Hydrochemical characterization and quality assessment of Groundwater in Tirupur Taluk, Tamil Nadu, India: Emphasis on irrigation utility

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Abstract

Tirupur Taluk is of particular importance in view of groundwater quality due to effluents from knitting industries, agricultural, sewage and urban runoff, altering the chemistry of groundwater. An investigation was carried out by collecting a total of 90 groundwater samples for two seasons namely Pre Monsoon (PRM) and Post Monsoon (POM) to decipher hydrogeochemistry and groundwater quality for determining its suitability for agricultural purposes. The water is neutral to alkaline in nature with pH ranging from 7.0 to 8.6. Higher electrical conductivity (EC) was noted along NE and central downstream parts of the study area. Higher NO3 was noted during (POM) due to the action of leaching and anthropogenic process. The Piper plot reveals Na–Cl, Na–HCO3, Ca–Cl, mixed Ca–HCO3 and Na–SO4 types of hydrochemical facies. Higher total hardness in the groundwater is due to the effect of dyeing and bleaching industries. Residual Sodium Carbonate (RSC) indicates 31% of samples unsuitable for irrigation purposes. Higher sodium percentage (Na%) during PRM indicates ion exchange and weathering reactions. Higher Sodium Adsorption Ratio (SAR) was noted during POM due to the effect of leaching and dissolution. The USSSL plot and Permeability Index (PI) indicates samples good to unfit for irrigation purposes. In general, groundwater in the study area is influenced by both natural and anthropogenic activities.

Keywords: Groundwater, hydrogeochemistry, spatial distribution, residual sodium carbonate, irrigation.

Introduction

Groundwater depending on its usage and consumption can be either renewable or non-renewable resource. It is estimated that approximately one third of the world’s population use groundwater for drinking purposes. Water shortages have become an increasingly serious problem in India, especially in the arid and semi-arid regions of the country due to vagaries of monsoon and scarcity of surface water. In India, groundwater constitutes about 53% of the total irrigation potential and about 50% of the total irrigated area is dependent on groundwater irrigation (Central Water Commission, 2006). Among the various reasons, the most important are non-availability of potable surface water and a general belief that groundwater is purer and safer than surface water due to the protective qualities of the soil cover. The quality of groundwater is the resultant of all the processes and reaction that act on the water from the moment it condenses in the atmosphere to the time it is discharged by a well. Therefore, determination of groundwater quality is important to observe the suitability of water for a particular use. The problems of ground water quality are more acute in areas that are densely populated and thickly industrialized and have shallow groundwater tube wells. In developing world, 80% of diseases are directly related to poor drinking water and unsanitary conditions (UNESCO, 2007). Geochemical studies of groundwater provide a better understanding of possible changes in quality as development progress. Suitability of groundwater for domestic and irrigation purposes is determined by its groundwater geochemistry. Sixty percent of irrigated food production is from groundwater wells (Shah et al., 2000; Nisi et al., 2008). All these lead to the over exploitation of this precious natural resource in several parts of the country resulting in declining groundwater level. Groundwater quality data gives important clues to the geologic history of rocks and indications of groundwater recharge, movement and storage (Walton 1970). Groundwater quality depends on number of factors, such as general geology, degree of chemical weathering of prevailing lithology, quality of recharge water and inputs from sources other than water-rock interaction (Domenico, 1972; Schuh et al., 1997; Freeze and Cherry, 1979; Hussein, 2004). Demarcation of groundwater zones on the basis of quality was attempted by Subba Rao et al. (2002) in Guntur of AP, India. Lithological influence and dominance of anthropogenic factors on groundwater chemistry in Salem district, TN, India was attempted by Srinivasamoorthy et al. (2009). Identification of geochemical facies and demarcation of locations unfit for human consumption was attempted by Mohan et al. (2000) in UP state of India. Nitrate contamination is strongly related to land use pattern has been attempted by Rajmohan et al. (2007). Similar studies in different parts of the globe have also been attempted by Stites and Kraft (2001), Ahmed et al. (2002) and Bathrellos et al. (2008).
A detailed geochemical study was attempted in Tirupur taluk of Tirupur District, TN, India to identify groundwater contamination processes. Groundwater quality depletion by industrial and anthropogenic activities, such as urbanization and agricultural activities is a major problem in Tirupur Taluk. Usage of toxic chemicals for dyeing and processing of fabrics, is one of the major threats to groundwater environment which has also increased the water demand in the proposed study area. It is also a hard rock terrain generally precarious to get their supply during monsoon seasons, during non-monsoonal seasons people depend on groundwater resources for their domestic, agricultural, and industrial activities. About 70% of the study area is dominated by industrial and human activities and the rest by agricultural activities. The groundwater level is also noted to fall based upon the long term trend analysis (CGWB, 2008). Hence, for the prevention and protection of water resources, proper planning and adoption of proper management strategies has to be adopted. In this context, an attempt has been made in the proposed study area to decipher the major sources altering the groundwater quality along with its suitability for agricultural purposes is aimed.

