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Hydrograph Analysis and Watershed Prioritization for Sustainable Development in the Thoppaiyar Sub-Basin Using GIS and Remote Sensing

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Abstract

The present study focuses on a comprehensive stream hydrography analysis of the Thoppaiyar sub-basin, a significant tributary system of the Cauvery basin located in Tamil Nadu, India. The analysis integrates morphometric evaluation, hydrograph interpretation, and geospatial techniques to assess the hydrological behavior of the basin for sustainable development. The basin is characterized by dendritic to sub-dendritic drainage patterns developed over Precambrian crystalline formations, indicating minimal structural disturbance and relatively homogeneous lithology. Quantitative morphometric parameters such as stream order, drainage density, bifurcation ratio, elongation ratio, and relief characteristics were derived using GIS and remote sensing data, particularly Digital Elevation Models (DEM). Hydrograph analysis reveals that the basin exhibits a rapid hydrological response to rainfall, with a steep rising limb, short lag time, and high peak discharge, suggesting low infiltration capacity and significant surface runoff. The recession limb is relatively steep, indicating limited groundwater storage and baseflow contribution. These characteristics reflect the semi-arid climatic conditions, sparse vegetation cover, and soil properties of the basin. Spatial analysis of slope, land use/land cover, and drainage distribution further highlights areas prone to soil erosion, runoff concentration, and water scarcity. The study emphasizes the importance of integrating hydrography with watershed management practices such as artificial recharge structures, check dams, afforestation, and sustainable land use planning. The delineation of micro-watersheds enables prioritization of critical zones for intervention. The results demonstrate that scientific hydrography analysis can significantly contribute to sustainable basin development by improving water resource management, minimizing flood risks, enhancing groundwater recharge, and maintaining ecological balance. This research provides a valuable framework for regional planning and can be applied to similar semi-arid basins across India.

Keywords: *Stream hydrograph, Eco-hydrology, Aquatic ecosystems, Biological response, Cauvery river system, Watershed management*

1. Introduction

The Thoppaiyar sub-basin forms an integral part of the Cauvery river system and plays a crucial role in sustaining local water resources, agriculture, and ecosystems in Salem and Dharmapuri districts of Tamil Nadu. The basin originates from the elevated terrains of the Shevaroy Hills and flows through undulating topography before joining the main river system. In recent years, the basin has experienced increasing stress due to erratic rainfall patterns, groundwater depletion, and land use changes. These challenges necessitate a scientific understanding of the basin's hydrological processes, particularly stream hydrography, which governs runoff generation, flow distribution, and water availability. Stream hydrography analysis provides insights into the temporal and spatial variation of streamflow and helps in identifying the response of the basin to precipitation events. By integrating morphometric parameters with hydrograph characteristics, it becomes possible to evaluate the basin's capacity for water retention, infiltration, and discharge. In semi-arid regions like the Thoppaiyar sub-basin, where water resources are limited and highly variable, such analysis is essential for sustainable basin development and long-term resource planning.

1.1.Study Area

The Thoppaiyar sub-basin is located in Dharmapuri and Salem districts respectively in the northern and southern part of the basin and it act as boundary for both districts. The sub-basin area is bounded between

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northern latitudes 11051'47''to 11059'56'' and eastern longitudes 77053'5''to 780 18'2'' (Fig.1). The highest elevation in the sub-basin is 1600m above mean sea level (amsl) in upstream at Muluvi and lowest elevation 240m amsl in downstream. The area is well connected by north south NH-7 and railway line. The total aerial coverage of the sub-basin is 462 sq.km. Thoppaiyar is the main river flow in the sub-basin. A significant percentage of the sub-basin is covered by reserved forest zone. There are five rain gauge stations in the sub-basin namely; Anaimaduvu, Bommidi, Thoppaiyar Dam, Thoppur and Mettur. The average annual rainfall of the Thoppaiyar sub-basin is 707mm. The climate in the sub-basin is generally warm. The hottest period of the year is generally from March to May and the temperature raises up to 380C during April. The climate becomes cool in December and continues upto February, touches minimum of 150C during January. The basin receives rainfall from the southwest as well as northeast monsoon.Shows Figure 1 Thoppaiyar sub-basin located in the southern India

