

Spatial and seasonal variation of groundwater levels in Vattamalaikarai River basin, Tamil Nadu, India - A study using GIS and GPS

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Groundwater is the major source of water in Vattamalaikarai River basin, Tamil Nadu, India for meeting the demand of the population for drinking and agriculture activities throughout the year. The basin occupies an area of 436.5 Km². Detailed field investigation was carried out in the basin during November 2011 for understanding the spatial and seasonal behavior of groundwater fluctuation. Groundwater levels were measured at 70 well locations with the help of water level recorder. GPS was used to find out the geographical coordinates and altitude of the wells with respect to the mean sea level. Hydrographs were prepared to understand the long-term groundwater fluctuation in various types of soils. It was observed that recharge rate was low in black cotton soil and high in alluvial soil. It was further observed that there was a quick response of water level to rainfall in red soil whereas the response was moderate to poor in calcareous soil. The minimum, maximum and average annual groundwater level fluctuations have been computed and plotted based on 21 years water level data and field observations. Groundwater flow directions were predicted using GIS based on the differences in groundwater head at various well locations. Spatial and seasonal groundwater level fluctuations were also plotted using GIS. Three dimensional water table elevation model was also prepared using GIS based on the groundwater levels in wells and topography of the basin.

[Keywords: Water table elevation model, groundwater fluctuation, hydrographs, groundwater flow, Vattamalaikarai Basin]

Introduction

Groundwater may be defined as the subsurface water in soils and rocks that are fully saturated. Due to precipitation surplus, part of the infiltrated rainwater flows through the soil and reaches the saturated zone, where it becomes groundwater¹. The increasing demands for fresh water, on the one hand, and the decrease in the availability, on the other, have become matters of serious concern². In general, fresh groundwater flows in the direction of the lowest groundwater heads, usually the lower elements in the landscape, where it finally exfiltrates as surface water. The flow speed depends on the gradient (slope) in the groundwater table and the permeability of the soil.

The Central Ground Water Board³ carried out groundwater level fluctuation study, pump-test analysis, rainfall variation analysis and assessment of chemical characteristics of groundwater in Vattamalaikarai River Basin. The Tamil Nadu State Public Works Department^{4,5} constructed observation wells in this basin and created borehole litho-log record. The PWD and the Tamil Nadu Water Supply and Drainage Board (TWAD) are regularly

monitoring these wells by analyzing water samples and measuring water levels. Vennila⁶ studied the rainfall variation with respect to space and time. Groundwater quality assessment for drinking and irrigation purposes was carried out by Vennila⁷ and Arya and Subramani⁸. However detail study on groundwater fluctuation with respect to space and time were not carried out in this region. Thus the present work was attempted to illustrate the spatial and seasonal variation of groundwater levels using GPS and GIS techniques.

Study Area

The Vattamalaikarai River basin covering an area of 436.5 km², falls between the latitudes 10°53'N and 11°01'N and the longitudes 77°15'E and 77°45'E (Fig. 1). The basin comes under parts of Palladam Taluk of Coimbatore District and Dharapuram Taluk of Erode District in Tamil Nadu State, India. It is named after the stream 'Vattamalaikarai', a tributary of Amaravathi River, which is one of the major tributaries of Cauvery River. The highest altitude from where the trunk system of the Vattamalaikarai

River originates is about 439 m above mean sea level (MSL).

The basin falls in dry plain area and is in the rainfall shadow region of the Western Ghats³. The average annual rainfall of the basin is 571 mm. The area is underlain by crystalline rocks of the Peninsular Gneissic Complex, comprising of hornblende-biotite-gneiss and charnockite⁹. Three major soil types viz, black soil, alluvial soil, red soil and calcareous soil are noticed. In the total area of the basin, about 250 km² comes under cultivated land, and the remaining areas fall under the category of barren and uncultivable lands.

Methodology

Well inventory survey was carried out in Vattamalaikarai River Basin with the help of Global Positioning System (GPS) and details such as location of wells, type of well, diameter of the well, usage of the well, depth of water table etc, were collected in the field. Details regarding cropping pattern, population statistics, command and non-command areas, groundwater abstraction for various needs and methods of irrigation were collected from the State Agriculture Department as well as through enquiries with the farmers in the field.

Toposheets on 1:50000 scale (58 E/12, 58 F/9 and 58 F/5) were collected from the Survey of India¹⁰. Other details such as satellite imageries, rainfall intensity, groundwater level, groundwater quality, borehole lithology, and pumping test details were collected from various government organizations.

