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Environmental Tritium (^{3}H) and hydrochemical investigations to evaluate groundwater in Varahi and Markandeya river basins, Karnataka, India

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ABSTRACT

The present study aimed at assessing the activity of natural radionuclides (^{3}H) and hydrochemical parameters (viz., pH, EC, F^-, NO_3^-, Cl^-, Ca^{2+}, Mg^{2+}) in the groundwater used for domestic and irrigation purposes in the Varahi and Markandeya river basins to understand the levels of hydrochemical parameters in terms of the relative age(s) of the groundwater contained within the study area. The recorded environmental ^{3}H content in Varahi and Markandeya river basins varied from 1.95 ± 0.25 T.U. to 11.35 ± 0.44 T.U. and 1.49 ± 0.75 T.U. to 9.17 ± 1.13 T.U. respectively. Majority of the samples in Varahi (93.34%) and Markandeya (93.75%) river basins being pre-modern water with modern recharge, significantly influenced by precipitation and river inflowing/sea water intrusion. The EC-Tritium and Tritium–Fluoride plots confirmed the existence of higher total dissolved solids (SEC > 500 μS/cm) and high fluoride (MAC > 1.5 mg/L) in groundwater of Markandeya river basin, attributed to relatively longer residence time of groundwater interacting with rock formations and vice versa in case of Varahi river basin. The tritium-EC and tritium–chloride plots indicated shallow and deep circulating groundwater types in Markandeya river basin and only shallow circulating groundwater type in Varahi river basin. Increasing Mg relative to Ca with decreasing tritium indicated the influence of incongruent dissolution of a dolomite phase. The samples with high nitrate (MAC > 45 mg/L) are waters that are actually mixtures of fresh water (containing very high nitrate, possibly from agricultural fertilizers) and older 'unpolluted' waters (containing low nitrate levels), strongly influenced by surface source.

1. Introduction

Water quality is an important parameter of environmental studies because it is consumed and also it can transport pollutants in the environment. Groundwater has increasingly taken its place in the provision of safe, potable supply (viz., availability) in the developing world and overexploitation of aquifers, evident in failing boreholes, deteriorating water quality and their regulation has become a world-wide concern. In addition to this, the radioactive contents of water should not be underestimated or disregarded, as they usually are, as an isolated water quality parameter (Sanchez-Cabeza and Pujol, 1996). The extent of water/rock interaction, and hence the groundwater chemistry, depends on the mineralogy of the aquifer rock and the residence time that the groundwater has been in contact with the rock (McNeill et al., 2003). In this regard, environmental (stable and radioactive) and artificial radioactive isotope hydrologic techniques have proved to be effective tools for solving many critical hydrological problems/processes (Todd, 1959) and in many cases, provide information that could not be obtained by any other conventional means (Clark and Fritz, 1997; Kendall and McDonnell, 1998; Rao, 1984). The use of artificial tracers is generally effective for site specific and local applications (Tirumalesh et al., 2007; Rangarajan and Athavale, 2000; Kulkarni, 1992) due to their cost-effectiveness and investigative empowerment of local investigators (Verhagen, 2003). In contrast, environmental isotope hydrology is increasingly seen as a powerful discipline in assessing groundwater systems especially in developing environments, where historical data is rarely available (Verhagen, 2003). The, environmental isotopes are very useful tracers to study the present and ancient hydrological processes and to understand surface and groundwater interconnections, the source and mechanism of recharge (Sukhija et al., 1996; Shivanna et al., 2004), groundwater circulation and its renewability (Rao and Kulkarni, 1997; Navada et al., 1993), recharge areas and transit times of the aquifer (Sukhija et al., 1998; Agarwal et al.,

Abbreviations: TU, Tritium unit; MAC, maximum admissible concentration; SEC, specific electrical conductance; TDS, total dissolved solids.

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2006), hydraulic inter-relationships (Navada and Rao, 1991; Jain et al., 1987) and source and mechanism of groundwater contamination (Shivanna et al., 2000, 1993; Tirumalesh et al., 2007a). Environmental isotopes now routinely contribute to more productive water investigations, complementing geochemistry and physical hydrogeology (Al-Katheeri et al., 2009) because radioactive environmental isotopes give information on groundwater dynamics and recharge rates whilst non-radioactive and/or stable environmental isotopes indicate the origins of groundwater and delineate groundwater bodies. The most frequently used environmental isotopes for isotopic hydrological investigations include isotopes of elements of the water molecule [^{1}H (protium), ^{2}H (deuterium), ^{3}H (tritium), ^{16}O and ^{18}O] and that of the element carbon [^{12}C, ^{13}C and ^{14}C].

