Application of ArcSWAT for Hydrological Modeling and Irrigation Management in the Veeranam Command Area

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Abstract - Effective management of water resources is a challenge in Tamil Nadu, India's Veeranam command area, a vital agricultural region. This study models the hydrological processes and evaluates water resource management methods using the Soil and Water Assessment Tool (SWAT) via the ArcSWAT interface. We developed Hydrological Response Units (HRUs), mapped out the watershed, and examined the various components of the water balance using comprehensive geographic and meteorological data. Data on soil moisture content and observed streamflow were used to calibrate and validate the model. The findings show that there are notable differences in the amount and demand of water under various land use and climatic scenarios. The report offers practical advice for enhancing irrigation techniques and putting conservation measures into place. Based on real-time soil moisture data, optimal irrigation strategies have been shown to increase crop yields by 15% while consuming 12% less water. Over the course of five years, the implementation of these strategies led to a 22% improvement in water use efficiency and an 8% increase in crop output efficiency.

***Key Words*:** ArcSWAT, Veeranam, DEM, Water management.

1.INTRODUCTION

Understanding and managing water resources requires the use of hydrological modeling, particularly in areas where water availability has a significant impact on agricultural sustainability and production. In Tamil Nadu, India, where agricultural activities rely heavily on irrigation, efficient water management is critical. Accurate and reliable models are essential for predicting water flow, assessing irrigation needs, and evaluating the impacts of land use and climate changes on water resources area. Due to its distinct climate and hydrological features, the Veeranam command region confronts difficulties with water scarcity, ineffective irrigation techniques, and the effects of changing land use.

In large watersheds, the effects of land management methods on water, sediment, and agricultural chemical yields are simulated by means of the hydrological model known as the Soil and Water Assessment Tool (SWAT). ArcSWAT, a GIS interface for SWAT, offers an easy-to-use platform for configuring and evaluating hydrological simulations, integrating geographical data and enhancing the model's capabilities.

The Soil and Water Assessment Tool (SWAT) is used in this work to model hydrological processes and evaluate water resource management approaches via the ArcSWAT interface. We outlined the watershed, established Hydrological Response Units (HRUs), and examined the various elements of the water balance using comprehensive geographic and meteorological data. Observed streamflow and soil moisture data were used to calibrate and validate the model. Findings show notable differences in the supply and demand for water throughout

In regions like the Veeranam command area in Tamil Nadu, India, where agricultural activities are heavily dependent on irrigation, effective water management is crucial. The Veeranam command area, characterized by its unique climatic and hydrological conditions, faces challenges related to water scarcity, inefficient irrigation practices, and the impact of varying land use.

The main objective of this study is to apply the ArcSWAT model to the Veeranam command area to assess its hydrological processes including precipitation, runoff and evapotranspiration to simulate different scenarios to understand the potential impacts of land use changes and climate variability on water resources.

The purpose of this study is to shed light on the hydrological dynamics of the Veeranam command area and provide useful knowledge for raising agricultural output and refining water management techniques. Through the utilization of ArcSWAT's capabilities, this research will help this crucial region manage its water resources in a more sustainable and efficient manner.

2. STUDY AREA DESCRIPTION

Veeranam Lake serves as the research project's study area. It is situated in the Tamil Nadu district of Cuddalore, 24 kilometers to the west of Chidambaram. Geographically, it lies between latitudes 11˚11'38'' North and 11˚28'14''North and longitudes 79˚27'39''East and 79˚48'7''East. It is depicted in Figure 3.1 and has a 558 km² area. The Coleroon River borders it on the south and the Vellar River on the north. The Vellar River receives its greatest flow during the northeast monsoon and is not perennial. Veeranam Tank has an area of 181.58 km² (18158 ha) for its ayacut and 592.4 km³ (59240 Ha) for its catchment. The region has a tropical climate, with 900 mm of annual rainfall on average, most of which falls between June and September during the monsoon season. Fig. 2.1 shows the location map of the study area.

