

Geographical Information System based assessment of spatiotemporal characteristics of groundwater quality of upland sub-watersheds of Meenachil River, parts of Western Ghats, Kottayam District, Kerala, India

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Abstract Hydrogeochemistry of groundwater in upland sub-watersheds of Meenachil river, parts of Western Ghats, Kottayam, Kerala, India was used to assess the quality of groundwater for determining its suitability for drinking and agricultural purposes. The study area is dominated by rocks of Archaean age, and Charnockite is dominated over other rocks. Rubber plantation dominated over other types of the vegetation in the area. Though the study area receives heavy rainfall, it frequently faces water scarcity as well as water quality problems. Hence, a Geographical Information System (GIS) based assessment of spatiotemporal behaviour of groundwater quality has been carried out in the region. Twenty-eight water samples were collected from different wells and analysed for major chemical constituents both in monsoon and post-monsoon seasons to determine the quality variation. Physical and chemical parameters of groundwater such as pH, dissolved oxygen (DO), total hardness (TH), chloride (Cl), nitrate (NO₃) and phosphate (PO₄) were determined. A surface map was prepared in the Arc-GIS 8.3 (spatial analyst module) to assess the quality in terms of spatial variation, and it showed that the high and low regions of water quality varied spatially during the study period. The influence of lithology over the quality of groundwater is negligible in this region because majority of the area comes under single lithology, i.e. charnockite, and it was found that the

extensive use of fertilizers and pesticides in the rubber, tea and other agricultural practices influenced the groundwater quality of the region. According to the overall assessment of the basin, all the parameters analysed are below the desirable limits of WHO and Indian standards for drinking water. Hence, considering the pH, the groundwater in the study area is not suitable for drinking but can be used for irrigation, industrial and domestic purposes. The spatial analysis of groundwater quality patterns of the study area shows seasonal fluctuations and these spatial patterns of physical and chemical constituents are useful in deciding water use strategies for various purposes.

Keywords Hydrogeochemistry · Spatiotemporal · Western Ghats · India

Introduction

Groundwater is a vital natural resource for the economic and secure provision of drinking water, which plays a fundamental role in human well-being. However, the pressure on groundwater, in terms of both quantity and quality, has increased to an extent whereby not only drinking water sources but also sensitive ecosystems are threatened by contamination through human exploitation. It is a well-known fact that a polluted environment has a detrimental effect on the health of people, animal life and vegetation (Sujatha and Reddy 2003). Groundwater is extensively used for domestic, industrial and irrigation activities. Water quality analysis is one of the most important issues in groundwater studies. Its monitoring and assessment is imperative for devising preventive

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measures against health hazards (Dhiman 2005). Quality of groundwater is equally important to its quantity owing to the suitability of water for various purposes. Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Subramani et al. 2005). The hydrogeochemical study reveals the zones and quality of water that are suitable for drinking, agricultural and industrial purposes (Anbazhagan and Archana 2004). The chemical quality of groundwater is related to the lithology of the area and the residence time of the water in contact with rock material. Weathered mantle, soils and atmosphere are the important factors responsible for contribution of dissolved solids to water. It is impossible to control the dissolution of undesirable constituents in the waters after they enter the ground (Srinivasa Gowd 2005).

Researchers in India and abroad have done a number of studies on various aspects of groundwater quality to find out the suitability of water for various purposes. Srinivasa Rao et al. (1999) performed a study to assess the groundwater quality in relation to agricultural and domestic uses in the Niva River basin, Chittoor district, Andhra Pradesh, part of the Peninsular Archean granite and gneissic complex of India. They have prepared correlation matrixes for assessing the relationship between physical and chemical parameters of groundwater. Umar and Sami (2000) have studied the drinking water quality of the Ganga–Kali sub-basin and concluded that water from the deep aquifer is comparatively free from contamination and the aquifers are subject to contamination due to sewage effluents and excessive use of fertilizers and pesticides in agriculture. Sreedevi (2002) studied the changes in the quality of groundwater with seasonal fluctuations of Pageru river basin, Cuddapah District, Andhra Pradesh, India and observed a significant increase in the chemical parameters and was attributed to the post-monsoon recharge. Sujatha and Rajeswara Reddy (2003) have studied groundwater and its suitability for irrigation in the southeastern part of the Ranga Reddy district, Andrapradesh, India. Rajesh and Murthy (2004) have analysed groundwater of coastal urban environment from the west coast of India for understanding quality and its change over a decade and found that the rapid urbanisation and industrialisation during the past decade has affected the groundwater quality of the area.