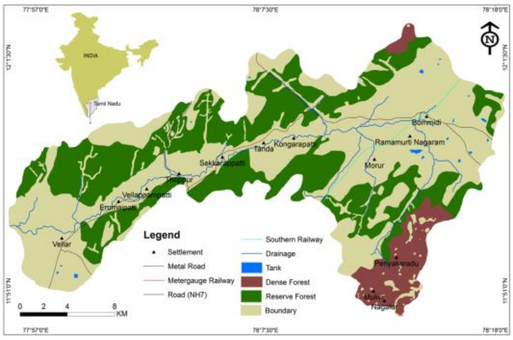

Figure 1 Thoppaiyar sub-basin located in the southern India

2. Methodology

Stream hydrograph analysis deals with the study of runoff records at a stream gauge. Hydrograph analysis is often combined with rainfall analysis to investigate how a watershed responds to rainfall. In many cases, hydrometric information is not available. This is especially[1] true for small watersheds. In such situations, rainfall information must be combined with rainfall-runoff models. Stream type analysis Study of the annual hydrographs of streams can help us to classify the streams into the following categories (Fig.2); Perennial streams: Perennial stream carry flow throughout the year, and hence usually carry a considerable amount of base flow. The water table in the area is normally above the river bed. Intermittent stream: Intermittent stream flows only during the monsoon season and contribution of base flow only during the rainy season. The water table in the area is above the river bed only during rainy season.Ephemeral streams: On the other hand, ephemeral streams do not receive any base flow contribution, since the water table in the area is always lower than the stream bed. The hydrography of such a stream exhibits[2] flash flows in response to rain storms. The inflow data for Thoppaiyar reservoir is collected from Water Resource Organization (WRO), PWD. Based on stream flow, a hydrograph is plotted for the year 2012, which shows that the Thoppaiyar River is in intermittent condition.Shows Figure 2 Stream type and hydrographs (after Garg, 1996)

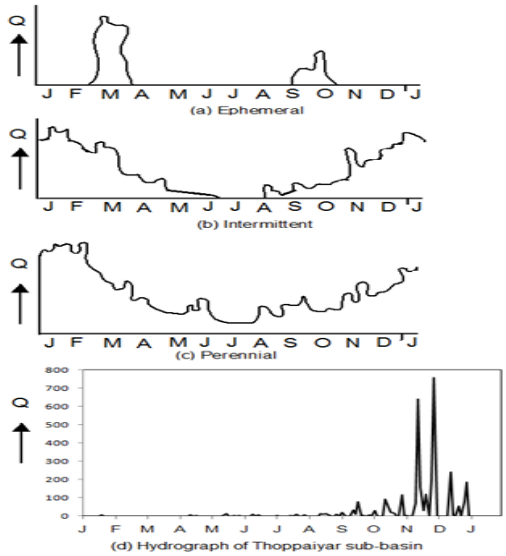

Figure 2 Stream type and hydrographs (after Garg, 1996)

3. Results and Discussion

3.1. Base flow analysis Stream flow measurement

Stream flow rate is measured in units of cubic meter per second (cms) or cubic feet per second (cfs). Direct measurement of flow rates requires knowledge of the complete cross sectional velocity profile, which vary

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with flow rate[3]. While it is tedious to measure flow rate directly, it is straightforward to measure river stage, for example by a gauge. Therefore, flow rates are measured only a few times, enough to establish a rating curve that describe[4] the relationship between flow rate and stage. Regular measurement of stage is then combined with the rating curve to produce time series of stream flow (Ratnayake, 2005).