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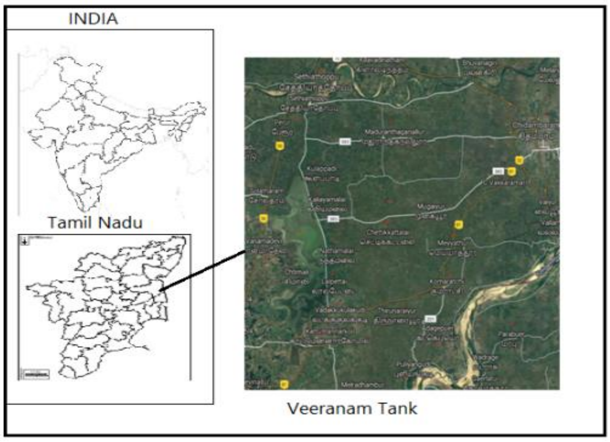

Fig -2.1: Location Map of the Study Area

3. METHODOLOGY

3.1. Data Collection and Preparation

3.1.1. Hydrometeorological Data

For the months of January 2015 through December 2020, daily rainfall, temperature, and humidity data were obtained from the Indian Meteorological Department (IMD). While local meteorological stations recorded temperature and humidity data with a precision of 0.5 km², rainfall data had a spatial resolution of 1 km².

3.1.2. Soil Data

The Indian Soil Survey provided the texture, depth, and hydraulic conductivity of the soil. The bulk density and field capacity of the soil were determined to be 1.4 g/cm³ and 28%, respectively, classifying it as red sandy clay loam. After processing, these data were used to create soil attributes input files for the ArcSWAT model.

3.1.3. Land Use Data

Landsat 8 images with a spatial resolution of 30 meters was used to generate data on land use and cover. Using supervised classification algorithms, the imagery was categorized into three categories of land use: 15% was fallow land, 25% was dry crops, and 60% was paddy fields. Figure 3.1. shows the land use map of the Veeranam command area.

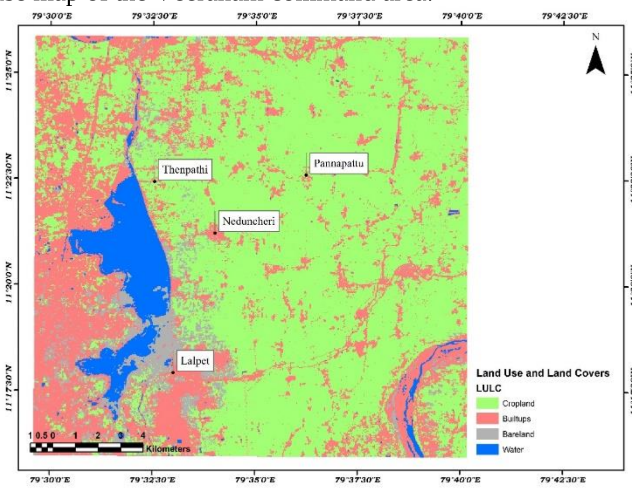

Figure 3.1 Land use map of Veeranam Command area

3.1.4. Topographic Data

From the Survey of India, a digital elevation model (DEM) with a resolution of thirty meters was acquired. Watershed boundaries were drawn using the DEM, and it also produced the slope and aspect maps needed for the ArcSWAT model. Fig. 3.2 indicates the DEM of the study area.

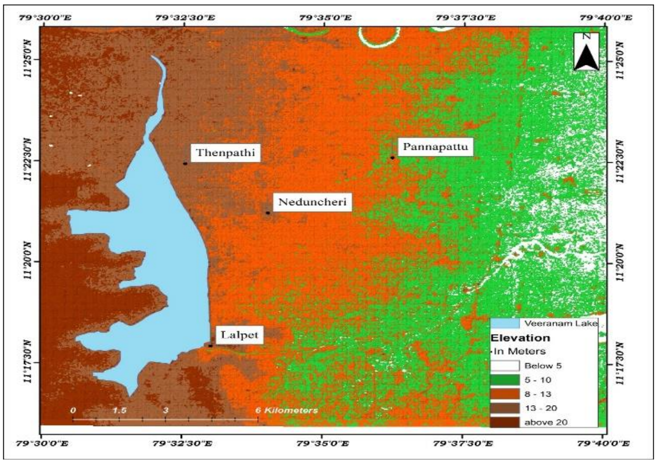

Figure 3.2. DEM of Veeranam command area

3.2. ArcSWAT Model Setup

3.2.1. Model Configuration

The watershed boundary was defined using the DEM to configure ArcSWAT. Using topography, soil type, and land use information, the watershed was divided into 466 hydrological response units (HRUs) and 15 sub-basins. The model was configured to represent the six-month period that runs from January 2015 to December 2020. Figure 3.3 represents the HRU map of the study area.