Geographical Information System (GIS) based groundwater studies were concentrated on the preparation of hydrogeomorphological maps, interpretation of lineaments and integrated terrain analysis (Kamaraju

1997; Srivastava and Battacharya 2000; Khan and Moharana 2002). Now, GIS is increasingly being integrated with groundwater and surface water quality assessment models. GIS can be used as a tool for spatial surveillance of epidemiological diseases and also as a spatial decision support system for public health management. The spatial patterns of chemical constituents are useful in deciding the water use strategies for various purposes. Collins et al. (1998) used the GIS to model the nitrogen leaching from the agricultural areas in Nepal and found that GIS application enabled them to work at whole catchment scale and to derive spatially distributed information on the nitrogen leaching. Gogu et al. (2001) used a GIS-managed hydrogeological database to support data used in vulnerability assessment techniques and numerical modelling for groundwater flow and contaminant-transport of the Walloon region, Belgium. GIS maps showing areas vulnerable to groundwater contamination for a region would help in the implementation of groundwater management strategies and also help in designing monitoring systems (Anbazhagan and Archana 2004; Dhiman 2005). Hrkal (2001) studied the vulnerability of groundwater to acid deposition, Jizerské Mountains, northern Czech Republic, and in his study he assessed the reliability of a GIS-based vulnerability map in the groundwater quality studies. He used different thematic maps related to the terrain for making the conclusion. Lee et al. (2003) have used GIS for the assessment of nitrate contamination in urban groundwater in South Korea and created a database, which contains the data such as land use, location of wells and groundwater quality data. Metni et al. (2004) used the DRASTIC model coupled with a GIS-based framework for assessing the regional groundwater vulnerability of Lebanon to prioritise protection efforts, whereby the most vulnerable areas to groundwater are targeted first, thus optimising the allocation of financial and human resources. Yoo (2005) developed a sewerage flow simulation and management system for Sindang drainage district of Seoul by integrating expert knowledge and GIS, and this facilitated the planning and decision support for redevelopment, sewer network administration, taxation rate assessment, programmed maintenance, management and flood control in the region.

The assessment of the groundwater quality is important to ensure sustainable safe use of these resources. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. The definition of water quality is therefore not objective, but is socially defined depending on the desired use of water (Babiker et al.

2006). The groundwater resources are under great risk due to the drastic increases in population, modern land use applications (agricultural and industrial) and demands for water supply which endanger both water quality and quantity. Assessing and monitoring the quality of groundwater is, therefore, important to ensure sustainable safe use of these resources for the various purposes. In the study area, the data pertaining to the groundwater quality are not recorded up to the time of this study. Hence, the present study is an attempt to understand and identify the spatiotemporal behaviour of groundwater quality of upland sub-watersheds of Meenachil River, parts of Western Ghats using GIS.

Description of the area

The upland sub-watersheds chosen for the study is located in the Meenachil river basin, which forms the western slopes of the Western Ghats, Kottayam district, Kerala, India. The study area is enclosed between 9°37'00" to 9°52'00" North latitudes and 76°44'00" to 76°56'00" East longitudes, covering an area of 218.44 km² (Fig. 1). The major two rivers flowing through the area are Kalathukadavu and Poonjar and these two confluence in Irattupettah to form the river Meenachil, flowing through the rolling plains of Kottayam and finally debouches into the Vembanad estuary. The elevation varies between 100 m in the west to 1,100 m above mean sea level

in the east. The area experiences good to high rainfall during the southwest monsoon (June–August) and northeast monsoon (October–December) seasons. The measured rainfall varies from 350 to 900 mm/day. Temperature of the area varies from 20° to 32° and the maximum in the summer seasons. In general, the climate of the area is good and is influenced by the high land regions and the monsoons. The regional geology of the Meenachil river basin point towards the Precambrian origin of basement rock (Charnockite) and basic intrusive dykes of Paleocene age. Major rock types found in the study area are Dolerite dykes, Pink/Gray Granite, Biotite Gneiss, Charnockite and Quartzite. Of this Charnockite occupies majority (94.41%) of the area.