3.2.Components of the hydrograph

The hydrograph describes flow as a function of time, usually known as a time series of flow. The interest may lie in the hydrograph of a long period of several years or only few selected rainfall events of a few hours or days[5]. The latter situation frequently occurs in the development of a rainfall-runoff relationship for a watershed (Ratnayake, 2005). There are two components in the hydrograph to be considered:

- Direct runoff the flow that results directly from the rainfall event. Usually after considering the associated losses from the gross rainfall. The volume of effective rainfall and the volume of direct runoff should be equal.
- Base flow that is unrelated to the rainfall event. The rainfall-runoff relationship describes the time distribution of direct runoff as a function of excess rainfall. Therefore, in developing the rainfall runoff relationship for a watershed based on observed hyetographs and hydrographs, one must first subtract the base flow from the hydrograph. Even after long periods without rain, water still flows in many streams and rivers. This flow is the result of seepage from groundwater aquifers into the stream channel[6]. In larger rivers, base flow can be significant. In periods without rain, the base flow in a stream will slowly decline as a result of the draw down of the groundwater aquifers. This phenomenon is called base flow recession. It is often assumed that base flow declines exponentially. Base flow separation involves dividing the hydrograph into a direct runoff component and a base flow component (Ratnayake, 2005).

3.3.Base flow separation

As the Unit Hydrograph concept applies only to direct runoff, the direct runoff must be separated from the base flow. Base flow separation or hydrograph analysis[7] is the process of separating the direct runoff (surface runoff and quick interflow) from the base flow. This separation is somewhatarbitrary, but corresponds to theoretical concepts of basin response (Ramírez, 2000).

3.4.Subjective methods

Several subjective methods are shown in Figure 4. The simplest one consists in arbitrarily selecting the discharge marking the beginning of the rising limb as the value of the base flow and assuming that this base flow discharge remains constant throughout the storm duration[8]. A second method consists in arbitrarily selecting the beginning of the groundwater recession on the falling limb of the hydrograph (usually assumed to occur at a theoretical inflection point) and connecting this point by a straight line to the beginning of the rising limb. A third example of subjective methods consists in extending the recession prior to the storm by a line from the beginning of the rising limb to a point directly beneath the peak discharge and then connecting this point to the beginning of the groundwater recession on the falling limb (Ramírez, 2000).Shows Figure 4 Graphical baseflow separation techniques including. 2a constant discharge method, 2b constant slope method and 2c concave method (after Linsley et al 1958)

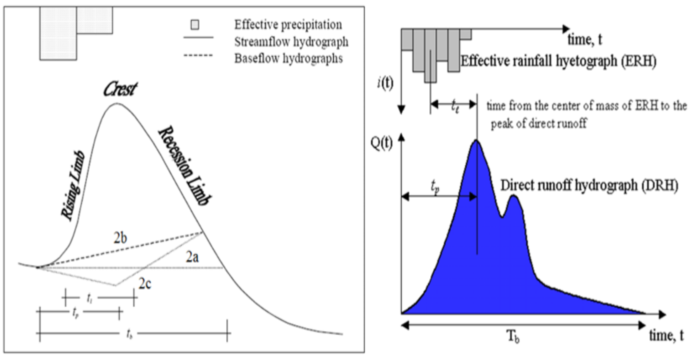

Figure 4 Graphical baseflow separation techniques including 2a constant discharge method, 2b constant slope method and 2c concave method (after Linsley et al 1958)

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3.5.Area method

The area method of base flow separation consists in determining the beginning of the base flow on the falling limb with the following empirical equation,

$$N = bA^{0.2}$$

Relating the time in days from the peak discharge (N), to the basin area (A). When A is in square miles, b equals 1. When A is in square kilometers, b equals 0.8. This equation is unsuitable for smaller watersheds and should be checked for a number of hydrographs before using. In the present study, a web based hydrograph analysis tool, WHAT has been used for estimating the base flow contribution. The procedure adopted in WHAT software is shown Fig.4.9. For Thoppaiyar sub-basin, the base flow contribution is insignificant 2-5%, which indicates the water table condition remains below the river bed (Fig.4.10). The direct runoff is ranges from 95 to 98%. The average stream flow in the river is 4200cfs (Table 4.7). During normal periods of rainfall, it contributes 4149cfs stream flow[9]. However, during drought condition, the stream flow is very meager (150cfs).Shows Figure 5 Methods of web-based hydrograph analysis, Table 1 Annual base flow in Thoppaiyar sub-basin. Figure 5 Monthly stream flow of Thoppaiyar (2002-2011)

