Water quality monitoring of selected dug wells of central India with special

L. N. Gupta, G. S. Gupta and Virendra Kumar Mishra*

*Department of Energy and Environment, Faculty of Science and Environment, Pollution research laboratory, Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya, Chitrakoot 485780, Madhya Pradesh, India

b Department of Environmental Science, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh 484887, India

* Corresponding author. E-mail: virendra78@gmail.com

Abstract

Dug wells water is frequently used for irrigation of crops in India. The huge quantity of various toxic pollutants enters to ground water through anthropogenic and geogenic sources, which make the ground water, unfit for irrigation. Such water if used for irrigation may pose a serious risk to quality and quantity of crops and other things. The present study highlights the water quality monitoring of selected dug wells of Central India (Rajaula ward of Chitrakoot town). Different water quality parameters such as pH, electrical conductivity, Ca++, Mg++, Na+, K+, HCO3-, CO3-, chloride, sulfate, sodium percentage (Na %), magnesium hazards, sodium absorption ratio (SAR), residual sodium carbonate (RSC), potential soil salinity and permeability index were investigated for monitoring of to assess its suitability for irrigation. Some models, i.e. Wilcox Diagram, U.S. Salinity diagrams, Doneen criterion, etc. were also used for conformation of dug well water quality for irrigation purpose. Results of the study indicated that all selected wells have mostly medium and high salinity, under limit of SAR, medium Na %, medium Mg hazards, under limit of RSC and low Cl- quantity.

Key words: Doneen criterion, water quality, irrigation, Na%, RSC, SAR, U.S. Salinity Diagrams, Wilcox Diagram

INTRODUCTION

Ground water bodies mostly dug wells water is frequently used for irrigation of crops. Almost 35% of the total area in central India is irrigated by dug well. The huge quantity of various toxic pollutants enters to ground water through anthropogenic (domestic sewage, agriculture waste, disposal of large quantity of solid wastes and its open dumping) and geogenic sources (due to mineral's abundance area). Also leaching, weathering, storm run-off, precipitation of rain etc. promote the above process and in long run water quality of dug wells is deteriorated. Such water when is used in agriculture for irrigation may pose a serious risk to quality and quantity of crops and other things (Laidlaw et al. 2015; Sappa et al. 2015; Vardanjani et al. 2015). Dug wells are one of the most important sources of irrigation in central India. Water quality of the dug well is one of the very important. Dug well water is mainly used for irrigation amid other ground water bodies. The high quantity of various toxic pollutants from anthropogenic (domestic sewage, agriculture waste, municipal and industrial solid wastes) and geogenic sources (due to mineral's abundance area) enter in ground water through leaching, weathering, storm run-off, precipitation of rain, etc. to the ground water bodies and thus deteriorates its quality (Nayer et al. 2007; Nam et al. 2015; Wang et al. 2015; Worqlul et al. 2015). In long run such water on irrigation may pose a serious risk in quality and quantity of crop as well as human health (Godfrey et al. 2011; Rahmana & Hasegawaa 2011).
Considering the above points it is planned to carry out water quality monitoring of some dug wells of central India. After a detailed survey Rajaula ward, Chitrakoot town of Madhya Pradesh state of central India was selected as study site for detailed investigation. This area has not been subjected to detailed investigation of water quality and only few data are available. Total seven dug wells were selected for detailed sampling details of which is given in next section.

**MATERIALS AND METHODS**

The water quality analysis of seven prime dug wells of Rajaula ward of Chitrakoot town was carried out. Location of each well was taken with the help of Global Possessing System (Model-Germin, 072). Their details are given in Table 1. Glasswares used in the study were of high quality borosilicate brand (Schott duran, Germany). Chemicals used were of AR/GR grade and obtained from Qualigen/ E-Merck/Hi-media. Dug well water samples were collected in pre-cleaned polypropylene bottles with necessary precautions (APHA-AWWA 2006).