Methodology

In the present study, water samples were collected from 28 dug wells in the study area. The study is carried out with the help of topographic sheets, Garmin GPSMAP76, ArcGIS 8.3 and fieldwork. Toposheets are used to prepare the base map, drainage map and to understand the general nature of the study area. GPS is used to map the location of each sampling well and finally the results were taken to the GIS for further analysis. The fieldwork included water level measurements, well inventory and collection of water samples from dug wells and the study of geological and geomorphological features of the area in general. The

Fig. 1 Study area location map

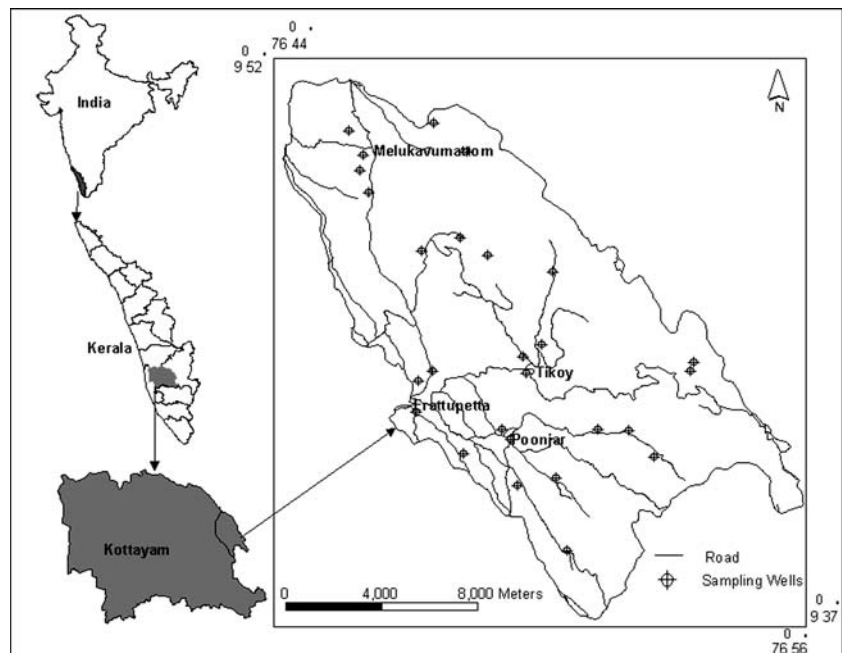


Table 1 Result of chemical analysis and statistical parameters of groundwater samples collected from the study area

