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Evolution of groundwater chemistry in and around Vaniyambadi Industrial Area: Differentiating the natural and anthropogenic sources of contamination

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ABSTRACT

Groundwaters in the crystalline aquifers are the major source of drinking water in Vaniyambadi area of Vellore district. Geochemical methods in collaboration with statistical methods were applied in this industrial area to understand the natural and anthropogenic influences on groundwater quality. To accomplish this objective, groundwater samples were collected and analyzed for physico-chemical parameters and the results showed a dominance in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ for anions and cations, respectively. In contrast to this anion dominance were changed to $Cl^- > HCO_3^- > SO_4^{2-} > NO_3^-$ in samples collected near the tannery industries. Groundwater quality evaluation using TDS and TH suggested that 57% of the total samples are hard-brackish type, indicating its unsuitability for drinking purpose. Generally the water type is Na^+—Cl^- to Ca^{2+}—Mg^{2+}—HCO_3^- type with an intermediate Ca^{2+}—Mg^{2+}—Cl^-, suggesting the mixing of fresh groundwater with tannery effluent and cation exchange. Factor analysis and bivariate plots of major ions suggests that both natural and anthropogenic inputs are equally influencing the groundwater quality. Further investigations proved that silicate weathering is the dominant geogenic source of groundwater solute content, whereas tannery effluent is the anthropogenic source. Saline water mixing index (SWMI) and Cl^- vs NO_3^- bivariate plot were employed to differentiate the tannery contamination from the other anthropogenic inputs such as agricultural fertilizers, municipal sewages, etc. This analysis shows that samples 2, 4, 8 and 9 (located within the tannery cluster) have a SWMI value greater than 1, representing the groundwater–tannery effluent mixing. This study infers that groundwater in the Vaniyambadi area is under serious threat from both natural and anthropogenic contamination. However, the controlling discharge of untreated tannery effluents must be regulated to reduce the further deterioration of this vital resource in this part of the country.

1. Introduction

Groundwater chemistry in the semi-arid region is controlled by number factors including geology, local hydrology–hydrogeology, rock–water interactions, evaporation, mineral dissolution and deposition, rainfall and to a larger extends anthropogenic activities. Groundwater caters majority of the population in the semi-arid regions, in the past few decades due to the increased pollution load and/or unavailability of adequate surface water resources. The cost of pumping, the major constraints of groundwater development may be negligible when comparing contamination chances and subsequent treatment requirement for surface water. The other major advantage is the availability of groundwater within the premises of common man. However, in certain industrial zones groundwater is equally or more prone to contamination as surface water.

Vaniyambadi is a hydrogeologically complex area, with numerous sources for the contamination of groundwater from the geogenic sources i.e., rock–water interaction, evaporation etc. As an add-on these area has several small scale leather industries which are contaminating the groundwater through its high saline effluents. Many researchers have reported the groundwater salinization in the immediate surroundings of tanning industries (Mondal et al., 2005; Srinivas et al., 1984; Kumar and Riyazuddin, 2010; Khwaja et al., 2001). Serious contamination of both surface water and

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groundwater has been observed in this area as a result of uncontrolled discharge of untreated effluents by these industries for the last three decades (Thangarajan, 1999). Tannery wastes are considered as one of the most hazardous industrial wastes (Ayoub et al., 2010). Dumping of high amount of industrial wastes of point and non-point sources may become harmful if hazardous heavy metals are present along with the common salt (Zahid et al., 2006). The major chemical constituents of the tannery effluents are sodium, chromium, magnesium, chlorides and sulphates (Rao and Thangarajan, 1999). Numerous health related issues including headache, stomachache, dizziness, night blindness, leprosy, dermatitis and other skin disorders were reported in humans by the consumption of tannery affected water (Parikh et al., 1995).

Numerous studies were carried out by researchers from different parts of the world to evaluate the salinization from tanneries and related groundwater contaminations. Rodrigues and Formoso (2006) studied the geochemistry of heavy metals in groundwater of Cadeia–Feitoria River basin, South Brazil and reported that level of chromium is exceeded the limit for drinking water. Similar cases were reported from Ranipet in Vellore, India (Rao et al., 2013; Sundar and Chandrasekaran, 2010). Geochemical methods in combination with multivariate statistical analysis are also proved as useful tool to identify the origin of contamination in tannery contaminated areas (Tariq et al., 2005; Gupta et al., 2007). Geophysical methods were also employed to delineate the groundwater contaminated zones (Mondal and Singh, 2004). Barker et al. (2001) effectively used sufficient resistivity contrast to identify subsurface contaminated zones in Dindigul district, Tamil Nadu. Mass transport model is an effective tool to study the pollutant migration near the tanning industries (Thangarajan, 1999). This study is conducted in upper Palar river basin using TDS as tracer and reported that advection is the mode of pollutant migration. Author reported that groundwater remain as polluted for several years even after the contamination sources are stopped completely. Mondal and Singh (2012) used Cl^- as tracer in mass transport modeling using MODFLOW in a tannery belt in southern India. They found that level of Cl^- in groundwater will not reduce to the permissible limit even if the pollutant load reduced to 50% of the present level. This problem is frequently reported from many parts of Tamil Nadu particularly from Chennai (Brindha and Elango, 2012), Dindigul (Mondal et al., 2005) and Vellore (Sajil Kumar et al., 2011). In a global context, Zinabu and Pearce (2003) reported that concentrations of trace elements in the water bodies of nine Ethiopian rift-valley lakes and six rivers are above their permissible limit. Armienta-Hernandez and Rodriguez-Castillo (1995) studied the environmental exposure to chromium compounds in the valley of Leon, Mexico and identified hexavalent chromium from the tanning industry which causes intense health effects. However, it must be noted that most of these studies did not studied the groundwater–tannery effluent mixing with reference to the natural/anthropogenic sources.