Materials and methods

Study area: The study area lies latitudes 10°58′N to 11°15′N and longitudes 77°15′E to 77°33′E (Fig. 1). It falls in Survey of India map 58 E/7, 8 and 58 F5 located at Tirupur District, TN, India. The geographical extent of the study is 629 km². Temperatures vary between 35°C to 18°C. The area receives scanty rains due to its location in leeward side of the Western Ghats. The average rainfall of Tirupur is 640 mm. The major structures identified areas are plateaus, structural, denudational and residual hills. The topography is undulating, with a gentle slope towards east to west with heights ranging 320 m above mean sea level (MSL). It is one of the oldest textile processing centers of South India to identify groundwater contamination processes. Groundwater quality depletion by industrial and anthropogenic activities, such as urbanization and agricultural activities is a major problem in Tirupur Taluk. Usage of toxic chemicals for dyeing and processing of fabrics, is one of the major threats to groundwater environment which has also increased the water demand in the proposed study area. It is also a hard rock terrain generally precarious to get their supply during monsoon seasons, during non-monsoonal seasons people depend on groundwater resources for their domestic, agricultural, and industrial activities. About 70% of the study area is dominated by industrial and human activities and the rest by agricultural activities. The groundwater level is also noted to fall based upon the long term trend analysis (CGWB, 2008). Hence, for the prevention and protection of water resources, proper planning and adoption of proper management strategies has to be adopted. In this context, an attempt has been made in the proposed study area to decipher the major sources altering the groundwater quality along with its suitability for agricultural purposes is aimed.

Groundwater quality: To assess the groundwater quality, a total of 90 groundwater samples were collected (45 per season) during PRM and POM seasons. The samples were collected from bore wells and analyzed for parameters using standard procedures (APHA, 1995). The groundwater locations were selected to cover the entire area with due attention in areas expected for contamination. The results were correlated with drinking water quality standards (WHO, 2008).

Laboratory measurements and data treatment: Groundwater samples were analyzed for Calcium (Ca), magnesium (Mg) by titration with standard EDTA, Chloride (Cl) by standard AgNO₃ titration, bicarbonate (HCO₃⁻) by titration with HCl, sodium (Na) and potassium (K) by flame photometry. EC, pH and TDS were measured in situ using multiprobe. Sulphate (SO₄²⁻), phosphate (PO₄³⁻) and silicate (H₂SiO₄⁻) were determined by spectrophotometer CL 22D. Nitrate (NO₃⁻), bromide (Br) and fluoride (F) by Consort electrochemical analyzer model C933. The analytical precision for ions was determined by using ionic balance (100 x (cations–anions)/(cations+anions) which is generally within ±5% (Srinivasamoorthy et al., 2010). The parameters such as SAR, %Na, RSC, PI, Kelly’s index (KI) were used to evaluate the suitability of water for agricultural purposes. Further the results of the analyses were interpreted using plots like US Salinity Laboratory (USSL) and Doneen.