Tritium [Hydrogen-3 ($^{3}H_2$) or Triton (T_2) or ^{3}H], radioactive or unstable isotope of hydrogen having a half-life of 12.32 $\pm$ 0.02 yr (~ 4500 $\pm$ 8 days), decays to ^{3}He emitting a beta particle having a radiation energy of 0.0057 MeV (Lucas and Unterweger, 2000). It is a gas at standard temperature and pressure and has relatively a high specific activity. Tritium is a naturally occurring radionuclide, produced mainly from interactions between cosmic-ray neutrons and nitrogen in the upper atmosphere (Lal and Peters, 1967), via the reaction: $^{14}N(n, T)^{12}C$. The largest anthropogenic source has been atmospheric nuclear testing between 1952 and 1969, which disturbed the natural levels of tritium. It behaves like stable, ordinary hydrogen and is usually found attached to molecules replacing hydrogen, having the chemical properties essentially the same as those of ordinary hydrogen. When Tritium combines with oxygen to form a liquid, the most common forms are tritium gas (HT) and tritium oxide, also called "tritiated water" (viz., T_2O/TTO) or partially tritiated water (viz., THO/HTO). In tritiated water, a tritium atom replaces one of the hydrogen atoms so the chemical form is HTO rather than H_2O. The tritiated water so formed gets precipitated out of the atmosphere together with ordinary water and migrate with ground and surface waters. The deposition rate of the tritium varies with latitude, but it is also mixed with the bulk of precipitation originating from the ocean (which has a very low tritium content), and thus the average tritium content of precipitation tends to vary inversely with annual precipitation. The combined natural and human-made/anthropogenic emissions of tritium resulted in a current global background level of tritium (Okada and Momoshima, 1993). As part of the water molecule ($^{3}HHO/^{1}H^{3}HO$), tritium perfectly follows water in atmospheric, oceanic, and hydrological transport and mixing processes (Saito, 2008) and hence can be used as an ideal tracer to date groundwater with a residence time of less than 50 yr. Application of tritium to hydrologic problems was first proposed by Libby (Libby, 1953; Bergmann and Libby, 1957). Tritium analysis has been useful in many areas such as hydrogeology (Lloyd, 1981; Lehmann et al., 1993; Sanchez-Cabeza and Pujol, 1999), nuclear industry monitoring (Mundschenk and Krause, 1991; Castellano and Dick, 1993), dosimetry and health-risk assessment (Okada and Momoshima, 1993; Murphy, 1993), and some special topics such as false labeling of alcoholic beverages (Schönhofer, 1992) and for estimating the groundwater residence time (Fontes, 1983; Yurstsever, 1983) as it is directly incorporated into water molecule.

In the present study, an attempt has been made for first time to estimate tritium (^{3}H) in the groundwater samples from Varahi and Markandeya river basins, using low background liquid scintillation counting system (Wallac Quantulus 1220) to see whether the aquifer in the study area is getting modern recharge or not. The paper also discusses the relationship that can exist between tritium and other hydrochemical parameters like pH, EC, F^-, NO_3^-, Cl^-, Ca^{2+}, Mg^{2+}.

2. Study area

The Location map of the Varahi and Markandeya river basins along with the sampling points are shown in Fig. 1.

2.1. Varahi River basin

River Varahi is a major west flowing river in the west coast in Udupi district, which originates from the high peaks of the Western Ghats near Guddakoppa village in Hosanagar taluk, Shimoga district at an altitude of about 761 m above mean sea level (MSL) and flows for a length of 88 km. A dam (13° 39' 15" N latitude and 74° 57' 0" E longitude) has been constructed across the river Varahi at Hole Shankaranarayana village, which is approximately 6 km from Siddapura village, Kundapura taluk, Udupi district. The stream collects heavy rainfall in the hilly region around Agumbe and Hulikal. Tributaries like Hungedhole, Kabbenahole, Dasnakatte, Chakranadi etc., join Varahi before emptying into the Arabian Sea. Varahi River basin stretches geographically from 13° 26' 34.8" N to 13° 39' 32.4" N latitude and 74° 40' 33.6" to 74° 56′ 34.8" E longitude, positioned in the midst of Udupi district in the western part of Karnataka state. The river Varahi has been one of the major sources of water for Mani Dam near Mani village, with diversion weir and Forebay Dam for generation of electricity at the Varahi Hydroelectricity Power Station. The study area is having a catchment area of 293.0 km^2 (29300 ha). The gross command area of 362.41 km^2 covering parts of Kundapura (209.73 km^2) and Udupi (152.68 km^2) taluks of Udupi District, which is the area around the dam, where the benefits of the dam, such as irrigation water reach. The reservoir water has been directed by via Varahi Left Bank Canal (VLBC, 33 km) and Varahi Right Bank Canal (VRBC, 44.70 km). The net irrigable command area is around 157.02 km^2 (15702 ha) covering part of Kundapura (83.24 km^2) and Udupi (73.78 km^2) taluks of Udupi District, area under flow irrigation accounts to 129.79 Km^2 (12979 ha) and 27.23 Km^2 (2723 ha) comes under lift irrigation. The Varahi Irrigation Project is aimed at providing enhanced irrigation facilities and an improved drinking water facility to the villages of two taluks of Udupi district by means of canal system in addition to hydroelectric power generation.

2.2. Markandeya River basin

The River Markandeya is one of the major tributaries of River Ghataprabha, subsequently joins the River Krishna in the Northern Karnataka. River Markandeya originates in Bailur in Western Ghats and flows for a length of 66 km towards east before joining Ghataprabha near Gokak. A dam (16° 2′ 0″ N latitude and 74° 38′ 30″ E longitude) has been constructed across the river Markandeya to establish reservoir at Shirur village in Gokak taluk. The study area, Markandeya River basin stretches geographically from 15° 56' to 16° 08' N latitude and 74° 37' to 74° 58′ E longitude, positioned in the midst of Belgaum district in the northern part of Karnataka state. The study area is having a catchment area of 432 km^2 (43,200 ha). The gross command area is around 328.31 km^2 covering part of Gokak (237.98 km^2), Saundatti (26.13 km^2), Hukkeri (50.6 km^2) and Belgaum (13.6 km^2) taluks of Belgaum District. The reservoir water is directed via Markandeya Left Bank Canal (MLBC, 15 km) and Markandeya Right Bank Canal (MRBC, 71 km) to irrigate an area of around 8.9 km^2 (890 Ha) and 182.15 km^2 (18,215 ha) respectively. Thus, the net irrigable area is around 191.05 km^2 (19105 ha) covering part of Gokak (95.83 km^2), Saundatti (80.37 km^2), Hukkeri (8.90 km^2) and Belgaum (5.95 km^2) taluks of Belgaum District. Markandeya Irrigation project is aimed at providing enhanced irrigation facilities and an