Hydrological water balance evaluation in Tirunelveli taluk, Tamil Nadu, India using Remote Sensing and GIS techniques

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ABSTRACT
Groundwater is a main resource for all purpose of human water requirements and also it plays an important role in Agricultural productivity. The main objective of the current study is to evaluate the groundwater resources available in Tirunelveli taluk of Tirunelveli District, Tamil Nadu, India using hydrological balancing approach. In this study the integrated remote sensing and geographical information system is utilized to carry the detailed hydrological study in Tirunelveli taluk. The study region lies between the 77˚32'16"E to 77˚48'8"E longitude and 8˚40'12"N to 8˚56'34"N latitude with 558.4 square kilometer spatial coverage. The data set used consisted of field rainfall and actual derived evapotranspiration and estimated surface runoff values. The groundwater stored in the subsurface of the study area were derived from the hydrological water balancing equation with the hydrological parameters namely runoff, evapotranspiration (ET) and precipitation which are derived from the field meteorological data that varied from 284 to 885 mm. The surface runoff estimated using the USGA SCS curve number method that varied from 110 to 847 mm and nearly 21% of rain water is flowing as runoff. The derived evapotranspiration of the area ranged from 637 to 1103 mm that was calculated from processed level 4 Terra MODIS data using the SEBS model. Finally the calculated range of groundwater is compared with the water table fluctuation data for the purpose of improving the result.

KEYWORDS: ET, Terra MODIS, USGA SCS curve number, GIS, MOD16, SEBS.

INTRODUCTION
The growing world population has put a lot of strain on natural resources [7]. In world scenario, groundwater is a main source for human daily water requirements and also it plays an important role in agricultural productivity and economical activities of many countries. In developing countries surface water sources fails to fulfill the peoples total water needs, therefore the majority of population is utilizing the groundwater as a primary water source. Exploitation of groundwater has increased greatly in the last two to three decades in India, particularly for agricultural purpose, because large parts of the country have little access to surface water sources [15]. Abstraction of groundwater from low potential areas may cause adverse environmental impact on wetlands ecosystem [10]. Based on the Central Ground Water Board, annual district groundwater brochure, the groundwater exploration in the Tirunelveli district down to a depth of 200 m below ground level has revealed that in western part of the district potential fractures are encountered beyond 100 m below ground level while in the rest of the area potential fractures are restricted to 100m below ground level. The availability and distribution of groundwater especially in hard rock terrain varies significantly depending on
the surface characteristics, subsurface geology and climatic condition. The distribution of rainfall in this area varies widely both in time and space. The groundwater extent in hard rock terrain is limited due to the less infiltration of precipitated water. Hydrogeomorphological studies coupled with hydrogeological and structural/lineaments have proved to be very effective tool to discern groundwater potential zone in watershed [3].

Remote sensing technique offers unique and powerful tool for obtaining accurate spatial-temporal information of large areas in a short time which enable economical utilization over conventional methods of hydrogeological survey [13,5]. The rapid development of computer will provide additional effective spatial analysis capability to GIS environment for integrating hydrological data of the groundwater studies. Integrated remote sensing and Geographical Information System technology have opened novel way in groundwater related studies [6]. In past numerous researchers namely Deepesh Machiwal et al. [5], C.Ashokraj et al. [2], Ratika pradhan et al. [12], M.Murugiah et al. [9], Murugesan Vasanthavigar et al. [8], Amaresh Kr.Singh et al. [1], B.C.Sarkar et al. [14], N.subba rao et al. [16], R.S.Suja Rose et al. [17], Binay Kumar et al. [3] have used remote sensing and GIS for groundwater studies with winning results. Recharge is vital for the replenishment of groundwater [7]. The infiltrated water reaches the water table is known as the recharge from the rainfall to the aquifer. Recharge through both the saturated and unsaturated soil is controlled by topographic, geological, vegetation and climatic factors [11]. Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system [12]. In arid and semi-arid environment, the water table lies far beneath the soil layers due to less rainfall and high water consumption. Only during local and episodic flood events the interaction between groundwater and drainage network might be extended beyond the drainage network [11]. The primary objective of the study is to understand the availability of groundwater resources in Tirunelveli taluk, Tirunelveli District, Tamil Nadu, India using remote sensing and GIS techniques and comparing it with the field data/existing data.

