Physico-chemical status of groundwater near Varuna river in Varanasi city, India

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ABSTRACT

The Varuna is a minor tributary of the Ganges and extended between 25°27’ N to 82°18’E and 25°45’ N to 82°3’ E flows east to southeast from some of 100 km from Phulpur tehsil of Allahabad and joins the Ganges at 25°19’ N 83°2’ E and 25° 32’ N 83° 44’ E just downstream of Varanasi. The lower Varuna river basin in Varanasi district situated in the central Ganga plain is a highly productive agricultural area and also one of the fast growing urban areas in India. The agricultural and urbanization activities have a lot of impact on the ground water quality of the study area. The study area is underlain by Quaternary alluvial sediments consisting of clay, silt, sand and gravel of various grades. The hydrogeochemical study was undertaken by randomly collecting 12 groundwater samples from dug wells and bore wells covering the entire area in order to understand the sources of dissolve ions and to assess the chemical quality of the promoting agricultural production and standard of human health. It is found that over exploitation of groundwater has detrimentally affected groundwater in terms of quality and quantity. Most groundwater samples are suitable for irrigation except one sample (sample no. 12). Although the general quality of groundwater of the lower Varuna river basin is suitable for irrigation purpose, forty one percent of the samples are found having nitrate content more than permissible limit (>45mg/L) which is not good for human consumption. Application of N-fertilizers on agricultural land as crop nutrients along the Varuna river course is responsible for nitrate pollution in the groundwater due to leaching applied irrigation water. The other potential source of high nitrate concentration in extreme northern, southern and southwestern parts of study area are poor sewerage and drainage facilities, leakage of human excreta from very old septic tanks, and sanitary landfills.

Keywords: Groundwater quality, nitrate pollution, irrigation water, sodium content.

1. Introduction

Water is the principal need of life on earth and is an essential component for all forms of lives, from microorganism to man. The unplanned urbanization and industrialization (Singh et. al, 2002) has resulted in over use of environment (Petak, 1980) in particular of water resource. A kind of crises situation has made getting clean water a serious problem. It is a known fact that when pure water is polluted its normal functioning and properties are affected. Water quality plays an important role in promoting agricultural production and standard of human health. Innumerable large towns and many new megacities in India derive a major component of their domestic, irrigation and industrial water supply from large number of private bore wells.
The water quality may yield information about the environments through which the water has circulated. Each groundwater system in the area has a unique chemistry, acquired as a result of chemical alteration of meteoric water recharging the system (Back, 1966; Drever, 1982). The chemical alteration of the rain water depends on several factors such as soil water interaction, dissolution of mineral species and anthropogenic activities (Future, 1998; Subha Rao, 2001; Umar and Ahmed, 2007). Knowledge on hydrochemistry is important to assess the quality of ground water for understanding its suitability for domestic, irrigation and industrial needs. Various researchers carried out the hydrochemical characteristics of groundwater in different basin as well in urban areas (Rao et al 2006; Subbramanan et al 2005; Umar et al 2006; Pandian and Sankar, 2007; Raju, 2007). Higher level of nitrate and other chemical pollution in the groundwaters and surface water in Varanasi and found nitrate concentration ranging from 66-199 mg / L (Bilas, 1980; Pandey, 1993; Sinha, 2003). High bacterial population and BOD values of the Ganga River may be attributed to discharge of untreated waste water and industrial effluent in the River Varuna at Varanasi (Singh and Singh, 1995).

In order to understand the groundwater quality of the lower Varuna River basin, 12 groundwater samples have been collected and analyzed for different chemical parameters. The study area forms a part of central Ganga alluvial plain. The land surface, in general, has a blanket of clay followed in depth by sands of various grades and clays at times admixed with kankar sands. Medium of the fine grained sands constitute the potential aquifers.

2. Study area

The study area lies between the latitudes 25°21'46.89” N to 25°21’44.88” N and 82°55’22.708” E to 82°58’28.33” E longitude. The total study area of lower Varuna basin is around 23.05 sq. km (Figure 1). The river Varuna is the tributary of the River Ganga and flows from west to east before finally join the Ganga at the Mohan Sarai. The study area enjoys tropical climate with mild winter and long summer days. The temperature of the area varies from 5°C to 46.5°C (17 may 2012). The area receives rainfall from the southeast monsoon lasting from June to September with a mean annual rain fall 102 cm. Based on major ion chemistry of 12 groundwater samples from dug wells and few from handpumps near Varuna river in Varanasi city of Uttar Pradesh, India, an attempt has been made to understand the spatial distribution of hydrogeochemical constituents and also interprets chemical variation in ground water under various natural and anthropogenic influences.

