International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 12 Issue: 03 | Mar 2025 www.irjet.net p-ISSN: 2395-0072

Assessment of Future Water Demand and Surface Water Balance Using WEAP Model in Muvattupuzha River Basin

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Abstract - *Water resource management is crucial as population growth, land-use changes, and climate variability increase pressure on water availability. This study assesses future water demand and surface water balance in the Muvattupuzha River Basin using GIS-based land classification and the WEAP (Water Evaluation and Planning) model. The results indicate a significant rise in water demand by 2050, with agricultural expansion and urbanization being key drivers. The findings highlight the necessity for sustainable water allocation strategies and conservation techniques.*

Key Words: **WEAP Model, GIS, Water Demand, Climate Change, Water Balance**

1.INTRODUCTION

Water scarcity is a critical global issue as only 2.5% of Earth's water is freshwater. The Muvattupuzha River Basin is a lifeline for the region, supporting agriculture, industrial activity, and urban settlements. However, rising demand coupled with climate-induced variability poses severe challenges. This study employs the WEAP model to forecast water demand and assess the surface water balance for the basin from 2022 to 2050. The objectives are to (i) analyze historical trends, (ii) simulate future water scenarios, and (iii) propose strategies to ensure sustainable water management.

2. LITERATURE REVIEW

Urbanization & Water Demand: Studies predict that by 2050, over 2 billion people will experience urban water shortages.

WEAP Model Applications: Used in India, South Africa, and Iraq for predicting water balance and demand.

Climate Change & Water Scarcity: Rising temperatures affect rainfall patterns and river flow, altering water resource sustainability.

3. STUDY AREA AND DATA COLLECTION

3.1 Study Area

The Muvattupuzha River Basin spans approximately 1,272 sq. km in Kerala, India, with elevation ranging from 0 to 1500 meters. Its diverse landscape includes fertile agricultural plains, forested highlands, urban centers, and wetlands. The river serves as the primary source of water for domestic, industrial, and irrigation needs.

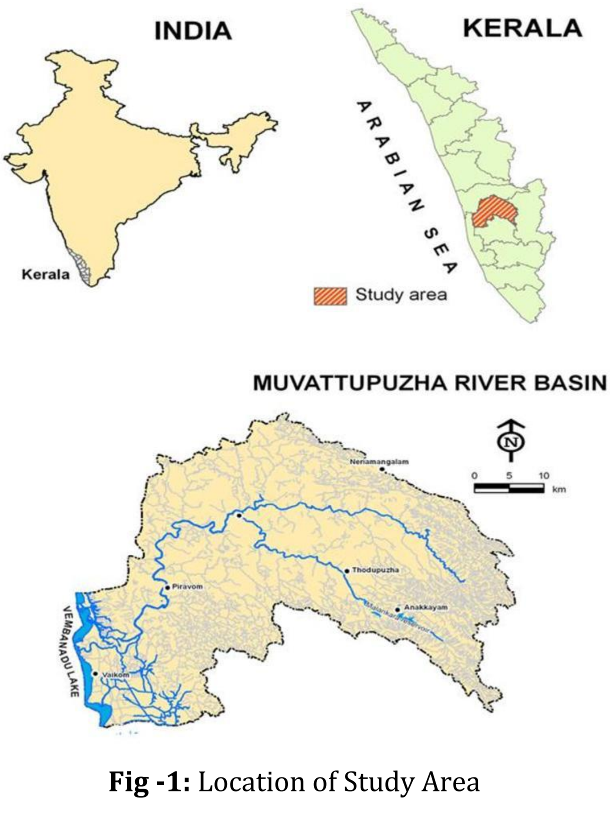

Fig -1: Location of Study Area

3.2 Data Collection

Data were collected from multiple reliable sources:

Elevation Data: Obtained from WEAP Model.

Land Use: Derived from WEAP Model.

Hydro-climatic Data: Rainfall, evaporation, and river discharge records from the IDRB (2010–2022).

Population Data: Sourced from the 2011 Census and projected to 2050.