Results and discussion

The physicochemical compositions of the groundwater samples are statistically analyzed and the results are represented in Table 1. The cations (TZ+) and anions (TZ–) accounts 94%, 98% and 96% and 97% during PRM and POM seasons respectively. The order of abundance of chemical ions are Na > Mg > Ca > K = Cl > HCO₃⁻ > SO₄²⁻ and Na > K > Mg > Ca = Cl > HCO₃⁻ > SO₄²⁻ during the both seasons. The pH ranges from 7.2 to 8.6 and 7.0 to 8.1 with an average of 8.2 and 7.77 during PRM and POM indicating the alkaline nature of groundwater. During POM, Na is found to be higher (782 mg/L) indicating sources from weathering of feldspar (plagioclase) and over exploitation of groundwater (Hem, 1991). Potassium is higher during PRM (336 mg/L) due to weathering of K feldspars and clay minerals from aquifers (Lakshmanan et al., 2003).
During PRM, Mg is higher (208 mg/L), indicating sources from dissolution of magnesium calcite, gypsum and/or dolomite from source rock (Garrels, 1967). During POM, bicarbonate is higher (689 mg/L) due to action of CO₂ chemically reacting upon the minerals present in soil and granitic rocks (Tyagi et al., 2009). Chloride is higher during POM (1631 mg/L) due to industrial, domestic wastages and/or leaching from upper soil layers in dry climates (Srinivasamoorthy et al., 2010). Higher SO₄ during PRM season (672 mg/L) may be due to action of sulphur gases from industries entering groundwater (Saxena, 2004). Higher Fluoride during POM (2.34 mg/L) may be due to leaching from fluoride rich source rocks (Srinivasamoorthy et al., 2011) due to semi-arid climate and long residence time of groundwater. Higher NO₃ is noted during POM (98 mg/L) due to plant nutrient leaching and application of nitrate fertilizers (Madson and Brunett, 1984). The hydrochemical evolution of groundwater is determined by plotting the cations and anions in Piper trilinear diagram (Piper, 1994). This diagram reveals similarities and differences among water samples (Todd, 1980).

The data points are pointed in two triangles and projected on to the diamond grid (Fig. 2). During PRM and POM majority of the groundwater samples irrespective of seasons fall in mixed Na–Cl and Na–HCO₃ type with minor representations from mixed Ca–Cl– mixed Ca–HCO₃ and NaSO₄ types. A change in the facies is noted during POM as: Ca–Mg–HCO₃, Ca–Mg–SO₄, Na–HCO₃– and Na–Cl. From the plot it is inferred that increase of alkaline and alkaline earth is noted during both the seasons. Weak acid (HCO₃) exceeds strong acid (Cl and SO₄) in both the seasons. In general, calcite dissolution and reverse ion exchange process controls the water chemistry in the study area.

Spatial representation: The simple way of representing groundwater quality is by contouring. Hence, an attempt has been made to infer spatial variations of crucial ions determining the quality of groundwater. EC is the most important parameter to demarcate salinity hazard and suitability of water for irrigation purpose. The EC varies from 420 to 3970 μS/cm and 230 to 6060 μS/cm during PRM and POM, respectively. Higher was noted during POM than PRE. The classification of groundwater on the basis of irrigation quality (WHO, 2008) shows that 58% of PRM and (47%) of POM samples falls within the permissible limits.

Table 1. Statistics of ground water chemistry in both seasons.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Pre Monsoon (PRM)</th>
<th>Post Monsoon (POM)</th>
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<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
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<tr>
<td>Ca</td>
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<tr>
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<tr>
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<tr>
<td>TH</td>
<td>70</td>
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</tr>
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SD: Standard deviation (all values in mg/L except pH and EC in μS/cm).

Fig. 2. Piper Trilinear diagram for PRM and POM seasons.

Piper Trilinear diagram for PRM and POM seasons.
The spatial plot for the study area (Fig. 3a, b) demarcates very high (>6,000 μs/cm) to higher EC (1,500 to 4000 μs/cm) prominent along upstream, central and downstream directions of the study area indicating the dominance of industrial, domestic and agricultural activities along upstream and downstream direction.