3. Methodology

A total of 12 ground water samples from dug wells and handpumps of the study area were collected in the month of February to March 2013 and analyzed to understand the chemical variation of the groundwater. For collecting the samples, pre-cleaned polyethylene containers of one liter capacity were used. Sampling locations are shown in figure 2. The physico-chemical characteristics of ground water samples were determined using the standard analytical methods (APHA, 1995), and the results of major are given in table 1. The pH and electrical conductivity were measured with portable benchtop ions meter (Multi-parameter portable ion meter, 2 to 5 points push-button calibration mV and Relative mV measurement mode).

Sodium and potassium were estimated by flame photometer. Total hardness and calcium were estimated by EDTA titrimetric method and magnesium estimated by the difference of the hardness and calcium. Total alkalinity, bicarbonate, carbonate and chloride were
estimated by titrimetric method (Titrimetric analysis consists in determining the number of moles of reagent i.e. titrant required to react quantitatively with the substance being determined).

The sulphate estimations were done by the gravimetric method. The nitrate was analyzed by UV- spectrophotometer. Total dissolve solids were estimated using calculation method. The accuracy of the chemical analysis was verified by calculating ion balance errors were generally around 8%.

Figure 1: Study Area as Viewed on IKONOS Satellite Data

Figure 2: Location of Sample Villages near Varuna River, Varanasi City
Understanding the quality of groundwater is important because it is the main factor which decides its suitability for domestic and agricultural purposes.

The water used for drinking purposes should be free from color, turbidity and microorganisms (Karnath 1989), chemically the water should be soft with less dissolved solids and free from poisonous constituents. To ascertain the suitability of groundwater for drinking and public health purposes, hydrochemical parameters of the study area are compared (table 3) with the guidelines recommended by WHO, 1993 and ISI, 1991. The study shows that groundwater is partially suitable for drinking purposes and public health, because the NO$_3$ and TDS in the groundwaters are observed to exceed the recommended limits for drinking purposes. In table 3, one groundwater sample TDS exceeding the permissible limit set by WHO, where as in the case of nitrate ion, five sample are exceeding both WHO and ISI standards.

The pH value of groundwater ranges from 7.97-8.83 with an average of 8.4, which indicate that the groundwater is moderately alkaline in nature. TDS values range from 305-1279 mg/L with an average value, 549 mg/L (Table 2). Water can be classified (Davis and Dewiest, 1966) on the basis of TDS, up to 500 mg/L as desirable for drinking; 500 to 1000 mg/L as permissible for drinking; up to 3000 mg/L as unfit for drinking and irrigation. Based on TDS classification out of 12 groundwater samples, 6 water sample are within desirable limit and 5 water sample are within permissible level in the absence of alternate source and 1 for agricultural purposes.

Among the cationic (Ca, Mg, Na and K) sodium is dominated ion (26.2-80.4 mg/L) followed by magnesium (23.8-78.3 mg/L), calcium (29-78 mg/L) and potassium (2.5-5.7 mg/L), among the anionic (HCO$_3^-$, SO$_4^{2-}$, Cl$^-$, NO$_3^-$ and F$^-$) concentration bicarbonate is the