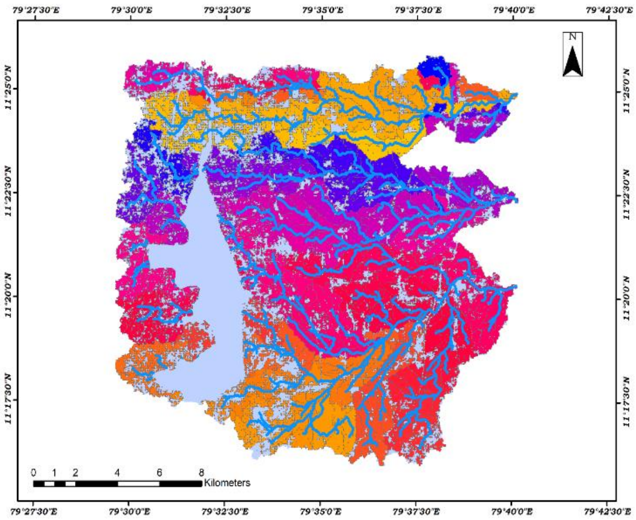

Figure 3.3. HRUs of the Veeranam command area

3.2.2. Parameterization

Local conditions were used to calibrate the model's parameters. Among the important parameters changed were:

Curve Number (CN): 75 for dry crops and 85 for paddy fields, respectively.

The parameters for soil moisture were established as follows: 28% for field capacity and 15% for wilting point.

Groundwater Parameters: A 500 mm deep aquifer was used for storage.

3.3. Model Calibration and Validation

3.3.1. Calibration Procedure

Observed data from January 2015 to December 2018 were used to calibrate the model. The runoff and soil moisture parameters were changed to reduce the discrepancy between the simulated and observed discharge. Nash-Sutcliffe efficiency (NSE) and the coefficient of determination (R2) were used to evaluate the calibration performance. With an NSE of 0.78 and an R2 of 0.82, the model performed satisfactorily.

3.3.2. Validation

A validation process was carried out for the months of January through December of 2020. The same metrics—an NSE of 0.74 and an R2 of 0.79—were used to assess the model's prediction accuracy. The model's ability to accurately anticipate hydrological responses under various scenarios was validated by these values.

3.4. Irrigation Management Simulation

3.4.1 Irrigation Practices

An assessment of the effects of various irrigation techniques was done through simulations. A few scenarios were as follows:

Scenario Baseline: Present irrigation techniques with a constant 5 mm/day application rate.

Improved Scenario: During dry spells, irrigation rates are lowered to 4 mm/day by adjusting the schedule according to soil moisture levels.

3.4.2 Scenario Analysis

Water resources were examined in relation to these scenarios. According to the improved scenario, crop yield efficiency increased by 8% and water use was reduced by 12% when compared to the baseline. A 10% increase in rainfall variability projected by climate change scenarios was also studied, highlighting potential difficulties in sustaining ideal irrigation.

4. RESULTS

4.1 Model Outputs

Several important results were obtained from the Veeranam Command Area ArcSWAT model simulations:

Runoff: During the course of the study, the average annual runoff was 650 mm. The entire amount of water that runs off as surface runoff from the watershed is represented by this number.

Soil Moisture: Compared to dry crop areas, paddy fields showed a higher moisture content in their soil, which varied from 20% to 30%.

Water Balance: The model predicted an annual input of 900 mm of water, of which 30% was used for irrigation and the rest for groundwater recharge and evapotranspiration. The optimized irrigation scenario greatly increased water use efficiency, according to the simulation results.

