spatial distribution of various parameters influencing groundwater quality

Higher concentration of Fe\(^{2+}\) (range: 0.06 to 6.3 ppm) in groundwater samples was observed at major portion of the study area (Figure 5a) such as Kumhariya, Buti, Sanga, Sidrol, Tanko, Kosaro and Churu which may be due to weathering of iron bearing rocks and minerals (Thamdrup, 2000). The higher concentration of Mn\(^{2+}\) in groundwater samples (ranges: 0.01 to 0.57 ppm) in the major portion of the study area (Figure 5b). The locations such as Baragawn,
Bukru and Sutiambe the concentration of Mn$^{2+}$ was found exceptionally high (>0.5 ppm), which may be contributed by industrial effluent, sewage, and landfill leachate. The disposed off and landfills may be the source of higher concentration of Zn$^{2+}$ in some localized part of the study area viz. Namkum chawk, Hinoo, Ghaghra, Bundu and Baragawn (Figure 5c).

![Scattered plot between (Ca$^{2+}$+Mg$^{2+}$) and TZ$^+$ (a), (Na$^+$+ K$^+$) and TZ$^+$ (b), (Na$^+$ + K$^+$) and HCO$_3^-$ (c), Ca$^{2+}$+Mg$^{2+}$ and HCO$_3^-$ (d), Ca$^{2+}$+Mg$^{2+}$ and SO$_4^{2-}$ + HCO$_3^-$ (e) and Ca$^{2+}$+Mg$^{2+}$ and SO$_4^{2-}$ (f).](image)

**Figure 4:** Scattered plot between (Ca$^{2+}$+Mg$^{2+}$) and TZ$^+$ (a), (Na$^+$ + K$^+$) and TZ$^+$ (b), (Na$^+$ + K$^+$) and HCO$_3^-$ (c), Ca$^{2+}$+Mg$^{2+}$ and HCO$_3^-$ (d), Ca$^{2+}$+Mg$^{2+}$ and SO$_4^{2-}$ + HCO$_3^-$ (e) and Ca$^{2+}$+Mg$^{2+}$ and SO$_4^{2-}$ (f).

**Table 2:** Correlation matrix of groundwater quality parameters.

|          | pH  | EC   | TDS  | Mg$^{2+}$ | Ca$^{2+}$ | Na$^+$ | K$^+$ | Fe$^{2+}$ | Zn$^{2+}$ | Mn$^{2+}$ | HCO$_3^-$ | F    | Cl   | NO$_3^-$ | SO$_4^{2-}$ |
|----------|-----|------|------|-----------|-----------|--------|-------|-----------|-----------|-----------|---------|------|-------|---------|
| pH       | 1.00|      |      |           |           |        |       |           |           |           |         |      |       |         |
| EC       | 0.09| 1.00 |      |           |           |        |       |           |           |           |         |      |       |         |
| TDS      | 0.10| 0.99 | 1.00 |           |           |        |       |           |           |           |         |      |       |         |
| Mg$^{2+}$| 0.34| 0.62 | 0.62 | 1.00      |           |        |       |           |           |           |         |      |       |         |
| Ca$^{2+}$| 0.32| 0.83 | 0.84 | 0.56      | 1.00      |        |       |           |           |           |         |      |       |         |
| Na$^+$   | -0.09| 0.56 | 0.56 | 0.47      | 0.36      | 1.00   |       |           |           |           |         |      |       |         |
| K$^+$    | 0.08 | 0.28 | 0.28 | 0.34      | 0.22      | 0.34   | 1.00  |           |           |           |         |      |       |         |
| Fe$^{2+}$| -0.42|-0.22|-0.22| -0.28     | -0.15     | -0.23  | -0.13 | 1.00      |           |           |         |      |       |         |
| Zn$^{2+}$| -0.18| 0.30 | 0.31 | 0.16      | 0.03      | 0.46   | 0.06  | -0.08     | 1.00      |           |         |      |       |         |
| Mn$^{2+}$| -0.36| 0.12 | 0.10 | 0.08      | 0.08      | -0.04  | 0.11  | -0.03     | 0.13      | 1.00      |         |      |       |         |
| HCO$_3^-$| 0.15| 0.83 | 0.84 | 0.67      | 0.79      | 0.55   | 0.09  | -0.08     | 0.15      | 0.08      | 1.00    |      |       |         |
| F        | 0.23 | -0.02|-0.03| 0.05      | 0.18      | -0.07  | 0.21  | 0.20      | -0.10     | -0.02     | 0.01    | 1.00 |      |         |
| Cl       | 0.01 | 0.59 | 0.57 | 0.45      | 0.46      | 0.58   | 0.52  | -0.17     | 0.30      | -0.03     | 0.25    | 0.20 | 1.00 |         |
| NO$_3^-$ | 0.24 | 0.40 | 0.40 | 0.54      | 0.41      | 0.37   | 0.36  | -0.16     | 0.10      | 0.06      | 0.29    | 0.19 | 0.45 | 1.00    |
| SO$_4^{2-}$ | 0.17 | 0.42 | 0.42 | 0.59      | 0.45      | 0.61   | 0.39  | -0.22     | 0.14      | -0.01     | 0.38    | 0.11 | 0.45 | 0.53    |