Sample no.	pH		DO (mg/l)		TH (mg/l)		Cl (mg/l)		NO ₃ (mg/l)		PO ₄ (mg/l)	
	Sept. 04	Jan. 05	Sept. 04	Jan. 05	Sept. 04	Jan. 05	Sept. 04	Jan. 05	Sept. 04	Jan. 05	Sept. 04	Jan. 05
W1	5.16	6.16	6.80	1.60	56	36	14.99	14.99	0.042	0.115	0.106	0.025
W2	5.38	5.42	1.20	1.60	24	20	49.98	14.99	0.004	0.363	0.014	0.024
W3	5.09	5.46	1.60	3.20	12	16	24.99	24.99	0.009	0.363	0.016	0.016
W4	6.24	5.25	1.20	4.80	16	36	9.99	14.99	0.004	0.188	0.005	0.023
W5	6.54	6.23	1.20	6.40	28	32	9.99	4.99	0.002	0.188	0.008	0.023
W6	5.64	5.58	1.60	1.60	12	24	9.99	24.99	0.001	0.319	0.023	0.013
W7	4.84	6.38	8.00	4.80	16	48	4.99	9.99	0.008	0.159	0.008	0.023
W8	4.92	5.36	1.20	3.20	20	28	14.99	39.99	0.028	0.156	0.011	0.008
W9	5.07	5.32	1.60	3.20	48	40	29.99	14.99	0.029	0.160	0.023	0.031
W10	4.80	5.19	8.00	4.80	32	40	14.99	9.99	0.025	0.120	0.028	0.025
W11	5.38	5.64	1.20	3.20	16	32	24.99	9.99	0.010	0.324	0.019	0.016
W12	6.94	5.81	1.60	1.60	20	48	39.98	14.99	0.009	0.275	0.012	0.012
W13	6.53	5.74	2.00	3.20	24	36	29.99	9.99	0.029	0.276	0.016	0.029
W14	5.35	6.39	2.40	3.20	12	32	24.99	19.99	0.011	0.142	0.025	0.035
W15	5.45	5.68	2.80	1.60	12	32	14.99	44.99	0.025	0.200	0.019	0.032
W16	5.64	5.39	1.60	1.60	36	44	24.99	34.99	0.011	0.239	0.023	0.008
W17	5.93	5.56	1.20	3.20	28	36	34.99	19.99	0.030	0.230	0.025	0.015
W18	5.38	5.49	1.60	1.20	32	20	24.99	9.99	0.009	0.115	0.014	0.012
W19	5.09	5.05	1.20	1.60	40	28	34.99	14.99	0.051	0.188	0.008	0.031
W20	4.76	5.30	2.00	1.60	16	32	4.99	9.99	0.026	0.207	0.031	0.013
W21	5.01	5.10	4.80	1.20	20	36	4.99	4.99	0.054	0.188	0.047	0.032
W22	4.71	5.21	2.40	2.40	20	36	4.99	14.99	0.840	0.187	0.031	0.007
W23	5.94	5.36	5.20	3.20	32	48	9.99	9.99	2.090	0.162	0.009	0.014
W24	4.89	5.15	4.40	3.20	44	44	4.99	4.99	1.280	0.142	0.050	0.021
W25	4.74	5.83	2.40	2.40	28	24	14.99	14.99	1.400	0.163	0.003	0.005
W26	6.28	5.84	8.40	6.00	20	20	4.99	19.99	0.051	0.288	0.022	0.008
W27	5.60	6.17	5.60	2.40	16	32	4.99	9.99	0.080	0.236	0.044	0.012
Min.	4.71	5.05	1.2	1.2	12	16	4.99	4.99	0.001	0.115	0.003	0.005
Max.	6.94	6.39	8.4	6.4	56	48	49.98	44.99	2.09	0.363	0.106	0.035
Mean	5.45	5.59	3.08	2.88	25.19	33.33	18.32	16.47	0.228	0.211	0.023	0.019
Mode	5.38	5.36	1.20	3.20	16.00	36.00	4.99	14.99	0.009	0.188	0.008	0.023
SD	0.62	0.39	2.38	1.43	11.73	8.94	12.55	10.07	0.52	0.073	0.020	0.009

monsoon water samples were collected during September 2004 and the post-monsoon water samples were collected during January 2005.

The collected samples were analysed for various chemical parameters as described by the American Public Health Association (APHA 1995). These parameters include pH, dissolved oxygen (DO), total hardness (TH), chloride (Cl), nitrate (NO₃) and phosphate (PO₄). The pH was measured by potentiometric method and the dissolved oxygen (DO) by the Winkler's method. The total hardness (TH) was calculated by the EDTA titrimetric method and the chloride (Cl) by the argentometry method. Phosphate (PO₄) and nitrate (NO₃) were analysed by the calorimetric methods. The location of each wells were taken in to the GIS environment and the results of each parameters analysed were added to the concerned wells. Spatial Analyst, an extended module of ARC-GIS 8.3 was used to find out the spatiotemporal behaviour of the groundwater quality parameters.

Result and discussion

Chemical analysis

The results of chemical and statistical parameters analysed are given in Table 1. The statistical parameters include minimum, maximum, mean, mode and standard deviation. Understanding the quality of groundwater is as important because it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes. The pH values of groundwater range from 4.71 to 6.94 with an average value of 5.45 during September 2004. However, during January 2005, it ranges from 5.10 to 6.39 with an average value of 5.59. This shows that the groundwater of the study area is mainly acidic in nature. The DO values range from 1.20 to 8.40 mg/l during September 2004 and 1.60 to 6.40 mg/l during January 2005. Total hardness (TH) ranged between 12–56 and 16–48 mg/l for September 2004 and January 2005, respectively.