Study Area:

The study area is Tirunelveli taluk in Tirunelveli district, Tamil Nadu, South India (Fig. 1). It lies between eastern longitudes 77˚32'16" & 77˚48'8" and northern latitudes 8˚40'12" & 8˚56'34" with 558.4 square kilometer area. The study area was covered in Survey of India Topographic sheets 58H/9, 58H/10 and 58H/13. The Tamirabarani and Chittar rivers is a major drainage streams which passes through this taluk and also this area consists of three tanks that are Manur, Palavadi and Gangaikondan tanks. According to the 2011 census the taluk of Tirunelveli had a population of 6, 43,341 with 3, 17,970 males and 3, 25,371 females. This area is generally hot and dry in May to June and pleasant weather in December to January. The average annual precipitation of this area is identified from available rainfall data 562-774 mm/year. The mean temperature of this study area varies from 22.9˚C to 33.5˚C and the relative humidity is on an average between 79 to 84% (CGWB). The elevation in the study area is in a range of 13 to 194m above mean sea level. The major soil units in this area are deep red soil, Red sandy soil and Black cotton soil. The infiltration behavior of the soil are generally influenced by the climatic condition, vegetation cover etc.

Fig. 1: Location map of Study Area.
MATERIALS AND METHOD

The overall methodology and processing steps of various datasets for this study is discussed as follows. The integrated remote sensing and GIS techniques are used to derive the different hydrological components of water mass balance equation for Tirunelveli taluk.

1. Preparation of Thematic layers:
   LANDSAT 8 OLI/TIRS satellite imagery of the study area acquired on 11th May 2014 which is used for obtaining surface information’s of the area. Visual interpretation process of the satellite imagery was done based on the standard photo interpretation elements like tone, texture, colour, pattern, shape, size and location to identify the landform units area and are digitized. The Survey of India topographic sheets 58H/9, 58H/10 and 58H/13 were used to prepare base map of the study area. The 90 meter resolution SRTM digital elevation model was utilized to get elevation information of the terrain. The average annual rainfall map was prepared from available rainfall data using IDW interpolation technique. The soil map was prepared from the available digital map of European Digital Archive of Soil Maps (EuDASM).

2. Water balance equation:
   The water balancing technique is used to describe the water inflow and outflow in the system. The influence of the hydrological components in the balanced system mainly depends upon the weathering condition in hard rock terrain. The general hydrological water balance equation for a hard rock terrain is shown in Eq. (1)
   \[ P = Q + ET + \Delta S \] (1)
   Where,
   \( P \) - Precipitation in mm
   \( Q \) - Surface runoff in mm
   \( ET \) - evapotranspiration in mm
   \( \Delta S \) - Change in groundwater storage in mm

3. Precipitation:
   The term precipitation indicates all forms of water like rainfall, snow etc derived from atmospheric vapour and deposited on the surface of earth. The major form of precipitation in the study area is rainfall. The meteorological rainfall data of 2012 for the study area is obtained from daily rainfall record of Tamil Nadu Agricultural engineering department. The current study utilizes data of seven rain gauge stations which are available in and around the study area and the spatial distribution map for the study area is generated by means of interpolation techniques.

4. Actual Evapotranspiration:
   The actual evapotranspiration of Tirunelveli taluk was estimated from the processed MODIS sensor data of TERA & AQUA satellite mission which was collected from NASA EROS Data Center. The MOD16A3 data with 1km spatial resolution is a product derived from the MODIS Sensor using MOD16 algorithm. The satellite data provides actual evapotranspiration of the terrain. The level 4 data product was in HDF file format which was converted into tiff format using MODIS Reprojection Tool of EROS data center. The format was directly imported into ArcGIS software.
5. **Surface Runoff:**

The average surface runoff from storm rainfall of the study area was derived by SCS-CN (soil conservation services curve number) model which was developed by USDA Natural Resources Conservation Service scientists. It consists of a simple empirical formula, standard tables and curves. The curve number technique is a simple and easy way to get average runoff values based on the surface characteristics of the terrain. Watershed coefficients which are required for the runoff formula is called as curve number. The CN value depends on the Landuse/Landcover, hydrologic condition and hydrological soil groups like A, B, C and D. The hydrological soil group of the study area was categorized based on the infiltration behaviour of the available soils. The Eq. (2) is the general equation for estimating average runoff.

\[
Q = \frac{(P-I_n)^2}{(P-I_n+S)}
\]

Where,
- \(Q\) is annual average rainfall runoff in mm/year
- \(P\) is total precipitation in mm
- \(S\) is the potential maximum soil moisture retention after runoff begins in mm
- \(I_n\) is the initial abstraction here it as assumed that \(I_n = 0.3S\)

Substituting, \(I_n = 0.3S\) in general average runoff equation we get

\[
Q = \frac{(P-0.3S)^2}{(P+0.75S)}
\]

and the general relational equation between CN and \(S\) is

\[
S = \frac{25400}{CN} - 254
\]

Finally this \(S\) value will be considered as an input for Eq. (2).