Water Use Data: Collected from Kerala Water Authority and Kerala Irrigation Department.

Table -1: Sources of Data Collection

Data Type	Source	Purpose
Elevation Data (DEM)	WEAP Model	Classify land by elevation zones
Land Use	WEAP Model	Identify agriculture, urban, forest, and wetlands
Climate Data	IDRB	Record rainfall, evaporation, temperature
Population Data	Census 2011	Estimate water demand

4. METHODOLOGY

4.1 GIS-Based Land Use Classification

Using ArcGIS and QGIS, land use data were overlaid with Digital Elevation Models (DEM) to classify the basin into three elevation zones:

0–500m: Predominantly agricultural with significant urban settlements.

500–1000m: Moderate agricultural and forest cover.

1000–1500m: Limited agriculture with sparse vegetation.

4.2 WEAP Setup and Scenario Development

The WEAP model was configured to simulate current and future water demand. Four scenarios were developed:

Table -2: WEAP Scenario Development

Scenario	Description	Growth Rate (%)	Impact on Water Demand
Base Case	Current trends, stable agriculture	2.2%	Moderate increase
High Population Growth	Urban expansion & migration	5%	Significant rise
Agricultural Expansion	More irrigation demand	1%	Higher water use
Industrial Growth	Expansion of industries	1.75%	Increased industrial demand

4.3 Data Input and Model Calibration

Historical hydrological data (2010–2022) were used to calibrate the model. Calibration involved adjusting parameters (e.g., infiltration, evapotranspiration) to achieve a high R-squared value (0.9944), indicating that the simulated data closely matched observed records.

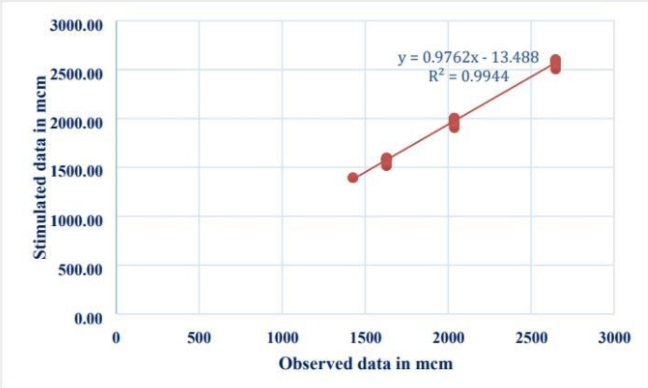

Fig -2: comparison between observed and stimulated data

5. RESULTS AND DISCUSSION

5.1 Land Use Distribution by Elevation

Table -3: Land Use Distribution by Elevation

Elevation (m)	Agriculture (ha)	Forest (ha)	Urban (ha)	Total (ha)
0 – 500m	65,171	47,929	3,648	126,116
500 – 1000m	1,822	3,083	0	4,986
1000 – 1500m	461	193	0	654

Agriculture is dominant at lower elevations, while forests decline with elevation.

Urbanization is highest in lowlands, increasing water demand.

5.2 Water Balance Analysis

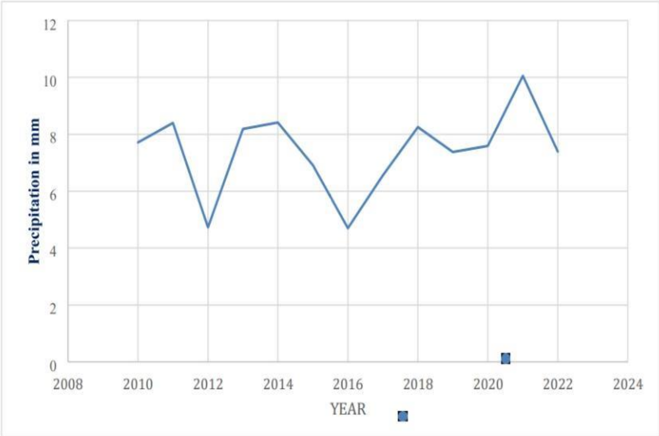

Fig -3: Annual Rainfall Trends in Muvattupuzha River Basin (2010-2022)

The annual rainfall trends from 2010 to 2022 show significant seasonal variations in the Muvattupuzha River Basin. The monsoon months (June to September) contribute the highest rainfall, leading to increased river recharge and surface runoff. Conversely, the dry months (January to April) experience a substantial decline in precipitation, resulting in reduced streamflow and lower water availability. The variability in rainfall patterns highlights the importance of efficient water storage and management strategies to mitigate seasonal shortages.