Table 2 A comparison of water quality parameters (drinking) of the study area with WHO and Indian Standards

Parameters	WHO international standard (1983)	Indian Standards for Drinking water specification (1995)	Mean value of parameters under analysis	
			September 2004	January 2005
pH	7–8.5	6.5–8.5	5.45	5.59
TH (mg/l)	100	300	25.19	33.33
Cl (mg/l)	200	250	18.32	16.47
NO ₃ (mg/l)	45	45	0.230	0.021
PO ₄ (mg/l)	–	–	0.237	0.019

The chloride (Cl) values range from 4.99–49.98 to 4.99–44.99 mg/l during September 2004 and January 2005. Nitrate (NO₃) in the groundwater varies from 0.001 to 2.090 mg/l during September 2004 and 0.115 to 0.363 mg/l during January 2005 and phosphate (PO₄) values range from 0.003 to 0.100 mg/l in September 2004 and 0.005 to 0.035 mg/l in January 2005.

The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values as recommended by the World Health Organisation (WHO 1983) and Indian Standards (ISI 1983) for drinking and public health purposes (Table 2). The table shows the most desirable limits of various parameters and it was found that all the parameters analysed are below the desirable limits of both standards.

Spatial analysis of groundwater quality

The GIS based analysis of spatiotemporal behaviour of the groundwater quality in the study area was done

using the Spatial Analyst module of ArcGIS 8.3. Powerful spatial analysis is feasible once the database is established. The interpolation technique used in the analysis is inverse distance weighted (IDW) method. IDW is an algorithm for spatially interpolating, or estimating values between measurements. Each value estimated in an IDW interpolation is a weighted average of the surrounding sample points. Weights are computed by taking the inverse of the distance from an observation’s location to the location of the point being estimated (Burrough and McDonnell 1998). The inverse distance can be raised to a power (e.g. linear, squared, cubed) to model different geometries (e.g. line, area, volume) (Guan et al. 1999). In a comparison of several different deterministic interpolation procedures, Burrough and McDonnell (1998) and Mathes et al. (2006) found that using IDW with a squared distance term yielded results most consistent with original input data. This method is suitable for datasets where the maximum and minimum values in the interpolated surface commonly occur at sample points (ESRI 2002).

The spatial pattern of parameters was analysed in two seasons, i.e. monsoon and post monsoon seasons. The spatial analysis of pH during the two seasons shows the change in the areas of spatial highs and lows (Fig. 2). During September 2004, the spatial highs are showing a clear NW–SE alignment, but in January 2005 it shows an eastward shift with a spatial maximum in the northeastern side. The DO highs are more prominent in September 2004 while compared to January 2005 (Fig. 3). The spatial highs are showing a NNW–SSE trend and the abundance of spatial highs during September 2004 points towards high rate of rainfall. The