**Table 1** | Details of Ground sampling sites, i.e. Dug wells

<table>
<thead>
<tr>
<th>Code of dug wells</th>
<th>Geographical location</th>
<th>Diameter (meter)</th>
<th>Total depth of dug well (meter)</th>
<th>Depth of water containing portion of dug well (meter)</th>
<th>Depth of water table (meter)</th>
<th>Availability of Water X10³</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW-1</td>
<td>25° 8' 39.5&quot; N 80° 50' 59.8&quot; E (M.S. L. 114 m.)</td>
<td>5.70</td>
<td>22.10</td>
<td>1.55</td>
<td>20.55</td>
<td>39.57</td>
</tr>
<tr>
<td>DW-2</td>
<td>25° 8' 46.3&quot; N 80° 50' 43.1&quot; E (M.S. L. 128 m.)</td>
<td>3.28</td>
<td>21.80</td>
<td>1.50</td>
<td>20.3</td>
<td>12.68</td>
</tr>
<tr>
<td>DW-3</td>
<td>25° 8' 51.8&quot; N 80° 50' 45.6&quot; E (M.S. L. 136 m.)</td>
<td>3.45</td>
<td>20.50</td>
<td>1.38</td>
<td>19.12</td>
<td>12.91</td>
</tr>
<tr>
<td>DW-4</td>
<td>25° 8' 56.1&quot; N 80° 50' 44.4&quot; E (M.S. L. 142 m.)</td>
<td>3.23</td>
<td>21.00</td>
<td>1.68</td>
<td>19.32</td>
<td>13.77</td>
</tr>
<tr>
<td>DW-5</td>
<td>25° 8' 57.0&quot; N 80° 50' 48.8&quot; E (M.S. L. 147 m.)</td>
<td>4.55</td>
<td>19.00</td>
<td>0.60</td>
<td>18.4</td>
<td>9.76</td>
</tr>
<tr>
<td>DW-6</td>
<td>25° 8' 57.7&quot; N 80° 51' 44.4&quot; E (M.S. L. 156 m.)</td>
<td>3.68</td>
<td>25.78</td>
<td>3.60</td>
<td>22.18</td>
<td>38.31</td>
</tr>
<tr>
<td>DW-7</td>
<td>25° 8' 58.2&quot; N 80° 51' 42.4&quot; E (M.S. L. 170 m.)</td>
<td>3.40</td>
<td>15.30</td>
<td>0.78</td>
<td>14.52</td>
<td>7.08</td>
</tr>
</tbody>
</table>

The parameters selected for monitoring were pH, electrical conductivity (EC), Ca⁺⁺, Mg⁺⁺, Na⁺, K⁺, HCO₃⁻, CO₃⁻ - chloride, sulfate, sodium percentage (Na %), magnesium hazards (MHs), sodium absorption ratio (SAR), residual sodium carbonate (RSC), potential soil salinity and permeability index (PI). The selected parameters were analyzed in the laboratory following the Standard Methods for the examination of water and wastewater (APHA-AWWA 2006). Measurement of pH, EC, Na⁺ & K⁺ were carried out using digital pH meter (Electronics India (EI), model-101 E), conductivity meter (Electronics India (EI), model-601) and flame photometer (Esco, model-1382), respectively. Measurement of cations Ca⁺⁺, Mg⁺⁺ and anions like HCO₃⁻, CO₃⁻, Cl⁻ were carried out by volumetric titration procedure as prescribed in APHA-AWWA (2006). Sulfate was analyzed with the help of digital spectrophotometer (EI, model-301) at 420 nm wavelength. Sodium percentage (Na %), magnesium percentage (Mg %), SAR, RSC, potential soil salinity and PI were calculated using the following formulas:

\[
\text{Na}^{\%} = \frac{100 \times \text{Na}^+}{(\text{Na}^+ + \text{Ca}^{++} + \text{Mg}^{++} + \text{K}^+)}
\]
\[
\text{Mg\%} = \frac{100 \times \text{Mg}^{++}}{\text{(Ca}^{++} + \text{Mg}^{++})}
\]

(2)

\[
\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\text{Ca}^{++} + \text{Mg}^{++}/2}}
\]

(3)

\[
\text{RSC} = (\text{HCO}_3^- + \text{CO}_3^-) - (\text{Ca}^{++} + \text{Mg}^{++})
\]

(4)

\[
\text{PS} = \frac{\text{Cl}^- + \frac{1}{2}\text{SO}_4^-}{\text{Ca}^{++} + \text{Mg}^{++} + \text{Na}^{+}} \times 100
\]

(5)

Where all cationic and anionic concentrations of the above equations are kept in meq/l. It is calculated by dividing the quantity of mg/l of parameters by equivalent weight of parameters.

RESULTS AND DISCUSSION

The results of water quality parameters of the chosen dug wells were mentioned in Table 2. The results obtained were compared with their standards prescribed by World Health Organization (WHO 1991) and Bureau of Indian Standard (BIS 1983).