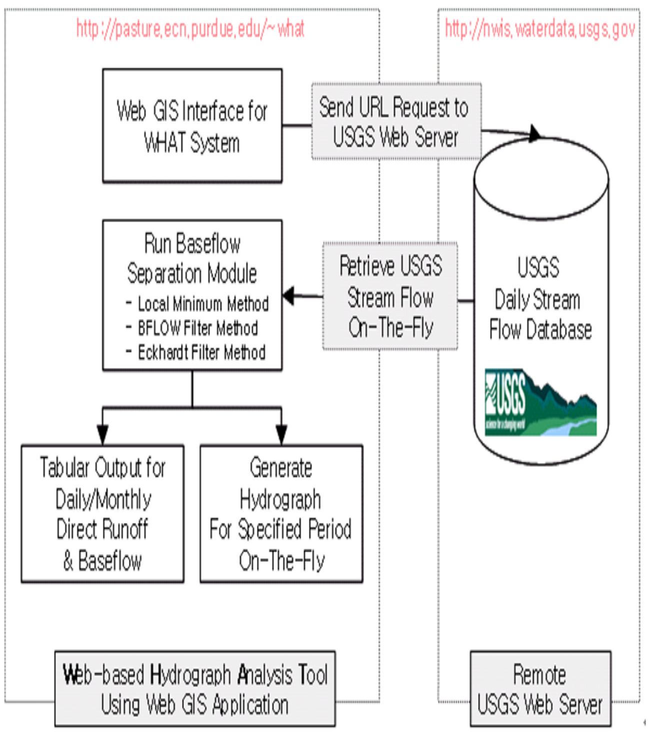

Figure 5 Methods of web-based hydrograph analysis

Table 1 Annual base flow in Thoppaiyar sub-basin

Year	Sream Flow (cfs)	Direct Runoff (cfs)	Base Flow (cfs)	Percentage
2001	709	676	33	4.9
2004	935	917	3	0.3
2005	11876	12248	444	3.6
2006	5823	5612	211	3.7
2007	4608	4441	167	3.7
2008	4304	4169	201	4.8
2009	150	147	3	2.1
2010	5576	5423	153	2.8
2011	3825	3710	115	3.1
Average	4200	4149	148	3.2

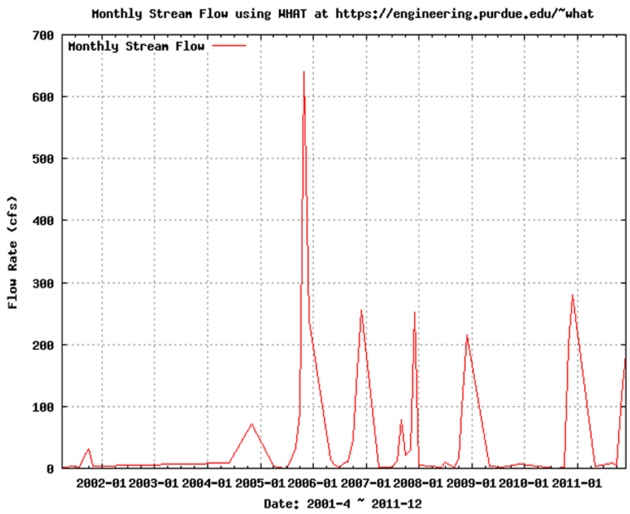

Figure 5 Monthly stream flow of Thoppaiyar (2002-2011)

Conclusions

The stream hydrography analysis of the Thoppaiyar sub-basin provides a comprehensive understanding of its hydrological and geomorphological characteristics. The integration of morphometric analysis, hydrograph interpretation, and geospatial techniques reveals that the basin is characterized by moderate drainage density, rapid runoff response, and limited groundwater contribution. These factors highlight the challenges of water scarcity and flood risk in the region. However, with appropriate watershed management practices and sustainable development strategies, it is possible to enhance water availability, reduce environmental degradation, and ensure long-term sustainability. The study underscores the importance of adopting a scientific and integrated approach to basin management, which can serve as a model for similar semi-arid regions.

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