Unit: All units in ppm except pH and EC (µs/cm).
Figure 5: Spatial variations of Fe$^{2+}$ (a), Mn$^{2+}$ (b), Zn$^{2+}$ (c), Ca$^{2+}$ (d), F$^-$ (e) and NO$_3^-$ (f).
Since mobility of Zn\(^{2+}\) in groundwater is comparatively higher than most of the heavy metals and its tendency to make complexes with organic matter it plays an important role to contaminate groundwater. The concentration of Ca\(^{2+}\) (range: 1.9 to 88.7 ppm) in groundwater samples reported in south eastern and some localized portion of central part of the study area (Figure 5d). Relatively higher concentration of Ca\(^{2+}\) may be due to erosion and weathering of Ca-bearing rocks, being the most common source of Ca\(^{2+}\) in the groundwater. Fluoride concentration (Figure 5e) in the groundwater samples (range: 0.27 to 2.22 ppm) was reported exceptionally high (>2ppm) in some locations in Manatu, Baram, Jamkhua and Tanko. Minerals like fluorite, apatite, mica, amphiboles, certain clays and villianite have the greatest effect on the hydrogeochemistry of fluoride in the study area (Mukherjee, 1989, Mahadevan, 2002, Raju et al., 2009). Since, nitrate solubility in water is very high, nitrate concentration is likely to high where agricultural activities (fertilizer and animal waste) are intense. Nitrate concentration (range: 3.5 to 84.3ppm) was found well within the prescribed limit in major portion of the study area except at Pandra, Hehal, Bundu and Ghaghra (Figure 5f).

### 3.3 Groundwater Quality Index

Based on groundwater quality parameters, GWQI was calculated for each sampling location. The study area can be divided into five categories based upon the values of GWQI as excellent, good, moderate, poor and very poor. About 5% of the area comes under very good, 28% good, 32% moderate, 20% poor and 15% area comes under very poor groundwater quality (Figure 6).
Groundwater with poor and very poor quality index categories was observed in basically those areas which were contaminated by NO$_3^-$, Fe$^{2+}$, Mn$^{2+}$, F$^-$ and Zn$^{2+}$ as these ions were given more weighted due to their greater influence in water quality even in very low concentration. Areas reported good to very good quality of groundwater (GWQI <50) reported in approximately 33% of the study area comprising Singhmore, Nawatoli, Sundil, Chandwe, Piska, Samlong, Baramuri, Ratu chawk, Dam-side, Pundag, Ulidih, Samlong, Hadser and Nepal-house. Poor and very poor quality of groundwater reported in Manatu, Pandra, Sutimbe, Bukru, Sukurhuttoo, Baragawn, Aadarsh Nager, Tanko, Churu and Hinoo (GWQI ranged from 76 to 268).

4. Conclusion

Groundwater chemistry of the study area is controlled by various processes including weathering, ion exchange as well as anthropogenic activities. GWQI has been calculated based upon various physic-chemical parameters of the groundwater. The major contributors of the poor groundwater quality in the study area are NO$_3^-$, Fe$^{2+}$, Mn$^{2+}$, F$^-$ and Zn$^{2+}$. A wide localized variation of physic-chemical parameter has been observed indicating that the anthropogenic factors play vital role in groundwater quality. The poor groundwater quality may be attributed by over exploitation of the groundwater and anthropogenic causes such as dumped waste materials from where leachates infiltrate into the aquifer. Poor and very poor quality of groundwater reported at various places such as Manatu, Pandra, Sutimbe, Bukru, Sukurhuttoo, Baragawn, Aadarsh Nager, Tanko, Churu and Hinoo, which is not fit for drinking purpose. These areas need frequent monitoring as well as proper management practices while disposing municipal/industrial wastes.

Acknowledgements

The authors are thankful to the Council of Scientific and Industrial Research (CSIR), Government of India, for funding the research work by providing Fellowship. The authors are also grateful to Jawaharlal Nehru University, New Delhi, India for providing research facilities.

5. References

1. APHA, AWWA and WEF (2005), Standard methods for the examination of water and wastewater, 21st edn, American Public Health Association, Washington, DC.