Table 2 | Physico-chemical Analysis of Dug Wells Water Undertaken Rajaula Ward

<table>
<thead>
<tr>
<th>Dug wells Parameters</th>
<th>DW-1</th>
<th>DW-2</th>
<th>DW-3</th>
<th>DW-4</th>
<th>DW-5</th>
<th>DW-6</th>
<th>DW-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.5</td>
<td>8.4</td>
<td>8.3</td>
<td>8.0</td>
<td>8.4</td>
<td>8.2</td>
<td>8.0</td>
</tr>
<tr>
<td>EC (\mu mho cm(^{-1}))</td>
<td>1411</td>
<td>1459</td>
<td>1494</td>
<td>1542</td>
<td>1580</td>
<td>1620</td>
<td>1662</td>
</tr>
<tr>
<td>Ca(^{++}) (mg/l)</td>
<td>80</td>
<td>84</td>
<td>86</td>
<td>90</td>
<td>92</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>Mg(^{++}) (mg/l)</td>
<td>37</td>
<td>40</td>
<td>44</td>
<td>47</td>
<td>50</td>
<td>54</td>
<td>56</td>
</tr>
<tr>
<td>Na(^+) (mg/l)</td>
<td>161</td>
<td>165</td>
<td>168</td>
<td>172</td>
<td>175</td>
<td>178</td>
<td>180</td>
</tr>
<tr>
<td>K(^+) (mg/l)</td>
<td>38</td>
<td>42</td>
<td>45</td>
<td>48</td>
<td>52</td>
<td>55</td>
<td>58</td>
</tr>
<tr>
<td>CO(_3)(^-) (mg/l)</td>
<td>20.00</td>
<td>26.00</td>
<td>30</td>
<td>36.00</td>
<td>42.00</td>
<td>46.00</td>
<td>48.00</td>
</tr>
<tr>
<td>HCO(_3) (mg/l)</td>
<td>276.00</td>
<td>274.00</td>
<td>272.00</td>
<td>272.00</td>
<td>270.00</td>
<td>270.00</td>
<td>272.00</td>
</tr>
<tr>
<td>Chloride (mg/l)</td>
<td>160</td>
<td>166</td>
<td>168</td>
<td>172</td>
<td>174</td>
<td>174</td>
<td>180</td>
</tr>
<tr>
<td>Sulfate (mg/l)</td>
<td>44</td>
<td>45</td>
<td>48</td>
<td>50</td>
<td>55</td>
<td>58</td>
<td>60</td>
</tr>
<tr>
<td>Sodium percentage (Na %)</td>
<td>46.65</td>
<td>45.61</td>
<td>44.64</td>
<td>43.83</td>
<td>43.14</td>
<td>42.12</td>
<td>41.40</td>
</tr>
<tr>
<td>Magnesium percentage (Mg %)</td>
<td>43.26</td>
<td>43.98</td>
<td>45.75</td>
<td>46.26</td>
<td>47.26</td>
<td>48.12</td>
<td>48.00</td>
</tr>
<tr>
<td>Sodium adsorption ratio (SAR)</td>
<td>3.73</td>
<td>3.71</td>
<td>3.67</td>
<td>3.66</td>
<td>3.65</td>
<td>3.60</td>
<td>3.57</td>
</tr>
<tr>
<td>Residue sodium carbonate (RSC)</td>
<td>-2.18</td>
<td>-2.56</td>
<td>-2.95</td>
<td>-3.30</td>
<td>-3.58</td>
<td>-4.04</td>
<td>-4.34</td>
</tr>
</tbody>
</table>

Units of sodium adsorption ratio (SAR) and residue sodium carbonate (RSC) are denotes in meq/l.

| PS%        | 5.10  | 5.29  | 5.38  | 5.42  | 5.63  | 5.66  | 5.85  |
| Potential Index (PI%) | 64.88 | 63.26 | 61.77 | 60.49 | 59.44 | 57.91 | 56.95 |
| TDS (mg/l) | 903   | 934   | 956   | 987   | 1011  | 1037  | 1064  |

The pH of well water depends on geology of the area and discharged waste in the surroundings. The values of pH were found in the range of 8.0–8.5 indicating the alkaline nature of water of all the dug wells. It may be due to the presence of limestone rocks in the surroundings of the sampling stations.
EC mostly occurred in the dug well water due to dissolved mineral matter by soil erosion and some gases especially CO₂. Dissolved mineral matter contains cations and anions in the water as it makes the relationship from TDS. Electrical conductance represents the salinity zone in water. Salinity problem may be resulted due to water logging, over irrigation and improper or poor drainage system in irrigated agricultural field. When the excess water evaporates result in it leaves salts on soil surface showing the salinity soil. The above soil may harm the plants because the water begins to flow out into plants passing the saline soil. Under present investigation EC was found in the range of 1,411–1,662 μmho/cm. On the basis of the EC, Richards had classified irrigation water in four salinity zone viz. low, medium, high and very high (Richards 1954). Irrigation water with value of EC below 250, 250–750, 750–2,250 and above 2,250 μmho/cm will be categorized as low, medium, high and very high saline, respectively. The present study indicated that EC of all water samples was found under the moderate and high salinity zone. Thus, some of the dug well water samples were not fit for irrigation purpose. The above water might affect adversely the growth of plant parts viz. seeds, fruits, leaves, roots, stems, etc.