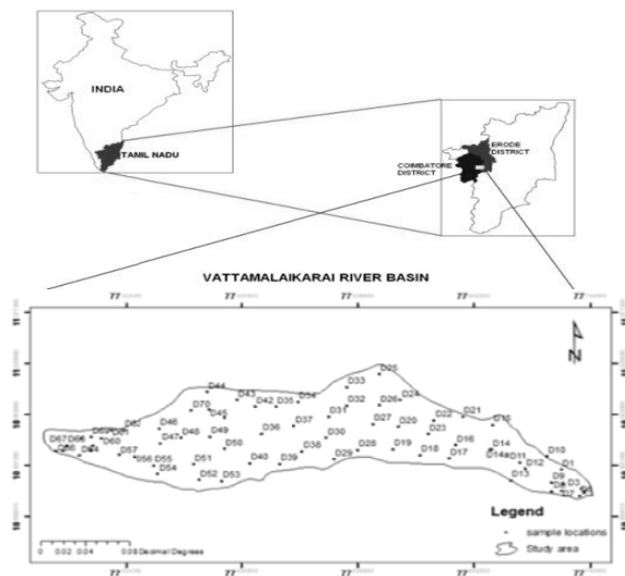


Fig. 1 — Study area map showing observation well locations

Monthly groundwater level data available for 12 wells for the period from January 1986 to December 2006 (21 years) was collected from the Public Works Department⁵. Most of these wells are shallow domestic and irrigation wells. Rainfall data of this region was collected for the period of 21 years (1986-2006) from the same source. Borehole lithological data for 17 wells were also collected from the PWD and the Central Ground Water Board¹¹.

Spatial variation of groundwater levels over the basin was plotted using GIS software. Seasonal fluctuations of groundwater at various locations were plotted in the fence diagram. Minimum, maximum and average groundwater level fluctuations in each well were also plotted in the fence diagram. Groundwater table elevation model and vector diagram showing groundwater flow directions were also prepared using GIS.

Results and Discussion

Topography

In general, topography plays a major role in groundwater management. To have knowledge about terrain slope and surface runoff, elevation contour map (Fig. 2) of the study area is important, and was prepared from the Survey of India toposheets¹⁰. Ground elevation varies gradually from 420 m above MSL in the west to 180 m above MSL in the east. The minimum ground level is observed near its confluence point with Amaravathi River, which is about 183 m above MSL. The total length of the main stream is nearly 63 km, having a mean bed slope of 3.68 m/km. The regional slope of the basin is towards east. It averages about 15.3 m/km. Since topography of this region controls the occurrence of groundwater, land use and drainage pattern, the three-dimensional digital elevation model (DEM) was generated from the elevation contour map using GIS.

Rainfall Variation

As India is a monsoon-dependent country for its major portion of rainfall, it is essential to analyze the occurrence and distribution of rainfall intensity. Rainfall in India is dependent largely on the south-west

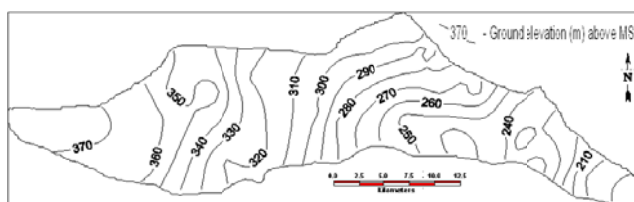


Fig. 2 — Elevation contour map of Vattamalaikarai Basin

and north-east monsoons, on shallow cyclonic depressions and disturbances, and on violent local storms. Demand for groundwater is increased due to frequent failure of monsoons and depleting surface water resources. It is, therefore, resulting in drought conditions in some parts of India during the non-monsoon periods. Thus, it is necessary to have thorough knowledge about water level fluctuations and rainfall occurrences for evolving a system to manage the water resources effectively^{6, 12}.

As Vattamalaikarai basin falls in the rainfall shadow region of the Western Ghats, the occurrence of rainfall is less than the normal rainfall of the state (920 mm). The average annual rainfall calculated for the past 10 years (1995-2004) is 571 mm⁶. The highest intensity of rain showers is recorded during the month of October (150 mm), and the lowest intensity during January (2.5 mm). Rainfall occurrence in the basin is summarized in Table 1. The perusal of data indicates that the basin experiences hottest weather during April and May³.

The maximum mean temperature of 36.6° C was recorded during April and the minimum mean temperature of 19.1° C during January.

Soil Type Vs Groundwater Fluctuation

In the study region, shallow to medium and medium to deep red calcareous soil occupying the majority of the portion. The long-term water level fluctuation reveals that rainfall recharge rate differs from one soil type to other. Black soil occurs as scattered patches in the western part of the basin, while red soil occurs as patches throughout the study area. The banks of Vattamalaikarai River are covered with alluvial soil.

