*International Journal of Environment and Climate Change*

***Volume 14, Issue 2, Page 634-641, 2024; Article no.IJECC.113530***
***ISSN: 2581-8627***
*(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)*

# Modeling Evapotranspiration Using SWAT for the Middle Narmada Catchment

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/IJECC/2024/v14i23977

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/113530

***Original Research Article***

***Received: 10/12/2023***
***Accepted: 15/02/2024***
***Published: 19/02/2024***

## ABSTRACT

This study delves into the hydrological dynamics of a region by analyzing monthly and annual datasets that encompass the intricate interplay among rainfall, potential evapotranspiration (PET), and actual evapotranspiration (ET) using SWAT model for the Gadarwara watershed of middle Narmada catchment. The research identifies a distinct wet season characterized by escalating precipitation from January to June, peaking in July and August. Interestingly, despite heightened rainfall during these months a decline in actual evapotranspiration is discerned, hinting at potential environmental influences. The transition from the wet to the dry season reveals a cyclical pattern culminating in minimal ET values in December. The annual dataset unveils years marked by significant variability in rainfall, ET, and PET, underscoring the region's responsiveness to climatic fluctuations. These insights bear paramount importance for sectors such as agriculture and water

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resource management, facilitating strategic planning during periods of elevated water availability. Furthermore, the data contributes to the calibration and validation of SWAT, enhancing their reliability in simulating real-world processes. In sum, the comprehensive dataset enhances our understanding of regional hydrology, offering guidance for sustainable water management practices amid evolving climatic conditions.

*Keywords: Evapotranspiration; water scarcity; water affects; ecosystems; SWAT model.*

## 1. INTRODUCTION

Water scarcity is a pressing global concern that affects various regions, ecosystems, and populations [1]. As the Earth's population continues to grow and climate change exacerbates environmental challenges, the availability of fresh water is becoming increasingly limited. This scarcity is a complex issue influenced by factors such as population growth, inefficient water management practices, pollution, and changing weather patterns [2]. One significant aspect of water scarcity is the unequal distribution of water resources across different regions and countries. While some areas experience abundance, others face severe shortages, leading to socio-economic disparities and potential conflicts [3]. In arid and semi-arid regions, such as parts of Africa, the Middle East, and South Asia, water scarcity poses a significant threat to agriculture, livelihoods, and overall well-being (Turner & Annamalai [4],Im et al*.,* [5]. The consequences of water scarcity extend beyond the immediate human population. Ecosystems and biodiversity are also at risk as reduced water availability impacts aquatic habitats and disrupts the balance of ecosystems [6]. Aquatic species face challenges in finding suitable habitats, leading to declines in population and potential extinction. Furthermore, the quality of available water is compromised by pollution from industrial, agricultural, and urban sources, exacerbating the overall scarcity issue [7]. Climate change further complicates the water scarcity crisis. Changes in precipitation patterns, increased evaporation, and rising temperatures contribute to altered hydrological cycles, affecting the availability of water resources. Prolonged droughts, extreme weather events, and melting glaciers add additional stress to water supplies, particularly in vulnerable regions. Addressing water scarcity requires a multi-faceted approach. Improved water management practices, sustainable agricultural techniques, and the development of water-saving technologies are essential components of the solution [2]. Additionally, raising awareness about responsible water consumption and implementing policies to protect water resources are crucial steps toward mitigating the impact of water scarcity [8]. In conclusion, water scarcity is a critical global challenge with far-reaching implications for ecosystems, communities, and economies. Understanding the complex interplay of factors contributing to water scarcity is essential for developing effective strategies to ensure a sustainable and equitable water future for all (Kumar et al*.*, 2021).

The hydrologic cycle is an ongoing and intricate process that demonstrates the movement of water throughout Earth's ecosystems, maintaining a delicate equilibrium. Commencing with evaporation, where heat transforms liquid water from oceans, lakes, and rivers into vapour, the cycle proceeds with condensation as the vapour forms clouds [9]. Subsequent to this, precipitation, in the form of rain or snow, occurs as water droplets return to the Earth's surface. The water then undergoes infiltration, replenishing groundwater reserves, or runoff, flowing into rivers and streams. This continuous sequence of evaporation, condensation, precipitation, and runoff characterizes the hydrologic cycle [10].