Extents of calcium and magnesium were found to be in the range of 80–100 mg/l and 37–56 mg/l, respectively. The higher value of calcium and magnesium than their prescribed limits in all water samples was recorded which might be due to presence of limestone, dolomite, calcite, magnetite and gyspiferous shell in the surroundings. Prescribed limits of Ca³⁺ and Mg²⁺, i.e. 75 mg/l and 30 mg/l, respectively, support to by keeping the soil permeable and in good tilth.

MH was proposed by Szabolcs & Darab (1964) indicating a percentage of Mg in water to be used for irrigation. According to them, if MH value of water is found less than 50% then water will be fit for irrigation. The MH values in the dug well water samples were found between 43.26 and 48.12% showing its suitability for irrigation.

Bicarbonate hazard: carbonate and bicarbonate are the major anions of irrigation water which associate with Ca⁺ and Na⁺ and variation in the pH. Carbonate values were found in the range of 20–48 mg/l indicating the pH more than 8.0. While bicarbonate values were found in the range of 270–276 mg/l indicating the pH in between 6.5 and 9.0 in all water samples (Table 2). The bicarbonate values were more than their permissible limit, i.e. 200 mg/l. The bicarbonate and carbonate values may also be expressed in term of RSC. It can be used as a criterion for finding the suitability of irrigation waters. If sum of the values of carbonates and bicarbonates ions is more than the sum of calcium and magnesium then it will promote precipitation of Ca and Mg which will also influence the suitability of water for irrigation purposes. Water with RSC values below 1.25, 1.25 to 2.5 and above 2.5 meq/l will be in safe, marginal and unfit states for irrigation purpose, respectively. In the study area RSC ranged from –2.18 to –4.34 meq/l. Negative values of RSC indicated that Ca and Mg were not completely precipitated due to very low concentration of carbonate–bicarbonate species. Such water will not be harmful to the growth of plants if same is used for irrigation purpose.

Sodium hazard: sodium ion (Na⁺) has an important consideration regarding irrigation water. It has minor importance regarding drinking and industrial purposes. When presents as NaCl the sodium ion (Na⁺) having concentration more than 500 mg/l, makes the water unpalatable and causes appetite (Manivasakam 1996). Larson & King (1954) reported that high concentration of sodium also affect the permeability of soil. Contrary to this its limited concentration maintains its balance with other mineral nutrients for good development of plants. Values of Na⁺ ranged from 40 to 373 mg/l. This value plays a key role in various parameters like as SAR, Na% and RSC which are significant characteristics of irrigation water. High Na⁺ content leads to development of an alkaline soil or Na hazards known as SAR. It occurs such areas where high salinity is expected due to poor drainage network system and high accumulation of sodium salts in the soil solution (Silva 2004). There is a significant relationship between SAR values of irrigation water and the extent of sodium adsorbed by the soils. If water used for irrigation is high in sodium and low in calcium, the cation exchange complex may
become saturated with sodium. This can destroy the soil structure due to dispersion of clay particles (Chopra & Kanwar 1999). Water with SAR values 0–10, 10–18, 18–26 and above 26 meq/l supposed to be excellent, good, poor and very poor quality, respectively. The value of SAR in the study area was calculated in the range of 1.80–1.81 meq/l indicating all samples of the dug well water were in excellent quality for irrigation purpose. The sodium percentage (Na%) is an important factor for irrigation water which is a ratio of extent of sodium ion and all other possible cations. When its value in water exceeds 60% then water will be unsuitable for irrigation purpose. Soil permeability of agriculture is also affected by high sodium ratio (Manivasakam 1996). The Na% in the all samples of study area was calculated in the range of 111–186% showing water of all dug wells was not fit for irrigation purpose.

Values of K⁺ ranged from 40 to 212 mg/l which was extremely higher than its prescribed limit, 12.0 mg/l. Very high value of K⁺ may be due to diffuse pollution from agricultural fields having use of potassic fertilizers in excess.