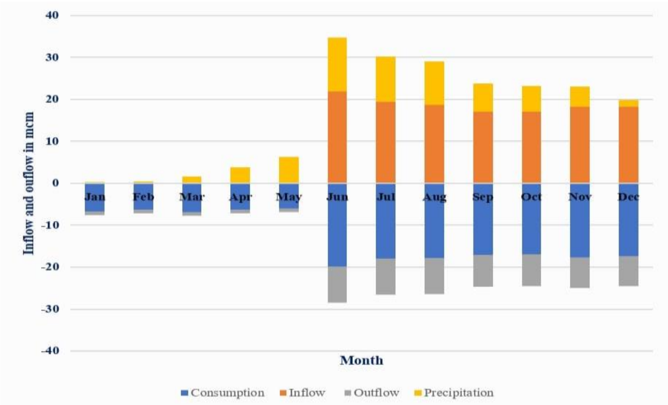

Fig -4: Monthly Variation of Rainfall and River Flow in Muvattupuzha River Basin

The monthly distribution of rainfall and river flow reveals distinct seasonal fluctuations, with the highest inflows recorded during the monsoon period (June-September). This period contributes the majority of the annual discharge, replenishing surface and groundwater resources. In contrast, the pre-monsoon and post-monsoon months (January-April) experience significantly lower precipitation, causing a decline in river flow and increased dependency on stored water. These findings emphasize the need for sustainable water management practices, particularly in dry months, to ensure a stable water supply throughout the year.

5.3 Scenario-Based Water Demand Projections

5.3.1 Population Growth Scenario

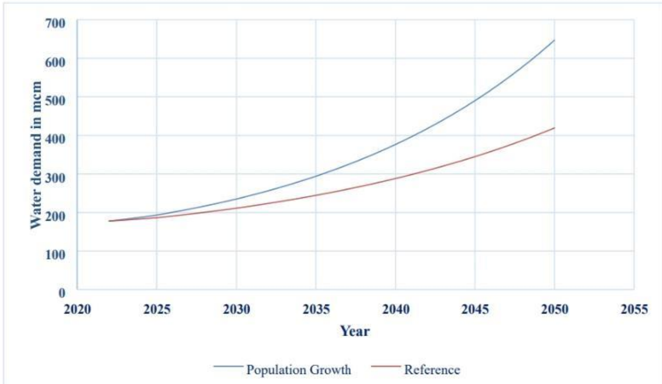

Fig -5: Water Demand Under Population Growth Scenario

The population growth rate is assumed to increase from 2.2 to 5 due to rapid-fire urbanization. As population expands, domestic water demand rises significantly from 108.6 MCM in 2022 to 4938.4 MCM by 2050. This sharp increase in demand puts stress on available water coffers, leading to implicit dearths.

Recrimination without structure expansion(e.g., budgets, water conservation programs), severe water failure is anticipated.