### Table 1: Physico-Chemical analysis of ground water samples

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Location</th>
<th>pH</th>
<th>EC (µS/cm)</th>
<th>TDS (mg/L)</th>
<th>Ca$^{2+}$ (mg/L)</th>
<th>Mg$^{2+}$ (mg/L)</th>
<th>Na$^+$ (mg/L)</th>
<th>K$^+$ (mg/L)</th>
<th>HCO$_3^-$ (mg/L)</th>
<th>SO$_4^{2-}$ (mg/L)</th>
<th>NO$_3^-$ (mg/L)</th>
<th>Cl$^-$ (mg/L)</th>
<th>F$^-$ (mg/L)</th>
<th>%Na (epm)</th>
<th>Pf (epm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Passour</td>
<td>8.74</td>
<td>1044</td>
<td>464</td>
<td>76</td>
<td>29.9</td>
<td>46.5</td>
<td>4.8</td>
<td>316</td>
<td>30</td>
<td>27.8</td>
<td>145</td>
<td>145</td>
<td>0.80</td>
<td>32.63</td>
</tr>
<tr>
<td>2</td>
<td>Dimдавpur</td>
<td>8.53</td>
<td>1029</td>
<td>694</td>
<td>67</td>
<td>30.6</td>
<td>31.1</td>
<td>3.4</td>
<td>375</td>
<td>40</td>
<td>23.5</td>
<td>12</td>
<td>12</td>
<td>0.57</td>
<td>19.08</td>
</tr>
<tr>
<td>3</td>
<td>Bhavannaigur</td>
<td>8.4</td>
<td>953</td>
<td>364</td>
<td>78</td>
<td>25.7</td>
<td>90.4</td>
<td>2.8</td>
<td>420</td>
<td>50</td>
<td>20</td>
<td>47</td>
<td>47</td>
<td>0.09</td>
<td>44.51</td>
</tr>
<tr>
<td>4</td>
<td>Chithanayanagar</td>
<td>8.71</td>
<td>1079</td>
<td>548</td>
<td>58</td>
<td>49.4</td>
<td>49.5</td>
<td>4</td>
<td>255</td>
<td>36</td>
<td>57.2</td>
<td>29</td>
<td>29</td>
<td>0.61</td>
<td>34.09</td>
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<tr>
<td>5</td>
<td>Sarhain</td>
<td>8.67</td>
<td>923</td>
<td>655</td>
<td>55</td>
<td>69</td>
<td>30.8</td>
<td>2.6</td>
<td>295</td>
<td>42</td>
<td>46.2</td>
<td>71</td>
<td>71</td>
<td>0.71</td>
<td>21.21</td>
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<tr>
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<td>Kuran</td>
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<td>544</td>
<td>53</td>
<td>65</td>
<td>40</td>
<td>3</td>
<td>332</td>
<td>40</td>
<td>55.1</td>
<td>109</td>
<td>109</td>
<td>0.34</td>
<td>26.70</td>
</tr>
<tr>
<td>7</td>
<td>Chamaw</td>
<td>8.7</td>
<td>1059</td>
<td>369</td>
<td>50</td>
<td>73</td>
<td>63</td>
<td>3.1</td>
<td>316</td>
<td>56</td>
<td>20</td>
<td>13</td>
<td>13</td>
<td>0.77</td>
<td>43.54</td>
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<tr>
<td>8</td>
<td>Tama</td>
<td>8.14</td>
<td>1074</td>
<td>305</td>
<td>29</td>
<td>35.7</td>
<td>26.2</td>
<td>3.9</td>
<td>170</td>
<td>5</td>
<td>75.8</td>
<td>41</td>
<td>41</td>
<td>0.54</td>
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<tr>
<td>9</td>
<td>Kottaw</td>
<td>7.97</td>
<td>1059</td>
<td>493</td>
<td>69</td>
<td>26.1</td>
<td>70.3</td>
<td>3.5</td>
<td>305</td>
<td>10</td>
<td>67.1</td>
<td>51</td>
<td>51</td>
<td>0.46</td>
<td>43.69</td>
</tr>
<tr>
<td>10</td>
<td>Tadhya</td>
<td>8.25</td>
<td>1044</td>
<td>303</td>
<td>65</td>
<td>23.8</td>
<td>77.6</td>
<td>5.7</td>
<td>412</td>
<td>20</td>
<td>9.6</td>
<td>19</td>
<td>19</td>
<td>0.37</td>
<td>48.40</td>
</tr>
<tr>
<td>11</td>
<td>Chittoumi</td>
<td>8.83</td>
<td>1059</td>
<td>369</td>
<td>35</td>
<td>78.3</td>
<td>39.6</td>
<td>2.5</td>
<td>173</td>
<td>45</td>
<td>11</td>
<td>35</td>
<td>35</td>
<td>1.34</td>
<td>24.09</td>
</tr>
<tr>
<td>12</td>
<td>Karout</td>
<td>8.3</td>
<td>1225</td>
<td>1279</td>
<td>47</td>
<td>67</td>
<td>40</td>
<td>4.3</td>
<td>412</td>
<td>37</td>
<td>20.4</td>
<td>97</td>
<td>97</td>
<td>0.26</td>
<td>27.98</td>
</tr>
</tbody>
</table>

(*epm- Equivalent per million)
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The dominant ion (170-430 mg/L), followed by chloride (12-145 mg/L), nitrate (9.6-75.8 mg/L), sulphate (5-56 mg/L) and fluoride (0.26-1.34 mg/L).