Chloride is an inorganic anion and also a main parameter for irrigation water. It adversely affects into the crop production when its concentration is more than >10 epm or 354.5 mg/l (Pokale et al. 2010). Extent of chloride in the study area was found in the range of 25–103 mg/l which was within permissible limit.

Sulfate mostly occurs in water as magnesium sulfate. Extents of sulfate were observed in the range of 48–60 mg/l. The value of sulfate of all water samples were found within prescribed limit, 200 mg/l by WHO and desirable for irrigation water. In irrigation water a classification was classified as categorized on the basis of sulfate value. If the sulfate is below 10, 10–20 and above 20 meq/l, then the water will be of excellent, good and poor quality respectively (Ayer & Branson 1975). The values of sulfate in all dug well water samples were indicated their quality in excellent and good states for irrigation purpose.

Irrigation water classification based on various models: sometimes various models, i.e. Wilcox Diagram, U.S. Salinity diagrams, Doneen criterion, etc. are applied in order to classify the irrigation water quality of various ground water, i.e. dug wells under different soil conditions (Garg 1982; Sutharsiny et al. 2012). Under present study Wilcox Diagram was plotted in order to know or classify the water quality for irrigation purpose. This diagram is platted between EC or TDS and sodium percent. It is obvious from Wilcox diagram (Figure 1) that all dug water samples fall under good to permissible class water quality result in all dug well water was suitable for irrigation based on EC and Na%.

U.S. Salinity diagram was constructed by U.S. Salinity Staff, 1954 used in order to classify ground-water sample for irrigation purpose. U.S. Salinity diagram is plotted between EC and SAR. The lines of its diagram represent to vertical columns and horizontal rows. Vertical column was depicted S1, S2, S3, etc. classes representing increasing exchangeable sodium. Whereas horizontal row was depicted by C1, C2, C3, etc. classes representing increasing salinity. It is clear from figure of its diagram (Figure 2) that all dug well water samples fall under C3S1 category indicating high salinity and low alkalinity hazard. Based on above results of classification, these dug wells may be permitted to use their water for irrigation purpose.

Doneen, 1962 developed a model based on salinity, permeability and toxicity. This diagram was improvement of the US salinity diagram. In this modal, potential salinity (PS) and PI are used for measurement of salinity and soil permeability.

PS: high solubility salts such as chlorides of calcium, magnesium and sodium, sulfates of magnesium and sodium and bicarbonate of sodium leads to increase risk of salinity as these salts accumulate on the soil. Whereas low solubility salts such as carbonates and bicarbonates of calcium and magnesium, calcium sulfate, etc. precipitate in soil as soil solution. These salts do not play much role in salinization of the soil. Potential soil salinity is defined by the concentration of chloride ion and half concentration of sulfate ion (Garg 1982). Donnen 1962 classified irrigation water for slow deep
percolation or restricted leaching and sensitive crops soil area based on PS having three PS zones viz. excellent to good, good to injurious and injurious to unsatisfactory. Irrigation water with value of PS less than 3 epm, between 3 and 5 epm and higher than 5 epm will be categorized as excellent to good, good to injurious and injurious to unsatisfactory class of potential saline respectively. Results showed in Table 2 that all dug water samples based on PS were found in good to injurious class.
PI- Permeability of soil is influenced by the sodium content of the irrigation water. PI is calculated by TDS which consider those ions (cations and anions) as those ions influence this index. PI shows to low, medium and high classes of peramebly soils. These classes are applied depending upon nature of soil (Garg 1982). Since Soil textures of its village are sandy loam indicating the highly permeable soils. Thus high permeability class is employed for calculation of its index. Figure 3 indicated that all water samples of high permeability class fall class-1 quality of water.

CONCLUSION

Findings of the study indicated that all the selected wells have mostly medium to high salinity, under limit of SAR, medium Na%, medium Mg hazards, under limit of RSC and low chloride quantity. The irrigation water quality also showed based on some models that as per salinity diagram, all dug well water samples fall under C3S1 category indicating high salinity and low alkalinity hazard. Based on above results of classification, these dug wells may be permitted to use their water for irrigation purpose. Moreover, as per Wilcox diagram, all dug water samples fall under good to permissible class water quality result in all dug well water was suitable for irrigation based on EC and Na%. As per results of PS, all dug water samples were found in good to injurious class. Based on high permeability class, all water samples fall first class quality of water. Thus, it can be concluded that water quality of all dug wells of the study area (Rajaula ward of Chitrakoot town) may give better result if its conventional treatment is done prior to use for irrigation purpose.

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