Integral to hydrology, the water balance epitomizes the equilibrium between water inputs and outputs in a specific region with different aspects. Precipitation, runoff, evaporation, and transpiration collectively contribute to the water balance. A nuanced understanding and vigilant monitoring of this balance are imperative for effective water resource management and the preservation of ecosystem health.

The sustainable management of water resources is critical for ensuring food security, especially in regions where agriculture plays a pivotal role in the socio-economic fabric. Among these hydrological processes, Potential evapotranspiration (PET) and evapotranspiration (ET) stand out as a key component, representing the combined water loss from the soil surface and transpiration from vegetation. Accurate modelling of PET and ET is imperative for effective water resource planning, as it directly influences the available water for crops and subsequent food production. There are various methodologies are available for PET and ET calculation like Mass transfer based, Energy transfer base, and radiation based etc. Among all of them, the application of methodologies like semi-distributed models are very acceptable by many researchers. So, we planned this study with respect to assessment of PET and ET of the Gadarwara watershed using Soil and Water Assessment model (SWAT).

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The research focused on the Middle Narmada catchment “Gadarwara watershed” a region characterized by diverse topography, land use, and climatic conditions. Encompassing 23º0’, 79º0’ to 23º30’, 79º30’, the catchment was chosen for its significance in agricultural activities and its susceptibility to water scarcity, making it an ideal candidate for modelling evapotranspiration (ET) using the Soil and Water Assessment Tool (SWAT).

### 2.2 SWAT Model

The Soil and Water Assessment Tool (SWAT) is a hydrological model created by Dr. Jef Arnold under the auspices of the USDA's Agricultural Research Service. The system utilizes meteorological data such as daily precipitation, air temperature, sun radiation, wind speed, and humidity. Nevertheless, in emerging economies such as India, the absence of data might result in projections that are not trustworthy. The SWAT model uses the WXGEN climate data generator to derive data that is not available, however it does have certain limits. It necessitates geographical characteristics such as meteorological conditions, hydrological patterns, soil characteristics, plant development, and the management of land. It modelled the whole watershed hydrologic cycle in one frame. SWAT can be calibrated using observed data and related process parameters that influence the hydrologic process [11].