**Sodium:** Sodium, unlike calcium, magnesium and silica, is not found as an essential constituent of many of the common rock-forming minerals. Sodium toxicity is recorded as a result of high sodium in water as Na% and SAR ratios. Typical toxicity symptoms to plants and trees are leaf burn and dead tissue along the outside edges of leaves (Srinivasamoorthy et al., 2011a). The maximum permissible limit of Na is 200 mg/L. The Na ranges between 37 to 529 mg/L and 7 to 782 mg/L during both the seasons. Water samples representing 36% and 40% above the prescribed limit. The spatial map demarcates eastern, central and down streams parts of the study as exceeding the permissible limit (Fig. 4a, b). The source of Na into the groundwater is due to the weathering of feldspar and due to over exploitation of groundwater (Hem, 1991).

**Chloride:** The sodalite and apatite are the common minerals identified in igneous/metamorphic rocks containing chloride as an essential constituent. Chloride is not adsorbed by soils, moves with the soil-water and adsorbed by crops in stem and leaves and develops leaf burn and tissue drying if intake beyond crop tolerance (Ayers and Westcot, 1994). The permissible limit of Cl is 600 mg/L (WHO, 2008). Chloride ranges between 25 to 964 and 18 to 1631 mg/L with an average of 263 and 274.2 mg/L during both the seasons. Table 2 shows, 6.67% and 4.44% of the samples falls above the allowable limit with higher concentration noted during POM (1,631 mg/L) indicating leaching from upper soil layers, domestic wastages and industrial activities. The spatial distribution plot indicates higher Cl along NE, central and SE parts of the study area (Fig. 5a, b).

**Nitrates:** Nitrogen is an important plant nutrient stimulating crop growth. When applied in excess, affects the crop by over stimulation of growth, delayed maturity and poor quality of crop yield. Crops are relatively unaffected until nitrogen exceeds 45 mg/L (Vasanthavigar et al., 2009). Consumption of nitrogen above the permissible limit creates severe problem of blue baby disease/Methemoglobinemia in children and gastric carcinomas. Nitrates in water sample ranges from 2 to 103 mg/L and 1 to 98 mg/L with averages of 36.7 and 35.3 mg/L during PRM and POM seasons. Higher nitrates >45 mg/L are noted along the north, eastern and northeastern parts of the study area where agricultural practices are dominant (Fig. 6a, b).

**Magnesium ratio (MR):** Generally Ca and Mg maintain a state of equilibrium in most groundwater (Hem, 1991). During equilibrium, more Mg in groundwater will adversely affect the soil quality by decreasing crop yield (Kumar et al., 2007). MR is calculated using the formula:

\[
MR = \frac{\text{Mg}^{2+}) \times 100}{(\text{Ca}^{2+} + \text{Mg}^{2+})}
\]
The MR values ranges from 20.66 to 85.10 mg/L and 16.13 to 85 for PRM and POM season respectively. During PRM 57% of samples and 64% during POM falls above the permissible limit of 50 mg/L indicating the unfavorable effect on crop yield and increase in soil alkalinity. Those samples would adversely affect the crop yield by making it more alkaline.

Total hardness: Hard water is a measure of Ca and Mg in groundwater, expressed in equivalent of calcium carbonate. Water hardness increases the chance of heart diseases (WHO, 2008). Hardness of water (temporary and permanent) is due to the soap action in water by the precipitation of Ca and Mg salts. Temporary hardness is due to the presence of calcium carbonate and gets removed when boiling water. Permanent hardness is caused by the presence of Ca and Mg which gets removed by ion exchange processes. The total hardness in mg/L is determined by the following equation (Todd, 1980).

\[
\text{TH mg/L} = 2.497 \text{Ca}^{2+} + 4.115 \text{Mg}^{2+}
\]

Residual sodium carbonate: RSC is calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water used for agricultural activities (Srinivasamoorthy et al., 2011b) determined by the formula:

\[
\text{RSC} = (\text{HCO}_3^- + \text{CO}_3^{2-}) + (\text{Ca}^{2+} + \text{Mg}^{2+})
\]

Where, all ions are expressed in meq/L. RSC during both the seasons range between 0.22 to 14.48 meq/L and 25.58 to 6.41 meq/L with averages of 3.74 and 4.68. From the observed values, 31% of the samples during both the seasons are not suitable for irrigation; use of high RSC waters will affect the crop yield.