Table 2: Range of chemical parameter in groundwater in a part of lower Varuna river catchment area

<table>
<thead>
<tr>
<th>Chemical parameters</th>
<th>Concentration</th>
<th>Sample number exceeding permissible limit of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>Calcium (mg/L)</td>
<td>29</td>
<td>78</td>
</tr>
<tr>
<td>Magnesium (mg/L)</td>
<td>23.8</td>
<td>78.3</td>
</tr>
<tr>
<td>Sodium (mg/L)</td>
<td>26.2</td>
<td>80.4</td>
</tr>
<tr>
<td>Potassium (mg/L)</td>
<td>2.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Bicarbonate (mg/L)</td>
<td>170</td>
<td>430</td>
</tr>
<tr>
<td>Sulphate (mg/L)</td>
<td>5</td>
<td>56</td>
</tr>
<tr>
<td>Chloride (mg/L)</td>
<td>12</td>
<td>145</td>
</tr>
<tr>
<td>Nitrate (mg/L)</td>
<td>9.6</td>
<td>75.8</td>
</tr>
<tr>
<td>Fluoride (mg/L)</td>
<td>0.26</td>
<td>1.34</td>
</tr>
<tr>
<td>Total dissolve solids (mg/L)</td>
<td>305</td>
<td>1279</td>
</tr>
<tr>
<td>Electrical conductivity (µS/cm at 25°C)</td>
<td>923</td>
<td>1225</td>
</tr>
<tr>
<td>Percent Sodium</td>
<td>19.08</td>
<td>48.40</td>
</tr>
<tr>
<td>Permeability index</td>
<td>30.94</td>
<td>58.82</td>
</tr>
</tbody>
</table>

Assessment of the suitability of groundwater for irrigation purpose requires consideration of the total dissolve solids. The concentration of the certain constituents and substances that may be toxic to the plants.

The EC and Na concentration are important in classifying irrigation water. The EC values ranges from 923 to 1225 µS/cm with an average of 1047. A high salt content (high EC) in irrigation water leads to formation of saline soil. This affects the salt intake capacity of the plants through their roots. On the basis of EC rules, Richards (1994) all water samples falling in medium salinity hazard can be used, if a moderate amount of leaching occurs. High salinity water can’t be used on soil with restricted drainage. Excess salinity reduces the osmotic activity of plants and thus interferes with absorption of water and nutrient from soil (Sales et.al. 1999).

\[
\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-})}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+)} \times 100 \quad (\text{all values in epm})
\]

The PI values of groundwater samples ranges from 30.94 to 58.82 with an average of 44.88 (Table 2). On the basis of Dodeen’s chart most of most of the water samples in the study are suitable for irrigation purposes.

Sodium concentration is important in classifying irrigation water because it reacts with soil to reduce its permeability. Sodium combining with carbonate can lead to formation of alkaline
soils, while sodium combining with chloride from saline soils. Both these soils don’t for the growth of plants.

Sodium percent represent in term of percent sodium. The observed values of percent sodium range 19.08 to 48.40 with an average of 26.5 (Table 2). The percent sodium is obtained by the below equation:

$$\text{Percent Sodium} = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

(all values in epm)

High concentrations of Na have ion exchange capacity; reduce soil permeability and finally results in soil with poor internal drainage (Collins and Jenkins, 1996; Saleh et.al. 1999).

The groundwater resources contaminated with high level of nitrate (>45mg/L) are an environmental hazard. Nitrogenous materials are rare in geological record; therefore, occurrence of nitrate in groundwater is an anthropogenic pollutant contributed by nitrogenous fertilizers, industrial effluents, human and industrial waste through bio-chemical activity of nitrifying bacteria, such as nitrosomonas and nitrobactor. Studies during last few years have indicated that the nitrate concentration in some aquifers in urban areas or similar or even higher than those in their surrounding areas. (Lerner et.al.1999; Wakida and Lerner, 2005). The high concentration of nitrate pollution in the study area reveals that due to following reaction.

Nitrosomonas

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{energy} \quad \text{(1)}$$

Nitrobactor

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{energy} \quad \text{(2)}$$

The organic nitrogen converted into nitrate during the percolation of domestic sewage water, directly from the open drainage and or stagnant water pools.

**Scientific sugression based on the data**

The groundwater in the study area is moderately alkaline in nature. Based on TDS, about fifty percent and forty one percent of the groundwater sample are respectively within desirable limit and permissible limits of drinking water in the absence of alternate source and about nine percent sample are unfit for drinking purpose but all samples are useful for irrigation purpose. The most conspicuous change in chemistry of groundwater is relative enrichment of drinking water beyond permissible limits (>45mg/L) of drinking water standards. The comparison of major ion data with the WHO and ISI standard indicate that about 41 percent sample exceed the nitrate content which need treatment before human consumption. The relatively higher concentration of nitrate in residential areas, other than agriculture activity, is due to improper sanitary conditions, lechates from animal wastes, sewage and solid waste dump. There is no full proof sewer system overflowing of domestic sewage channels on the surface and indiscriminate disposal of solid wastes are common sense in Varanasi city, which cause the nitrate pollution in study area. Reverse osmosis, ion exchange and distillation are some of the useful methods of nitrate removal for safe drinking water.
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