Hydrographs correlating water level fluctuation and rainfall were prepared for the wells located in different soil types. Monthly rainfall and water level data of a 21-year period (1986-2006) collected from Tamil Nadu Public Works Department⁵ were used for preparing the hydrographs, which reveal that the wells

located in alluvial soil (Figure 3b) retain the water level to higher range irrespective of the magnitude of rainfall. The red soil responds quicker to rainfall, reflecting more recharge rate (Figure 3a). However, the recharge rate is comparatively slow in the wells located in medium to deep red calcareous soil (Figure 3c). This is however, not clearly observed in some hydrographs because groundwater is overexploited during the monsoon (rainy) season.

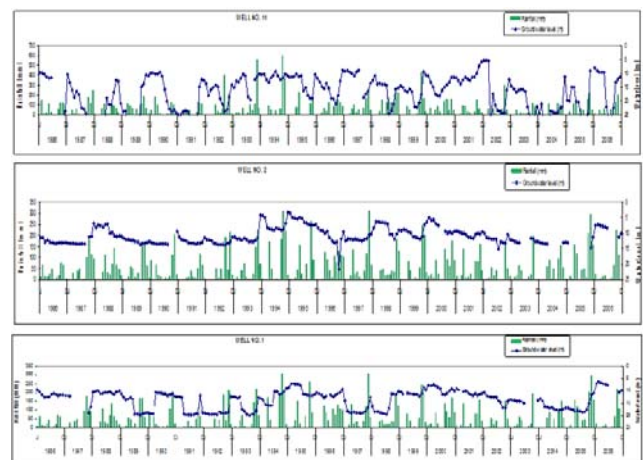
Groundwater table elevation model

The subsurface borehole lithological details of Vattamalaikarai Basin are plotted in the Figure. 4. The study area has a wide variation of soil thickness with a maximum of 5 m in the south-east part of the basin and a minimum of 1m in the extreme eastern part of the basin. Weathered zone thickness ranges from 8 to 37 m below ground level. The weathering thickness is maximum in the north-eastern and north-western parts of the basin.

The groundwater level data and water quality parameters using a decision support system like the GIS can be useful for taking quick decisions. As understanding the fundamental concepts of describing groundwater flow is becoming increasingly important, attempt has been made to generate maps to predict groundwater flow using water level data for the Vattamalaikarai River Basin. Depth of groundwater observed in open wells during November 2011 is illustrated in Table 2. The spatial variation of depth of

Table 1 — Average, maximum and minimum occurrences of rainfall during various seasons

Monsoon/ Season	Average contribution (1995-2004)		Maximum Occurrence		Minimum Occurrence		
	in mm	in %	Year	in mm	in %	Year	in mm in %
Post-monsoon	6.89	1.2	2000	112.0	16.7	Except 2000	0 0
Pre-monsoon	123.8	21.70	1995	302.0	50.9	2000	25 3.7
NE monsoon	304.5	53.34	1999	619.7	70.3	2003	111.8 41.3
SW monsoon	135.6	23.75	1998	433.0	37.6	1995	0 0



- (a) Hydrograph of a well located in Red soil
- (b) Hydrograph of a well located in Alluvial soil
- (c) Hydrograph of a well located in Medium to deep red calcareous soil

Fig. 3 — Long-term groundwater level fluctuations in Vattamalaikarai Basin

Table 2 — Depth of groundwater during November 2011

Parameters	Minimum	Maximum	Mean
Depth of groundwater in m (below ground level)	2	25.4	8.5
Groundwater Head in m (above mean sea level)	198.5	432.2	312.6