5.3.2 Agricultural Expansion Scenario

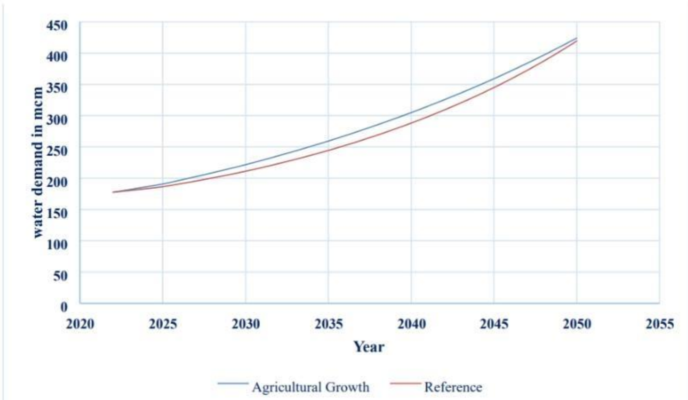

Fig -6: Water Demand Under Agricultural Expansion Scenario

The irrigation water requirement increases annually by 1% due to expansion of cultivated land.As a result, water demand rises from 177.6 MCM in 2022 to 8097.9 MCM in 2050.The agricultural sector is the largest water consumer, and increasing cultivated area intensifies pressure on water resources.

Implication: Improving irrigation efficiency (e.g., drip/sprinkler irrigation) is necessary to reduce excessive water consumption.

5.3.3 Industrial Growth Scenario

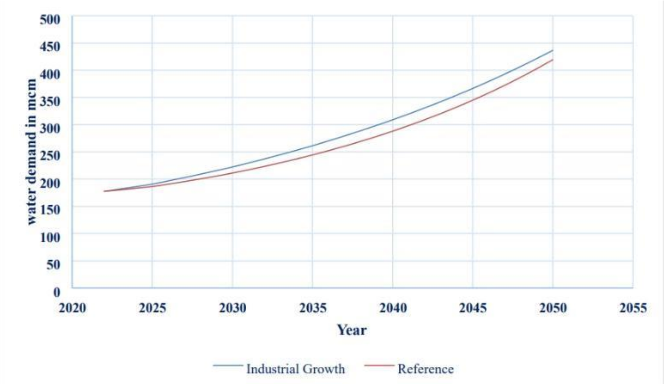

Fig -7: Water Demand Under Industrial Growth Scenario

The industrial growth rate is projected to increase from 1.5% to 1.75% annually, driving up water demand in industrial sectors.

As industries expand, water demand will rise by approximately 15% over the next 20 years.

The industrial sector contributes significantly to water pollution, requiring better wastewater management to prevent environmental degradation.

Implication: Sustainable industrial policies, water recycling, and pollution control measures are necessary to balance economic growth with water sustainability.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The WEAP model simulations reveal a significant rise in water demand across the Muvattupuzha River Basin by 2050, primarily driven by rapid urbanization, expanding agricultural activities, and increasing industrial growth. As population growth accelerates, the demand for domestic, agricultural, and industrial water supply is expected to outpace available resources. Additionally, seasonal fluctuations in rainfall further intensify the challenges of maintaining a stable water balance, with monsoon seasons replenishing water sources and dry months causing severe shortages.

The scenario analysis highlights that if current trends continue, the region will experience critical water deficits, negatively impacting food security, industrial output, and urban sustainability. Without strategic interventions, over-extraction of surface and groundwater resources could lead to aquifer depletion, reduced river flow, and ecosystem degradation. Therefore, integrated water resource management strategies must be prioritized to ensure long-term sustainability, equitable distribution, and climate resilience.

6.2 Recommendations

Based on the findings, the following water management strategies are recommended to mitigate the predicted demand surge and enhance water security in the basin:

1. Adopt Efficient Irrigation Techniques

Implement drip and sprinkler irrigation systems to minimize water wastage and enhance efficiency in agricultural practices.

Promote precision agriculture and smart irrigation technology to optimize water use based on real-time soil moisture levels.

2. Enhance Rainwater Harvesting & Groundwater Recharge

Construct rainwater harvesting structures in urban and rural areas to capture excess rainfall during monsoon months.

Promote check dams, percolation tanks, and artificial recharge wells to replenish groundwater reserves and improve aquifer sustainability.

3. Strengthen Urban Water Conservation Policies

Implement water-saving regulations in residential, commercial, and industrial sectors, including efficient plumbing fixtures and water reuse systems.

Promote wastewater treatment and recycling in industrial zones to reduce freshwater dependency.

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