![Fig. 3: Landuse/Landcover map of Tirunelveli Taluk.](image1)

![Fig. 4: Soil map of Tirunelveli Taluk.](image2)

6. **Change in Water level:**

The net change in water level for the Tirunelveli taluk was estimated from the PWD department water level data. The monthly water level fluctuation plot derived from 19 observation wells of public works department
09 dug well and 10 bore well) for the year of 2012. These data were analyzed and the change in water level ΔWL was computed based on the graphical approach. The major part of study area was covered with weathered Granitic gneiss and weathered biotite gneiss complex. Therefore the study area comprises moderate infiltration behaviour and moderate water level fluctuation.

RESULTS AND DISCUSSION

The important aspect of water balance equation in a catchment is about the hydrological components that are, based on the inflow and outflow character in Tirunelveli taluk are discussed below.

1. Precipitation:
In the arid and semi-arid region the precipitated water is the prime component of water balance equation because the other components are depended on it. The annual rainfall data for the Tirunelveli taluk is prepared based on the collected daily rainfall data. (Tamil Nadu Agricultural Department, Tirunelveli). In the current study the rainfall layer is developed based on the annual average rainfall values of 7 rainfall stations by using spatial interpolation techniques namely Inverse Distance Weighted method which is available in ArcGIS. In this area, Palayamkottai and Tirunelveli rain gauge stations are influencing more compared to other rain gauge stations like Tenkasi, Ayikudi, Senkottai, Ambai, Sankarankovil. The rainfall values of the Tirunelveli taluk are ranges from 562 to 774 mm/year. The spatial distribution map of rainfall is shown in Fig. 2.

2. Actual Evapotranspiration:
The actual ET values for the Tirunelveli taluk during the year 2012 was acquired as MODIS satellite products. ET value of this area ranges from 500 to 1154 mm per year. The North-Western part of the study (reserve forest) area and along the Tamirabarani stream will have the maximum amount of ET due to the high vegetation density. The spatially distributed actual evapotranspiration over the study area for the year of 2012 is shown in Fig. 6 which was derived from MODIS data.

Fig. 5: Spatial distribution SCS-CN Parameters and Rainfall runoff.
3. Surface Runoff:

The average rainfall runoff for the study region was estimated using SCS curve number technique. Fig. 3 shows the land use / landcover map of the study region which was prepared from LANDSAT data using on screen digitization. Fig. 4 shows the soil map of the taluk and further it may be converted based on the hydrological soil group. In the current study CN values ranges from 30 to 100; a least value indicates low runoff and highest value indicates more runoff. In this study the forest with group A soil gets CN value of 30 and the surface water bodies receive high value of 100. The estimated annual runoff for the study region ranges from 110 to 847 mm. The north, south and south east part of the study area consists of more runoff due to the presence of two drainage streams namely Tamirabarani and Chittar. Especially around the Thamirabarani River the runoff is more compared to other area. The estimated average surface rainfall runoff due to the rainfall occurred in and around the study area as shown in Fig. 5 and Table-1 shows the Curve number for corresponding soil group for each landuse category of the study area.

Table 1: CN value for corresponding soil group for each landuse category.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Landuse classification Type</th>
<th>Curve Number for Corresponding Soil Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>Water body</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Built up Land</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>Forest</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>Agricultural</td>
<td>67</td>
</tr>
</tbody>
</table>

Fig. 6: Spatial distribution map of evapotranspiration.

![Spatial distribution map of evapotranspiration.](image)

Fig. 7: Resultant water level fluctuation maps

a. Water balance based Change in storage

b. Well data based water level fluctuation
4. **Analysis and Validation of Change in Groundwater storage:**

In this study the change in the ground water storage was estimated using the water balance equation and further validation was made through estimated raise in water level data. The general water balance equation for change in water level is as follows:

\[ \Delta S = P - (Q + ET) \]  

The computed annual change in groundwater level ranges from 289.8 mm and 1030 to mm which is an abnormal component in balancing of subsurface water. The computed groundwater storage values are compared with field calculated groundwater rise value. The computed groundwater storage values are compared with field calculated groundwater rise value. The field based computed raise in groundwater level ranges from 2811.5 to 10188.4 mm. This abnormality is because of the failure in consideration of the consumption. Fig. 7 shows that the resultant water level fluctuation maps.

**Conclusion:**

The study provides water quantity information and water balance in Tirunelveli taluk. The rainfall is the only direct source of water in the study area. Since the study is not done on the watershed, the water consumption is not considered in the study. The water consumption along with the excess evapotranspiration is greater than the rainfall. It is evident that the water from neighboring basin are utilized to meet out this consumption. River Tamirabarani and Chittar plays an important role in serving this demand in consumption. Extensive consideration of areas in the containing watershed regime will be helpful in precise quantification of components. The consumptive use of water has to be incorporate for effective water balance.

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**REFERENCES**