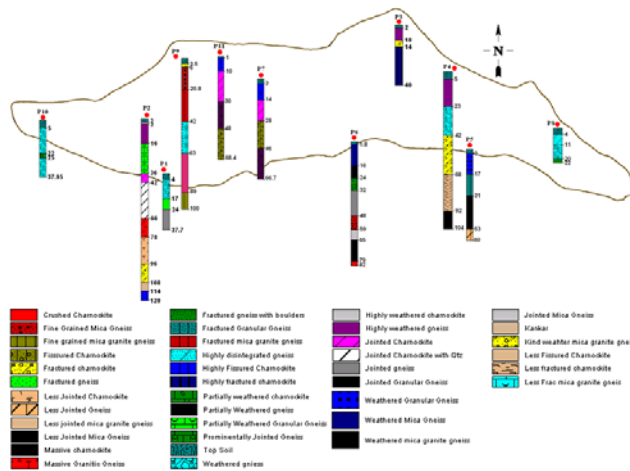


Fig. 4 — Detailed subsurface lithology of Vattamalaikarai Basin

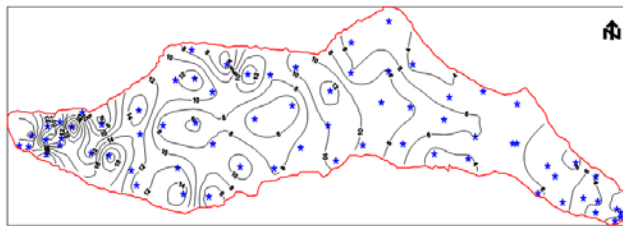


Fig. 5 — Spatial variation of groundwater level (bgl) during November 2011

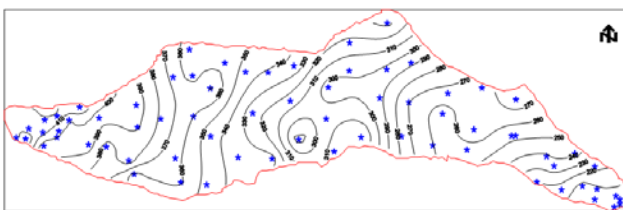


Fig. 6 — Spatial variation of groundwater head (msl) during November 2011

groundwater with respect to ground level (bgl) and the groundwater head with respect to mean sea level (MSL) are shown in the figures 5 and 6 respectively. The minimum, maximum and average depth of groundwater (bgl) in different parts of the basin is illustrated in the Figure 7.

MSL of wells, groundwater level below ground level and groundwater head above MSL were stored in GIS. Groundwater head was calculated for all the

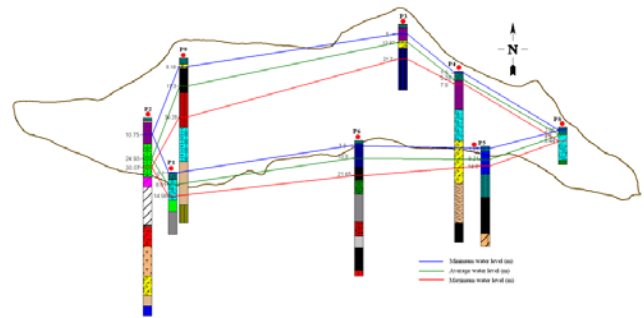


Fig. 7 — Minimum, Maximum and Average depth of groundwater levels in Vattamalaikarai Basin

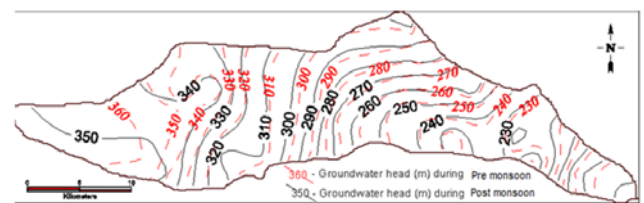


Fig. 8 — Observed groundwater heads during pre- and post-monsoon seasons

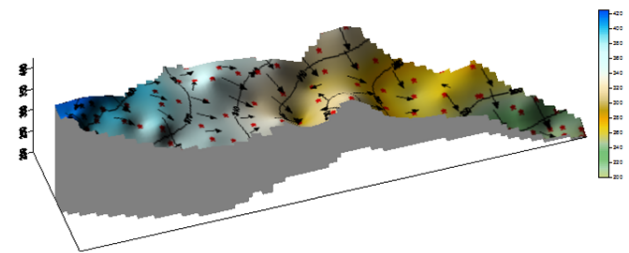


Fig. 9 — Groundwater Table Elevation and Flow Model of November 2011

monitoring wells from the collected groundwater level data. The head varied between 352 and 178 m during July 2007 and between 359 and 180 m during February 2008. Comparison of groundwater heads for pre- and post-monsoon has been illustrated in the Figure 8. Three dimensional groundwater head and vector diagram showing groundwater flow were also prepared using GIS. The water table elevation model February 2008. Comparison of groundwater heads for pre- and post-monsoon has been illustrated in the Figure 8. Three dimensional groundwater head and vector diagram showing groundwater flow were also prepared using GIS. The water table elevation model of November 2011 shows that there is a gradual decrease in the head downstream side (Fig. 9).

Conclusion

Detailed investigation was attempted to understand the mechanism of groundwater level fluctuations in

Vattamalaikarai River Basin, Tamil Nadu, India. Hydrological, topographical, geological and hydrogeological parameters were considered in the present study. The borehole lithological studies indicate that soil thickness varies from 1 to 5 m and weathered zone thickness varies from 8 to 37 m below ground level. Hydrographs indicate that rate of infiltration is high in alluvial soil and moderate to high in red soils. It is further noticed that recharge rate is moderate to poor in calcareous and black cotton soils respectively. It is observed that the depth of groundwater varies from 2 to 36.25 m with an average depth of 8.5 m. In the western part of the basin, water table is lowered more than 30 m during summer season leading most of the open wells dry. However groundwater fluctuation is minimum in the eastern part of the basin. Three-dimensional groundwater table elevation model has been developed using GIS to understand the direction of groundwater flow. The regional groundwater flow in the basin is towards southeast.

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