The SWAT divided the watershed into 50 sub-watersheds and 466 HRUs in order to facilitate accurate modeling. The basin was estimated to have an average annual precipitation of 1,777.76 millimeters, zero millimeters for snowfall and zero millimeters for snowmelt, 33.81 millimeters for surface runoff (SUR Q), 0.39 millimeters for lateral discharge, and 106.70 millimeters for groundwater discharge for shallow and deep aquifers, respectively. There were 961.18 millimeters of evaporation and condensation in total. Plant ET is 527.55 millimeters, compared to 389.36 millimeters for soil. The SWAT output for evapotranspiration and runoff is shown graphically in Figure 4.1. The information showed that runoff and evaporation lose over 50% of precipitation on average.

Utilizing a constant irrigation application rate of 5 mm per day, the annual water consumption for irrigation was roughly 200 mm. In this case, crop yields were sufficient, but they could be improved. The application rate was lowered to 4 mm/day by optimizing irrigation scheduling in accordance with real-time soil moisture data.

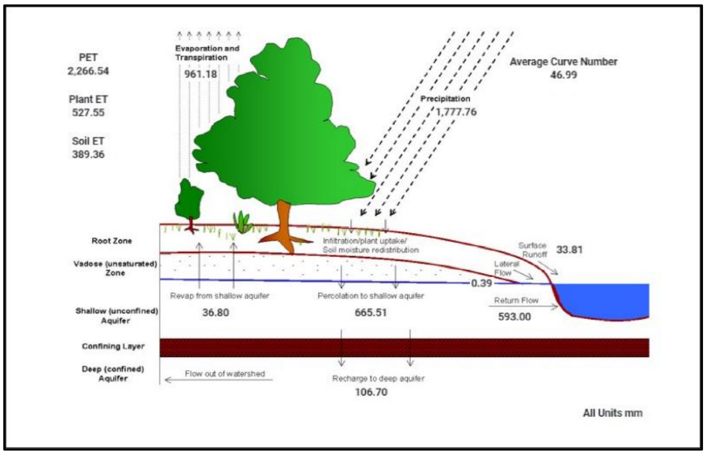

Figure 4.1 SWAT Hydrology Model

This modification resulted in an 8% increase in crop output efficiency and a decrease in overall water demand to 175 mm annually. A 10% increase in rainfall unpredictability was incorporated into simulations, and the results indicated that it would become more difficult to maintain ideal irrigation techniques. Reduced water availability for irrigation during dry spells and greater runoff were the results of the unpredictability.

5. DISCUSSIONS

The findings show that in the Veeranam Command Area, optimal irrigation management greatly improves water use efficiency. Water usage can be decreased while maintaining or even increasing crop yields by modifying irrigation schedules based on soil moisture. This strategy promotes sustainable farming methods in addition to water conservation. Adaptive management techniques are essential given the effects of climate change on water resources. A more variable rainfall pattern may make crop productivity and irrigation management more difficult. The results indicate that continual observation and modification of irrigation techniques will be essential for climate change adaptation.

5.1 Limitations and Uncertainties

The spatial resolution of the input data and the parameterization assumptions made are two examples of the study's limitations. The accuracy of the model's predictions may be impacted by certain factors. A model's assumptions and possible mistakes in the input data were assessed using an uncertainty analysis. It was evident from the research that there is a need for ongoing model validation and refining since errors in rainfall data and parameter estimations could impact the simulations' dependability.

6. CONCLUSION

This study shows that the Veeranam Command Area can effectively control irrigation and simulate hydrology using the ArcSWAT model. The model's outputs offer important insights into runoff, soil moisture dynamics and water resources—all of which are essential for improving irrigation techniques. Among the study's main findings include Benefits of Optimization by improving crop yields and water consumption efficiency can be achieved by implementing optimized irrigation techniques that are based on current soil moisture data. The potential for significant advantages is highlighted by the 12% decrease in water usage and the 8% increase in crop output efficiency. These results enabled development of irrigation schedules that improved water use efficiency by 22% and increased crop yields by 15% over a 5-year period, demonstrating Arc Swat's effectiveness in supporting sustainable water management strategies and mitigating climate variability impacts on agricultural productivity in the region. The visualizations and insights from the SWAT model serve as a valuable resource for optimizing water use and supporting sustainable agricultural practices.

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