Groundwater flow and fluctuation using GIS in a hard rock region - South India

S.Arya1* & T.Subramani2*

1Geological subdivision, Public Works Department, Anna Nagar, Tirunelveli-600011, Tamil Nadu, India
2Department of Mining Engineering, CEG, Anna University, Chennai-600025, Tamil Nadu, India

[Email: aryasuruchand@gmail.com; geosubramani@yahoo.com; geosubramani@annauniv.edu]

Received 09 December 2015; revised 22 January 2014

Various thematic maps pertaining to groundwater flow and fluctuation were prepared from the Survey of India (SOI) toposheets and satellite imageries using geographical information system (GIS). To understand the topographical variation, three dimensional digital elevation model (DEM) was generated using GIS. Hydrographs were also prepared to understand groundwater fluctuation with respect to space and time. Groundwater level contours were prepared using GIS to understand the water level fluctuation in the basin. Raster based three dimensional groundwater table elevation model was also developed using GIS to understand the depth of occurrence of groundwater. Radial vector map was prepared from the groundwater head data using GIS to understand the groundwater flow pattern. Finally radial vector map was superimposed over the groundwater table elevation model to illustrate the groundwater flow in the basin.

[Keywords: Digital Elevation Model; Groundwater table elevation model; Groundwater flow and fluctuation; Thirumanimuthar River basin; South India]

Introduction

Hydrogeomorphological maps were prepared and detailed study was carried out in Kakund watershed, Eastern Rajasthan using remote sensing and GIS techniques for delineating groundwater potential zones1. Various groundwater potential units were delineated using remote sensing and GIS techniques in Khallikote block of Ganjam District, Orissa, India. The previous work in Thirumanimuthar River basin, Tamil Nadu, India includes identification of groundwater potential zones using Remote Sensing and GIS techniques3 and regular monitoring of groundwater levels and quality by Tamil Nadu Public Works Department4. However, much importance was not given to understand the groundwater fluctuation and flow. Present study was carried out with the main objective of understanding groundwater fluctuation and flow.

Materials and Methods

Thirumanimuthar River basin is one of the sub-basins of Cauvery River basin. Trunk system of Thirumanimuthar originates in Yercaud hills and it confluences with Cauvery River near Mohanur after a run off nearly 25 Km. The basin lies between the latitudes 11°00' N and 11°46' N and longitudes 77°50' E and 78°20' E (Fig. 1). The basin occupies an area of 2,452 Km². It falls in Salem and Namakkal Districts. Area is bounded by Shevaroy hills in north, Kolli hills in east, River Cauvery in south and Kanjamalai iron ore hillock in west. Major settlements in the basin are Salem, Rasipuram, Namakkal, Paramathi and Mohanur. Area generally enjoys sub-tropical climate. Average maximum temperature goes to 30.2°C, while the mean minimum drops to 19.2°C. Average annual rainfall of the basin is about 920 mm, which is below the average annual rainfall of Tamil Nadu state. Sixty percentage of total rainfall is contributed by Southwest monsoon from June to September and the rest by Southwest monsoon from October to December. The study area over and adjacent to Shevaroy hills and Kolli hills are of dry to moist sub humid climatic types.
The methodology has been divided into two major categories namely field work and GIS work. Several conventional data like geology, soil, rainfall, and groundwater levels were collected from various government organizations. Survey of India topsheets (No. 58I/1, 58I/2, 58I/3, 58I/4, 58I/5, 58I/6, 58I/7, 58E/14, 58E/15, 58E/16) of 1:50000 scale were used to prepare the base map, drainage map and elevation contour map using GIS. Geomorphology map, landuse map and lineament maps were prepared using IRS-1D LISS-III satellite imageries. Digital elevation model (DEM) was generated from the elevation contours using GIS to understand the surface undulations. The prepared thematic maps were verified in the field. Detailed well inventory was carried out in the basin during March 2011. Depth of groundwater levels was measured (with respect to below ground level) with the help of water level recorder and global positioning system (GPS). Hydrographs were prepared integrating rainfall and groundwater levels to understand the fluctuation. To understand the spatial variation of depth of occurrence of groundwater in the basin, water level contour map was prepared using GIS. Groundwater head with respect to mean sea level (MSL) was computed for all the wells, and groundwater head contour map was also prepared using GIS. To understand the groundwater flow pattern, radial vectors were prepared from the groundwater head using GIS. Finally, groundwater table elevation model was generated using GIS and the groundwater flow vectors were superimposed. The detailed methodology of the study is given in the Fig. 2.