Sodium percentage: Sodium is an important ion used for irrigation classification of water due to its reaction with soil, reduces permeability. Sodium is usually expressed as %Na (Wilcox, 1955). The Na% is computed as:

\[
\text{Na}^+\% = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + k + \text{Na}^+}
\]

All the ions are expressed in meq/L (Table 2). It is observed that about 31% and 44% of the samples are suitable for irrigation during PRM and POM seasons. Higher Na% is observed during PRM, indicating the dominance of ion exchange and weathering from litho units of the study area.
Sodium adsorption ratio: Total salt concentration and probable sodium hazard of irrigation are the two major constituents for determining SAR. Salinity hazard is based on EC values. If water used for irrigation is high in Na and low in Ca, the ion-exchange complex may become saturated with Na, destroying the soil structure, due to clay dispersion which reduces plant growth (Todd, 1980). The SAR is computed, using the formula (Hem, 1991):

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\text{Ca}^{2+} - \text{Mg}^{2+}}}$$

Ions are expressed in meq/L. The SAR values ranges from 1.64 to 23.39 and 0.31 to 34.57 indicating 93% of the samples during PRM and POM are suitable for irrigation. SAR is higher during POM season, indicating water with high salinity and medium sodicity, cannot be used on fine-grained soils with restricted drainage (Srinivasamoorthy et al., 2012). This is due to restricted flow which results in the accumulation of salts in the root zones of crops restricting infiltration of water. Representations are also noted in C4S3 and C4S2 category indicating samples not suitable for irrigation purposes due to very high salinity and sodium hazards which affects the plant growth.

Permeability index: The permeability of soil is affected by long-term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil. Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on PI. It is calculated by using the formula; where all the ions are expressed in meq/L.

$$\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-}) \times 100}{\text{Ca}^{2+} - \text{Mg}^{2+} + \text{Na}^+}$$

Representations are also noted in C4S1 category indicating water suitable for plants having good salt tolerance but unsuitable for irrigation in soils with restricted drainage (Mohan et al., 2000). In both seasons 15% of the samples fall in C3S2 category, indicating water with high salinity and medium sodicity, cannot be used on fine-grained soils with restricted drainage (Srinivasamoorthy et al., 2012). This is due to restricted flow which results in the accumulation of salts in the root zones of crops restricting infiltration of water. Representations are also noted in C4S3 and C4S2 category indicating samples not suitable for irrigation purposes due to very high salinity and sodium hazards which affects the plant growth.
PI ranges between 31.03 to 96.34 meq/L and 40.34 to 102.29 meq/L during PRM and POM, respectively (Fig. 8a, b). As per PI values, the groundwater samples fall in class I and class II during both seasons indicate water is moderate to good for irrigation purposes (Arumugam and Elangovan, 2009).

**Kelly’s index:** For Kelly’s index, sodium is measured against calcium and magnesium to determine the suitability of irrigation water. When KI (>1) indicates higher sodium and vice versa (Kelly, 1940). KI is calculated by using the formula; where all the ions are expressed in meq/L.

\[ KI = \frac{Na^{2+}}{(Ca^{2+}+Mg^{2+})} \]

KI, varied between 0.36 to 14.08 and 0.26 to 7.12 during PRM and POM seasons. A total of 87% during PRM and 80% during POM fall in the unsuitable limit indicating higher percentage due to weathering and leaching of feldspars from the litho units of the study.

**Conclusion**
The groundwater quality in Tirupur Taluk has been evaluated for their chemical composition and suitability for domestic and agricultural uses. The piper plot indicates calcite dissolution and reverse ion exchange process control the water chemistry. Higher EC were observed in locations influenced by domestic, industrial and agricultural activities. Higher sodium observed during POM season indicating effective leaching from source rocks.

Higher Fluoride during PRM indicates leaching from fluoride rich source rocks. Higher NO₃ is observed during POM in areas with intensive irrigation practices. Higher Na% observed during PRM due to ion exchange and weathering processes. SAR is higher during POM s due to leaching and dissolution of salts. The PI values indicate groundwater samples with excess sodium. The overall hydrochemical study reveals 36% of the samples unsuitable for irrigation purposes.

**Acknowledgements**
The corresponding author is thankful to the Department of Earth Sciences, Annamalai University for providing the necessary analytical facilities.

**References**