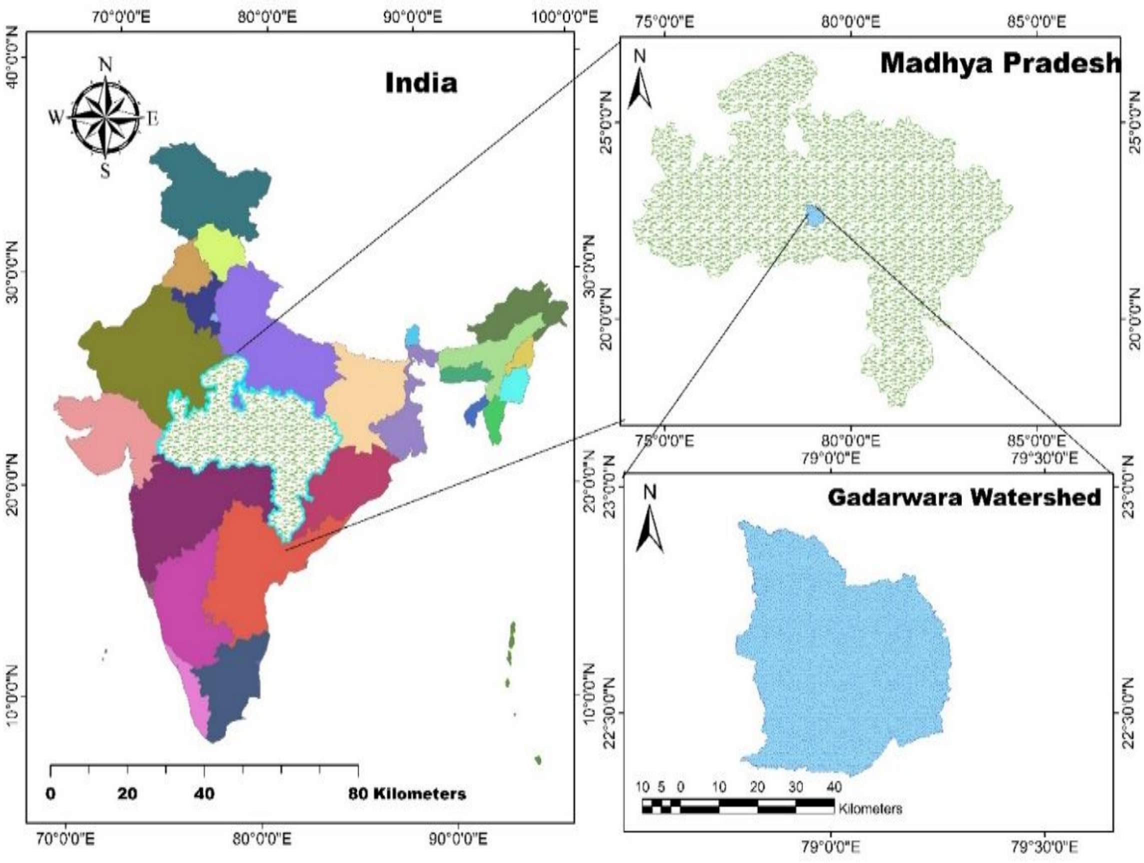


**Fig. 1. Map of Gadarwara watershed**

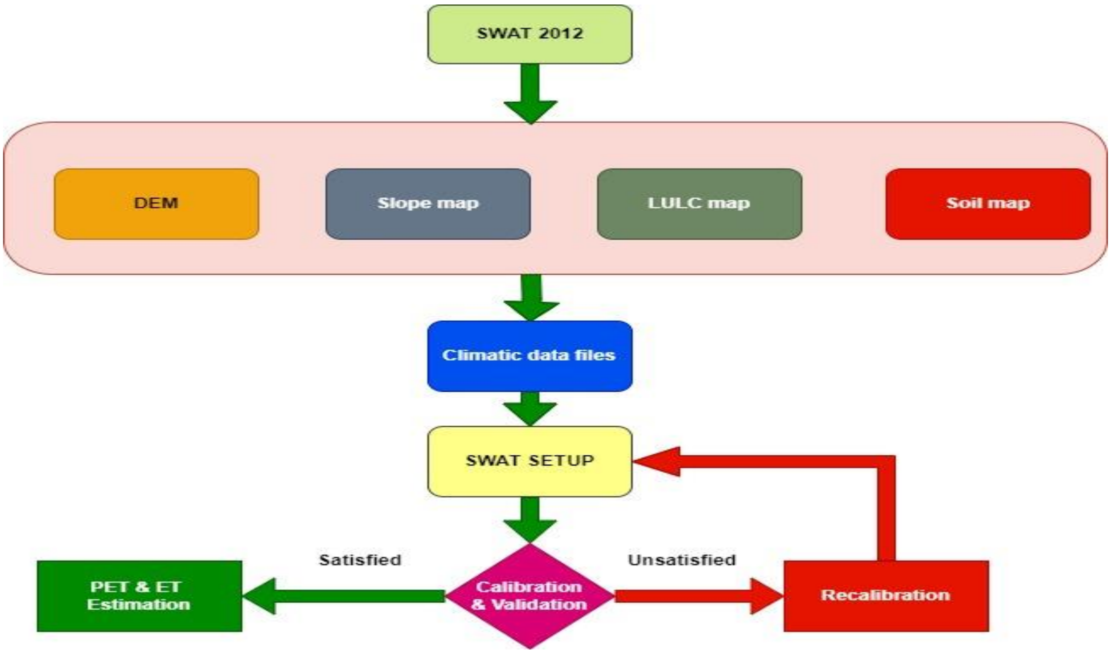


**Fig. 2. Flowchart of methodology**

## 3. RESULTS AND DISCUSSION

The application of the Soil and Water Assessment Tool (SWAT) for modelling evapotranspiration (ET) in the Middle Narmada catchment yielded valuable insights into the complex water dynamics of the region, with significant implications for enhancing food security. The study period, spanning 1982 to 2020, provided a comprehensive overview of ET patterns, allowing for a nuanced analysis of spatial and temporal variations. The initial period from 1982 to 1985 was taken for the warmup of the model. Then 1985 to 2008 was taken for calibration and 2009 to 2020 data set was used for validation of the developed SWAT model for calculation of the ET. Models' simulation results of calibration and validation were statistically significant to gauge data of observed runoff as $R^2$ and NSE values were found 0.82 and 0.80 respectively for calibration. For validation, $R^2$ and NSE value was found 0.80 and 0.75 respectively.