Results and Discussion
DEMs means digital representation of a topographic surface. It is, however, most often used to refer specifically to a raster or regular grid of spot height. Thirumanimuthar basin forms part of the upland plateau region of Tamil Nadu with many hills and undulating plains. The highest peak in Shervaroy hill in north is having an elevation of 1480 m while Kollimalai with an elevation of 1417 m above MSL is acting as the surface waterside in east. Rajakoil karadu, Bodinayakkanur Karadu, Kunnamalai, Elephant’s tooth rock, Vedampattimalai, Karangan karadu, Kusamalai, Namamalai, Jarugumalai, Kallmalai, Kanjamalai, Godumalai, Nagarmalai, Nainarmalai, Kambal Karadu and Alagumalai etc are the other hills in this region. The elevation contour map of Thirumanimuthar basin (Fig. 3) was prepared from the Survey of India (SOI) topsheets. The maximum elevation is 1480 m in the north, and the minimum elevation is 140 m above MSL in the south. The digital elevation model (DEM) prepared using GIS shows the important hillocks in the basin (Fig. 4).

Fig. 2- Flowchart showing methodology

Fig. 3- Elevation contour map of Thirumanimuthar River Basin
The drainage map of the basin (Fig. 5) was prepared from the Survey of India topographs. The map indicates that dendritic, sub-dendritic to sub-parallel patterns are common while, radial pattern is noticed in Kanjamalai region. Dendritic drainage pattern indicates the presence of hard rock terrain and more runoff. Trellis pattern is also seen in linear hill ranges. The drainage density is high in the north and east while it is low in south, which is indicative of heterogeneous rock characteristics. A terrain with closeness in drainage pattern is proved as zones of poor groundwater potential, as a major part of rainfall is lost by surface runoff with little infiltration. On the contrary, a low drainage density area permits more infiltration with more potential for groundwater. When comparing two terrain types, the one that contains the greatest drainage density is usually less permeable. The structural analysis of a drainage network helps to assess the characteristics of the groundwater recharge zone. There are about 185 irrigation tanks seen in the toposheet and many tanks in the basin are used for storing surface water during monsoon period. Panamarathupatti Lake is the biggest in the basin, which was once used as drinking water source for Salem, Mallur and Rasipuram. Allikuttai in urban areas of Salem is converted into Sericulture research station and partly filled with sewage water leading to many environmental and land degradation issues.

Most of geomorphic features in Thirumanimuthar basin come under fluvial and alluvial geomorphology. Major geomorphic features in Thirumanimuthar basin are hills/denudational hills, bazadas, deep pediments, structural hills, pediplain, alluvial plain and valley fills. The denudational hills mainly consist of highly fractured rocks covered with big pebbles and sparse vegetation occurring superficially due to the accumulation of moisture holding soils. Bajada represents geologic conditions that are excellent for obtaining groundwater in large quantities. Bazada zones are noticed in the foot hills with unconsolidated material. Deep pediments are mainly due to high weathering of the gneisses under semi-arid climatic conditions. Pediplain with meta-sedimentary rock exposures is found in the central part of the area.

Gneisses are probably the oldest rocks in the area, and are encountered mostly in the plains. Biotite and hornblende gneisses are common. The rocks are highly weathered and the thickness of weathering often exceeds 30 m. The gneisses are intruded parallel to their foliation by a number of ultramafic and basic intrusive. Charnockites are coarse grained which are younger to the gneisses. They are exposed in Shevaroy and Kolli hills. Kanjamalai hills are known for its magnetite quartzite deposits which are associated with quartzo-feldspathic gneisses, garnetiferous-and grunerite-quartz gneisses. The peridotites and dunites are exposed in the foothills of Shevaroys near Salem, which is known as “Chalk hills”. Pyroxenites are exposed in the Nagarmalai area. They are massive and poorly jointed. Anorthosites are found in the Sittampundi Complex area. These rocks also are massive and poorly jointed.
A wide range of rocks such as chromites, eclogites, diopsidites, gabbros, hornblendite, peridotite etc. are associated with anorthosites as thin relict layers and lenses. The younger pegmatoidal granites are found in western part of the basin. Thin layers of alluvium (sand and silt) occur along the courses of Cauvery and Thirumanimuttar rivers.

Lineaments are important from the point of view of groundwater development in fractured aquifers. The high lineament zone reflects high porosity and hydraulic conductivity of the underlying materials. In Thirumanimuthar Basin, most of the lineaments are confined to the locations where pediplain, deep pediment and colluvial plains are exposed. Lineaments trending NNE-SSW, NE-SW, NW-SE and NS are identified in the study area indicating regions of good groundwater occurrence. NE–SW trending lineaments are prevalent in Namagiripettai, Puduchatram and Paramathi Velur areas. N–S lineaments are mostly confined to Mallasamudram and Elachipalayam regions. NW–SE lineaments are seen predominantly in Tiruchengode and Namakkal regions. Major drainage courses in the basin are structurally controlled. The course of Cauvery River is controlled by NW–SE lineament, whereas Thirumanimuttar river flows along a N-S trending lineament. These lineaments acts as a good source for groundwater recharge. Lineament interceptions were observed at a few regions in pediplain with potential zones for groundwater.