Fig. 2 Maps showing spatiotemporal variation of pH in the study area

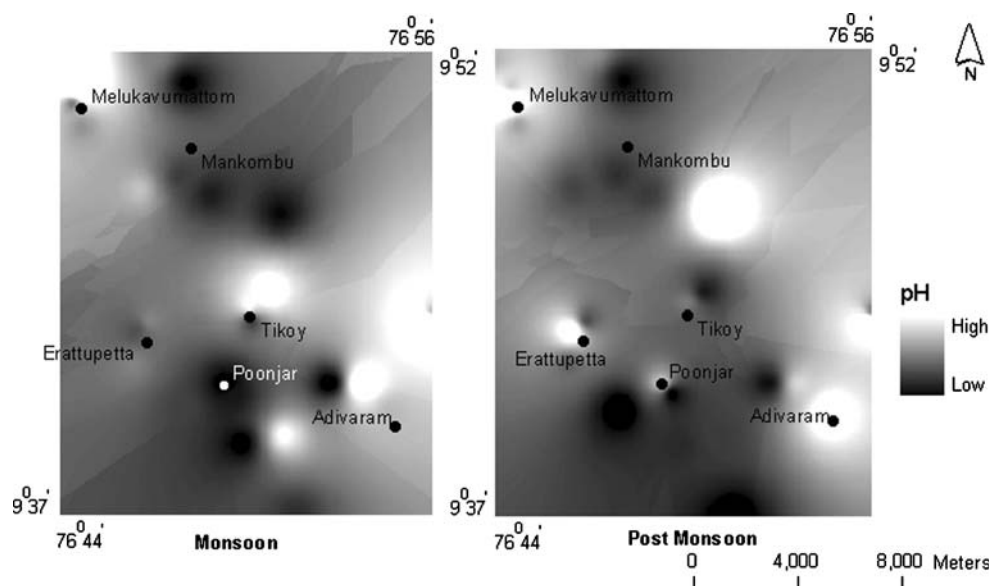


Fig. 3 Maps showing spatiotemporal variation of DO in the study area

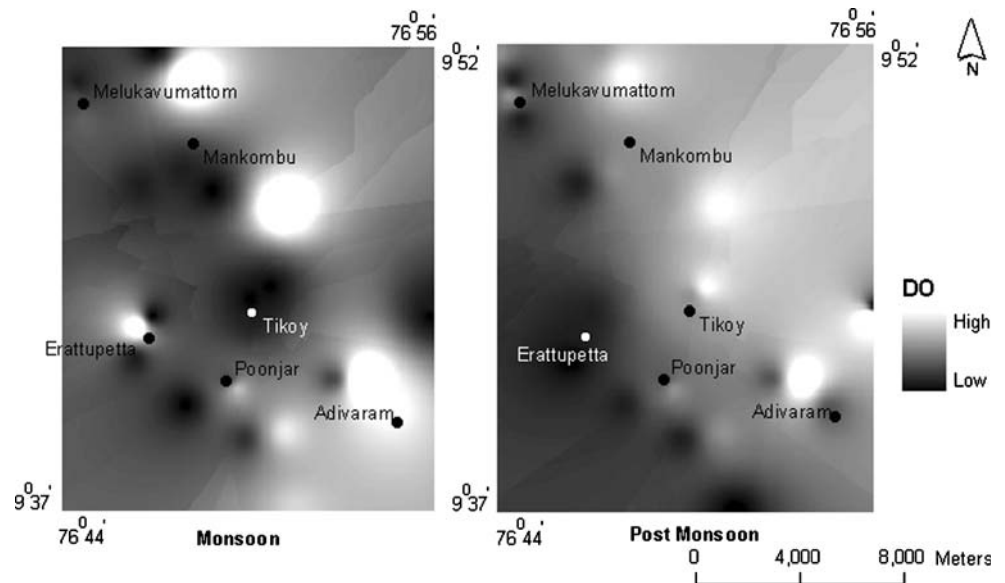
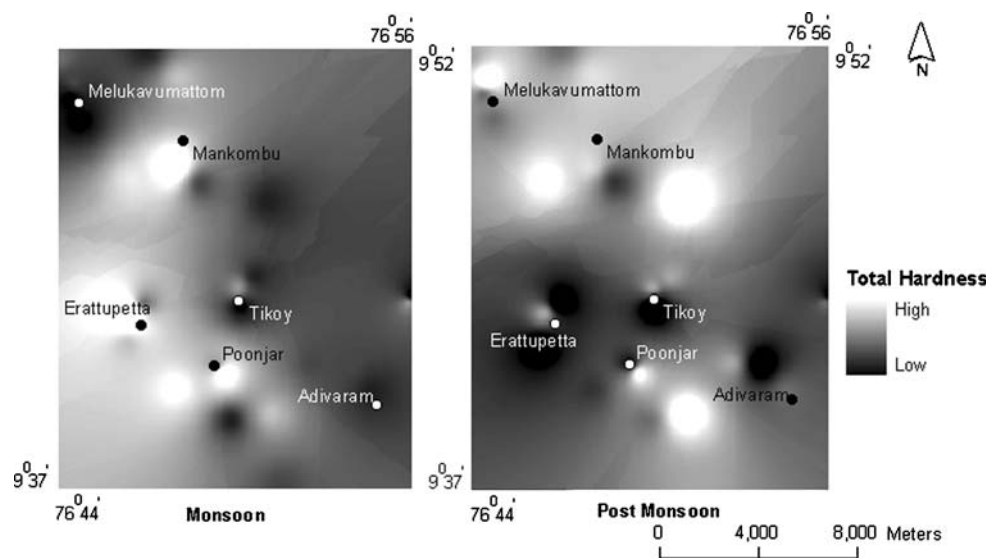


Fig. 4 Maps showing spatiotemporal variation of total hardness in the study area



spatial distributions of total hardness (TH) highs are very less in September 2004, but in January 2005 the distribution of TH highs are prominent (Fig. 4). This hardness is attributed to the use of fertilizers and pesticides in the plantation. Cl during September 2004 shows isolated highs and this has undergone a spread on January 2005 (Fig. 5). However, in the case of NO_3 and PO_4 , the spatial highs show a spread in September 2004, and during January 2005 the isolated patches of highs are distributed in the area (Figs. 6, 7).