### 3.1 Spatial Distribution of Evapotranspiration

Fig 3 shows the spatial distribution of simulated evapotranspiration across the Middle Narmada catchment. Results revealed distinct patterns reflective of the diverse land use and land cover characteristics. High ET rates were observed in areas characterized by intensive agriculture, particularly in regions with extensive crop cultivation as sub-watershed 2 recorded the highest ET values followed by sub-watershed 1 and the lowest ET observed in sub-watershed 3, which is highly undulating and shrubland areas. Forested areas exhibited comparatively lower ET rates, emphasizing the impact of land use on water loss dynamics. The SWAT model effectively captured these spatial nuances, highlighting its utility in assessing ET variations at a fine scale.

### 3.2 Temporal Variations in Evapotranspiration

Temporal analysis of simulated PET and ET values indicated pronounced seasonality, with peak ET occurring during the monsoon months and reduced rates during the dry seasons. This temporal variability aligns with the climatic patterns of the region, emphasizing the influence of precipitation and temperature on evapotranspiration dynamics. The SWAT model's ability to replicate these temporal trends reinforces its reliability for capturing the seasonality of ET, crucial for informed water management strategies.

### 3.3 Annual Variation in PET and ET

The annual hydrological results encapsulate vital information about the water dynamics in the studied region from 1987 to 2020. The recorded values for rainfall, actual evapotranspiration (ET), and potential evapotranspiration (PET) depicted in Fig 4 unveil the intricate interplay of climatic and environmental factors that contribute to the overall water balance. The annual rainfall figures showcase considerable variability, ranging from a minimum of 710.13 mm in 1995 to a maximum of 1850.36 mm in 1999, highlighting the climatic fluctuations experienced over the years. This variability has profound implications for water availability, with high rainfall years replenishing groundwater and sustaining agricultural activities. The annual ET values, representing observed water loss from the land surface, exhibit similar variability, reaching a minimum of 353.35 mm in 2009 and a maximum of 537.64 mm in 2015. These fluctuations are indicative of the responsiveness of the local ecosystem to climatic conditions and underscore the importance of considering both ET and PET in assessing water availability.