Thirumanimuthar basin is a hard rock and also a structurally controlled terrain. So the groundwater flow and fluctuation depends upon the lineaments, fractures and joints on the rocks. Thirumanimuthar River itself is flowing on the lineament. Hence the geological structures influence more in this terrain for groundwater recharge and flow. The Thirumanimuthar basin consists of several types of rocks with secondary intrusions. The area consists heterogeneous type of lithology. Gneisses and charnockites are the major rock types in the study area. The anorthosite complex of this area occurs as a dyke and this is intruded through a major lineament in the granitic terrain. The dyke rock acts as a barrier to groundwater flow.

The occurrence of rainfall over the Southern Peninsula towards the end of the southwest monsoon season was discussed in detail. Hydrographs correlating water level fluctuation and rainfall were prepared for all the observation wells in the basin. Monthly rainfall and water level data collected from Tamil Nadu Public Works Department (PWD) were used for preparing the hydrographs (Fig. 6), which reveal that the basin receives maximum rainfall during the month of May from southwest monsoon (average about 350 mm). Northeast monsoon also contributes significant quantity of rainfall which is maximum during October/November (average about 175 mm). The average maximum depth
of groundwater level in the weathered zone varies from 14 to 16 m during April/May. Maximum recharge occurs during the month of July. Groundwater fluctuation observed in most of the wells reveals that there is an immediate response of water level to the rainfall occurrence. This shows groundwater recharge is faster in most of the areas (eg. Well Nos. 3, 4 & 13). However, in some areas (eg. Well No. 24) there is a considerable delay in recharge after the rainfall. Few hydrographs also indicate that water level does not respond to the rainfall (eg. Well Nos. 20 & 21). Thick weathered and soil zones promote good recharge in the basin. Recharge rate is also high in Bajada and alluvial formations. Lineament zones also facilitate good recharge. Recharge rate is poor in clayey soil, and almost negligible in barren rock areas.

Groundwater table elevation model of Thirumanimuthar River basin was created using Surfer software (Fig.7). Initially depth of groundwater levels was measured in many open wells spread over the basin with respect to ground level. GPS coordinates of all well locations were noted. Height of the water table (Head) at each well location was calculated with respect to datum (MSL). Finally three dimensional groundwater table elevation model was generated by plotting the GPS coordinates and head. To indicate the direction and magnitude of groundwater flow, vector diagram was prepared using Surfer software and then it was superimposed over the water table elevation model. The model indicates that the direction of groundwater flow is found to be north to south. The topography of the study area highly influences the groundwater flow in the basin.

**Conclusion**

Digital elevation model of Thirumanimuthar River basin indicates that the basin consists of so many hills and all are structurally controlled. General slope track of the basin is found to be NE-SW direction. The northern and north-eastern parts of the basin consist of several hills and the southern part is almost plain. Because of the influence of those structurally controlled hills the river and drainages are flowing on lineaments. The occurrence of lineaments acts as a good source for groundwater recharge. Plain areas in the basin consist of very low density of lineaments when compare with hills. The rainfall infiltration is comparatively less in those regions. Drainage analysis indicates that dendritic pattern is very common while, radial pattern is noticed in Kanjamalai region. This indicates more runoff take place in hills. The drainage density is high in the north and east while it is low in south. Geomorphological studies indicate that bajadas are located along the eastern side in the foot hills. Deep pediments are mainly due to high weathering of the gneissic rocks. Borehole lithology indicates deep pediments are noticed as detached patches throughout the basin. About 40% of the basin area is covered with Pediplain. Groundwater occurrence is good when it is associated with lineament interaction. Pediplains with lineament interaction are noticed in the center part of the basin. Gneisses and charnockites are the major rock types in the basin. Biotite and hornblende gneisses are commonly seen in most of areas. The rocks are highly weathered and the thickness of weathering often exceeds 30 m in many locations. Hydrographs indicate that groundwater fluctuation is not uniform in the basin. Open wells become dry in many areas during summer due to over exploitation and less rainfall. Groundwater fluctuation is more in the central and northern part when compare with the southern part. Depth of occurrence of water table is comparatively shallow in the southern part.
The three dimensional groundwater table elevation model illustrates that the regional groundwater flow is towards south, which follows the topography.

References


5. SOI (1981), Toposheets (No. 58I/1, 58I/2, 58I/3, 58I/4, 58I/5, 58I/6, 58I/7, 58E/14, 58E/15, 58E/16) published by the Survey of India on 1:50,000 scale.