Conclusion

The purpose of present study was to understand the groundwater quality in the sub-watersheds and picto-

rially represent it using GIS. GIS is an effective tool for storing large volumes of data that can be correlated spatially and retrieved for the spatial analysis and is able to take temporal changes into account and to provide the final more reliable and current version of outputs (Hrkal 2001). Moreover, GIS makes the groundwater quality maps into an easily understood format.

The chemical characteristics of the water samples reveal slight seasonal variations. The waters of the region are generally acidic and show slight changes seasonally. Hrkal (1992) statistically demonstrated the degree of acidification and its impact at elevations and a decrease in pH relative to elevation. All the other parameters analysed are below the desirable limits of WHO and Indian standards for drinking water. Hence

Fig. 5 Maps showing spatiotemporal variation of chloride in the study area

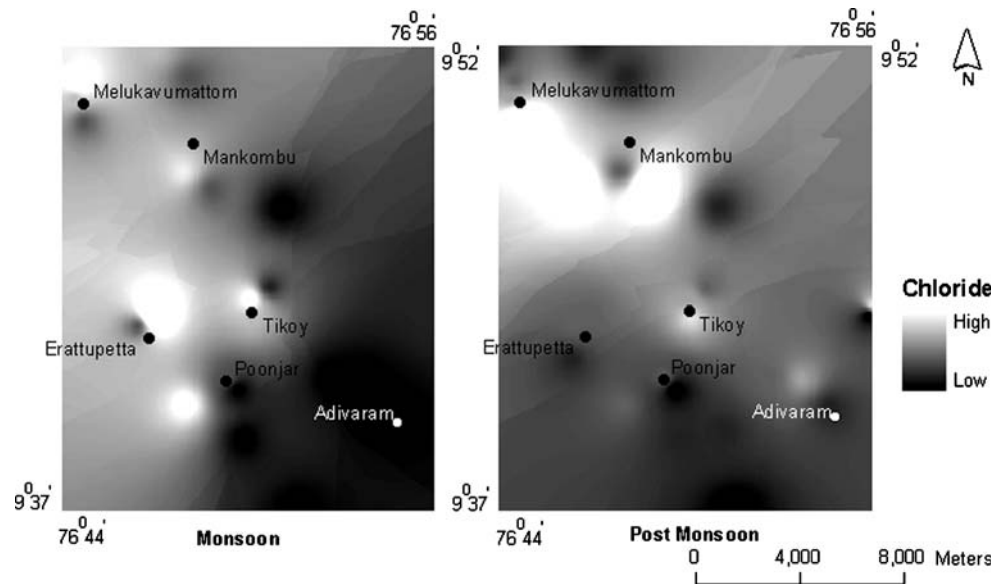
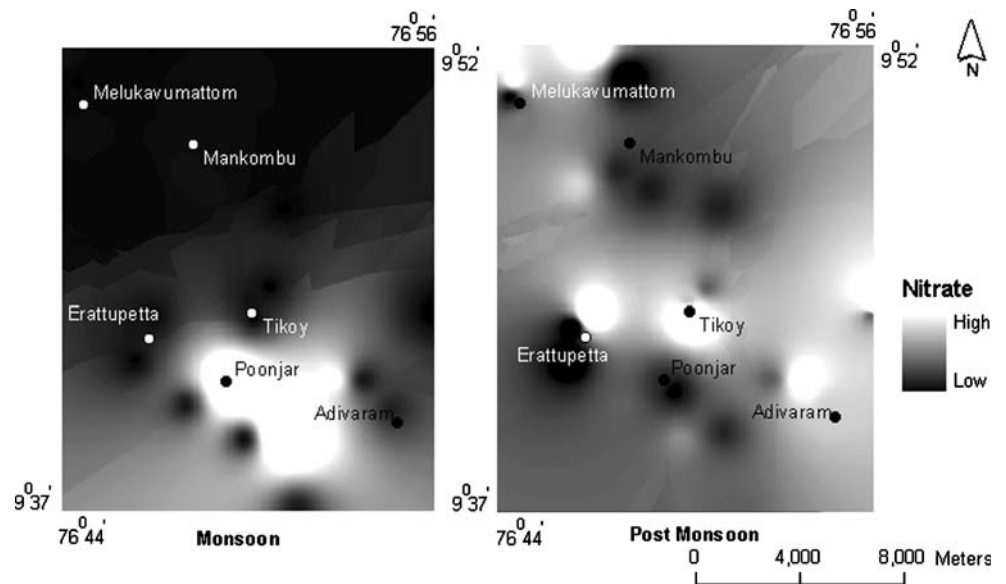