The objective of this study was to investigate the groundwater evolution and to characterize the natural and anthropogenic influences with a special emphasis on groundwater–tannery effluent mixing, as starting point to initiate the remediation and/or controlling measures.

2. Study area settings

Present study is carried out in the Vaniyambadi region of Vellore district (Fig. 1), lies between the geographic coordinates (78′25″–78′47″) and (12′30″–12′40″). This is a typical semi-arid area in the Tamil Nadu state. The annual average rainfall is 949.8 mm, with a larger contribution from NE monsoon season during September–December. The mean daily minimum and maximum temperature are 18.2–36.8 °C and the highest is reported in May. Physiographically the region is undulating with hilly and valley areas. Hilly areas comprises mainly of red loamy soils whereas the black cotton soils in the valley areas.

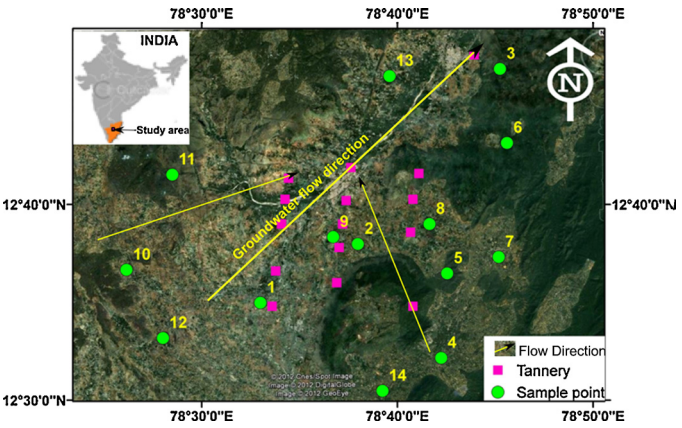

Fig. 1. Satellite image of the study area showing the sample points and the tannery industries. The satellite image of the study area is adapted from Google Earth 6.0.2.

This region is underlain by geological formations ranging from Archean crystalline rocks to recent alluvium. Crystalline formations in the study area comprise mainly of charnockites, gneisses and granites (see Fig. 2). A narrow strip of the river alluvium is also seen along the floodplains of river Palar. In the consolidated formations, occurrence of groundwater is largely controlled by the fractures and weathered zones. The thickness of the weathered zone is up to 15 m depending on the topography (CGWB, 2009). The other influencing factor of groundwater occurrence is lineaments. Remote sensing data shows a predominant trend of lineament is NE–SW and NW–SE. Groundwater level contour lines show a general trend toward SW to NW directions, happened to be the flow direction of river Palar. However, a local sink in water level is observed in the center part of the study area. The tannery industries are situated in the so called sink and this will have an effect on the solute concentration and their transport through the flow line. Previous studies in the study area reported groundwater contamination due to the high saline tannery effluents. However, being a semiarid-hard rock area, natural contamination such as rock–water interaction and evaporation may also have influences on the groundwater quality. Under these circumstances, present study focuses on the mixing of tannery effluent with the groundwater and their impact on the hydrogeochemistry of the region.

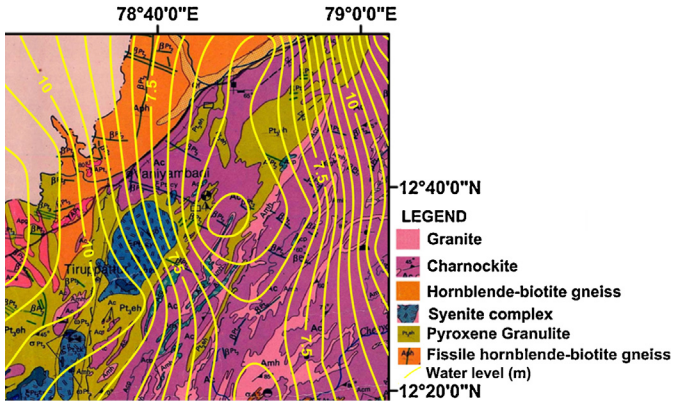

Fig. 2. Geological map of Vaniyambadi area.