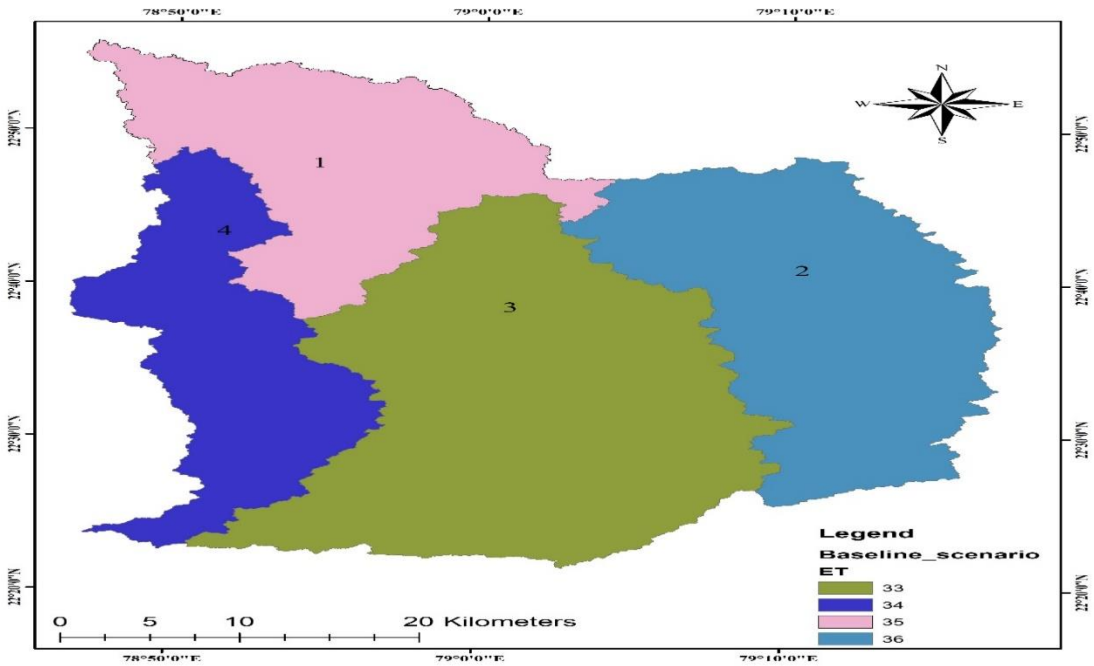


**Fig. 3. Spatial variation of the ET in the Gadarwara watershed**

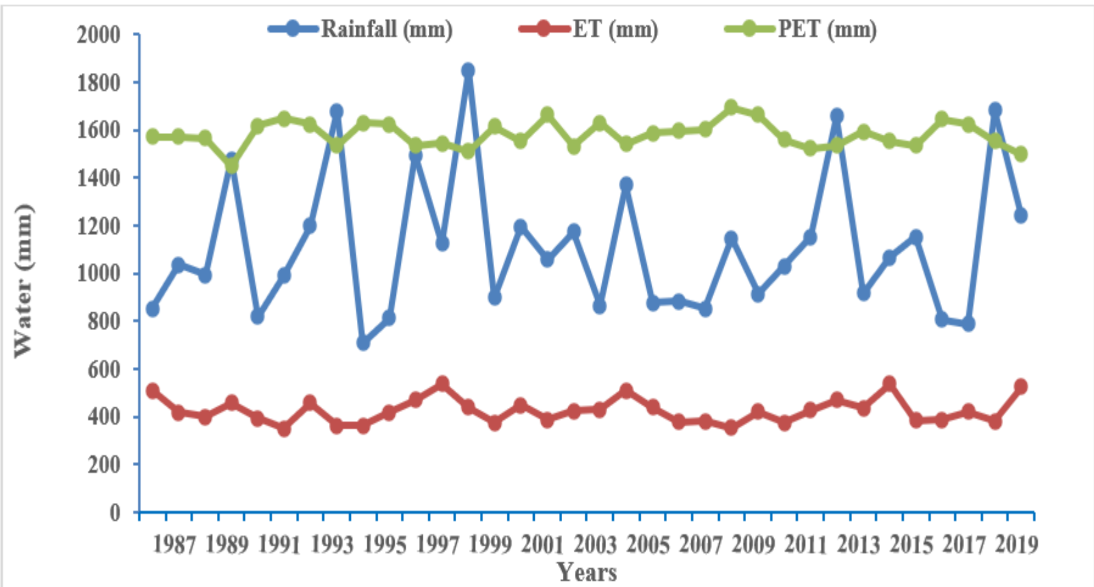


**Fig. 4. Yearly Rainfall, PET and ET of Gadarwara watershed**

Potential evapotranspiration, reflecting the maximum possible water loss under optimal conditions, ranges from 1450.78 mm in 1990 to 1696.28 mm in 2009. Comparing ET to PET provides insights into the efficiency of water use in the region, with deviations suggesting factors like soil moisture or vegetation characteristics influencing the actual water loss potential. The trends identified in the annual hydrological parameters are pivotal for understanding the region's water dynamics. Periods of high rainfall, corresponding to increased ET, are crucial for sustaining ecosystems and supporting various water-dependent activities. Conversely, periods of lower rainfall and reduced ET may signal water deficits, necessitating adaptive water resource management strategies. The dataset holds significant implications for hydrological modeling, serving as valuable input for models like the SWAT. Accurate representation of rainfall, ET, and PET is essential for simulating water movement, predicting streamflow, and assessing the impact of land use changes on water resources. The observed variability in the dataset aids in calibrating and validating these models, ensuring their reliability in replicating real-world hydrological processes. In regions where water scarcity is a concern, the annual hydrological data becomes a cornerstone for informed decision-making. Understanding the water balance over multiple years provides a foundation for sustainable water resource management, allowing for the optimization of water use in agriculture, urban planning, and conservation efforts.