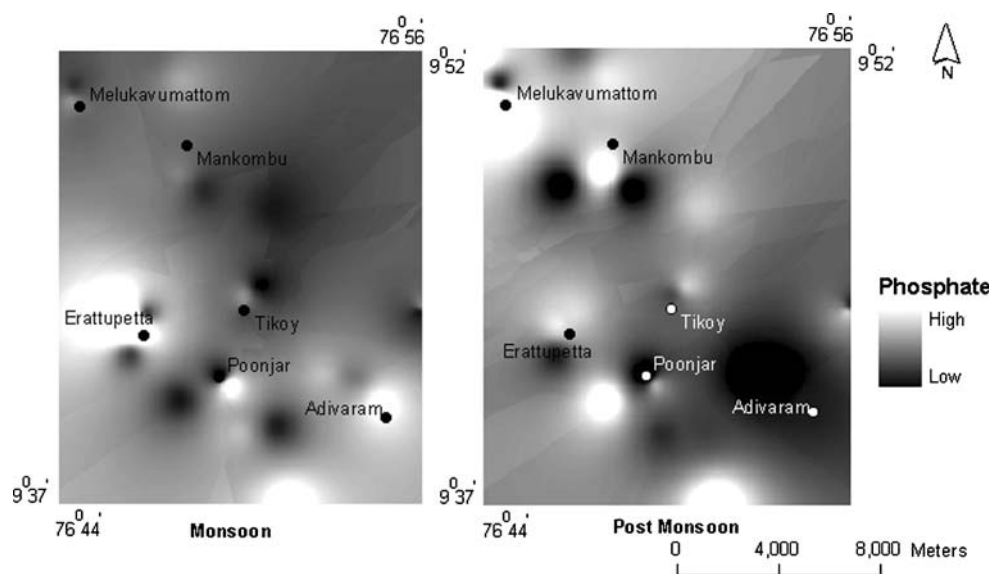
Fig. 6 Maps showing spatiotemporal variation of nitrate in the study area



the groundwater in the study area is not suitable for drinking but can be used for irrigation, industrial and domestic purposes. The post-monsoon groundwater samples show maximum deviation, as this is the time when precipitation is less so that the concentration of ions will increase considerably. The influence of lithology over the quality of groundwater is ruled out because majority of the area comes under single lithology, i.e. charnockite, and it does not have much influence over the quality of water. An excessive use of fertilizers and pesticides in agriculture practice were noticed during the fieldwork. Hence, proper attention should be given to water-quality monitoring along with groundwater resource development.

Pattern of chemical constituents could be used in understanding the geochemical process in the study area. The lack of reliable data on groundwater quality is currently a serious constraint for the preparation of rural water-supply projects. The development of an information system linking the various drinking-water assessment programs is of vital importance. Drinking-water sampling and monitoring should be critical elements of program planning, implementation, and evaluation. Further, groundwater development schemes for drinking, industrial and agricultural purposes can be initiated and approximate measures should be taken in the planning stage. GIS based pattern of groundwater quality can also be used for

Fig. 7 Maps showing spatiotemporal variation of phosphate in the study area



public health management. GIS maps are routinely used by management, and integrated water quality in this format will likely improve the overall effectiveness of environmental restoration efforts.

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