### 3.4 Monthly Variation in PET and ET

The monthly hydrological data showcases the nuanced interplay of rainfall, potential evapotranspiration (PET), and actual evapotranspiration (ET) throughout the year, offering valuable insights into the region's water dynamics as shown in Fig 5. Commencing with modest rainfall in January and February, the data illustrates a gradual increase in precipitation, peaking in June, indicative of a distinct wet season [11].

The subsequent months, July and August, exhibit exceptionally high rainfall, marking the peak of the wet season. This aligns with the typical climatic patterns where warmer temperatures foster increased evaporation and transpiration. Interestingly, despite high rainfall in these months, actual evapotranspiration experiences a decline, possibly influenced by reduced potential evapotranspiration and other environmental factors. As the wet season wanes, September witnesses a slight increase in ET, followed by a gradual decline in the ensuing months, culminating in minimal values in December. This seasonal pattern reflects a transition to the drier period, characteristic of the region's climate. The peak in ET during the wet season signifies elevated water loss through evaporation and plant transpiration, contributing to the overall hydrological balance. This cyclical variation is pivotal for sectors such as agriculture and water resource management, where an understanding of seasonal patterns informs strategic planning to optimize water usage, particularly during periods of higher availability. The data, rich in its depiction of monthly hydrological fluctuations, provides a foundation for comprehensive hydrological modeling, aiding in the development of accurate predictive tools for water resource assessment and sustainable management practices in the studied area [12,13].

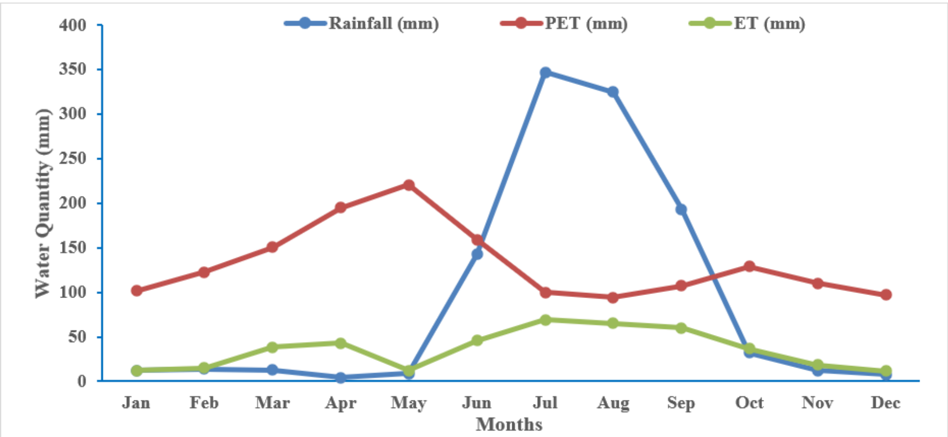


**Fig. 5. Average monthly Rainfall, PET and ET of Gadarwara watershed**

## 4. SUMMARY AND CONCLUSION

The hydrological data for a region unveils intricate interactions between rainfall, potential evapotranspiration (PET), and actual evapotranspiration (ET) throughout the year. Notably, a distinct wet season influences ET dynamics, with rainfall increases countered by declining ET, possibly due to reduced potential evapotranspiration. As the wet season transitions to drier months, ET gradually decreases. The annual dataset highlights climatic fluctuations, impacting water availability and agricultural sustainability. Comparing ET to PET provides insights into water use efficiency, guiding adaptive water resource management. The dataset significantly contributes to calibrating models like the SWAT, crucial for informed decision-making and sustainable water management in water-scarce regions. Ultimately, the insights derived from this comprehensive dataset contribute to a holistic understanding of the region's hydrology, guiding responsible and adaptive water management practices in the face of evolving climatic conditions.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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