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Uncertainties In Climate Change And Human Intervention Affecting Water Resources: A Study Of Kallada River Basin In The State Of Kerala, India

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Abstract: *In the 21st century, changing climatic conditions and extensive human activities have become a significant concern. These are associated with multiple uncertainties and have influenced the global water cycle. A lot of existing research is available on the impact of climate change on water resources in developed regions. However, only a few studies have examined the uncertainties of human activities affecting water resources. Thus, this research has yet to receive considerable attention on the impact of climate change and human activities on water resources, particularly in developing countries like India. Therefore, the study aims to analyze the uncertainties in climate change and human intervention affecting water resources. In this study, rainfall, reservoir levels, river discharge, and land use changes in the Kallada River basin from 2000 to 2020 are analyzed by rainfall, reservoir, river discharge, and land use data. The study shows that the years with high discharge, such as 2013, 2016, and 2018, correspond to years of heavy rainfall and reservoir releases, which increase downstream flow and heightened flood risks. Furthermore, human activities influence all aspects of water resources, particularly reduced soil absorption, which exacerbates flood risks during heavy rainfall.*
Keywords: *Climate Change, Human Activities, Water Resources, Land Use, and Kallada River Basin.*

1. INTRODUCTION

Water is one of the most significant natural resources, and it plays a major role in maintaining biodiversity, health, social welfare, and economic development. In India, rainfall distribution is highly non-uniform in terms of time and space. As a result, water must be stored and utilized to meet different sectors' demands throughout the year [1]. Climate change increases the lack of access to safe drinking water, sanitation and hygiene, and other water-related disasters, including scarcity and pollution. Today, every country on each continent is affected by climate change [2, 3]. Recently, documented activities contributing to climate change and human intervention can significantly challenge freshwater quantity or quality availability. Human actions further compound the issue of climate change, especially in nations already encountering water shortages [4, 5, and 6]. Thus, this leads to water shortages, environmental deterioration, and disorder between the economy and the environment, which seriously restricts the economic and social development of the region. Humans suffer from a lack of water and natural ecosystems in many river basins [7, 8]. Figure 1 depicts the impact of climate change and human intervention on water resources.

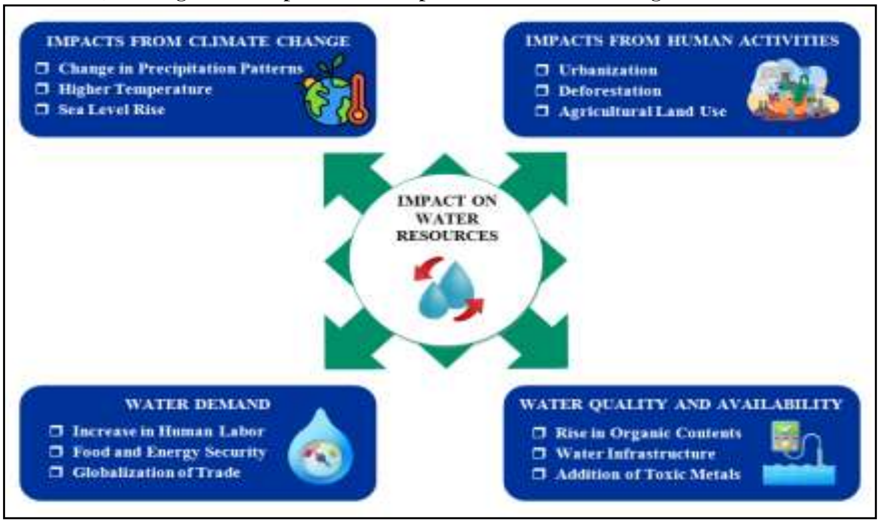

Figure 1: Uncertainties of climate change and human activities

The studies on climate change's impact on various aspects of water availability in India are very few and far between. The impact of climate change data and human intervention on river basin water resources is valuable and essential for managing water resources and facilitating regional development [9, 10]. Currently, it appears that no research has been conducted in the river basin in Kerala state related to the assessment of the impacts of climate change and human intervention. Therefore, this study addresses the research gap and investigates the impact of climate variability and human interventions on water resources in the Kallada River basin, Kerala, by analyzing long-term rainfall, reservoir levels, river discharge, and land use changes. It also proposes adaptive strategies for sustainable water resource management. The following objectives are,

- To analyze the variability of annual and seasonal rainfall patterns in the Kallada River basin from 2000 to 2020 and assess its impact on water availability, reservoir levels, and flood risks.
- To evaluate the long-term trends in reservoir water levels at the Kallada Reservoir and their correlation with rainfall variability, focusing on water storage capacity during high rainfall and drought.
- To examine river discharge patterns at the Punalur station and assess the influence of rainfall, reservoir releases, and land use changes on flood risks and water scarcity.
- To assess the impact of human interventions, such as deforestation, urbanization, and agricultural expansion, on runoff, water absorption, and flooding in the Kallada River basin.
- Adaptive water resource management strategies, including improved rainfall forecasting, dynamic reservoir management, and integrated land use planning, are proposed to mitigate the impacts of climate variability and human interventions in the Kallada River basin.

The draft of the article includes the following parts: Section 2 presents a related literature review; Section 3 provides the description of the data, study area, and the methods used for the analysis; Section 4 represents the result and discussion of the analysis, and lastly, Section 5 provides the conclusion along with possibilities for future work.

2. LITERATURE REVIEW

A. Loukas et al. [11] investigated the impact of climate change and human intervention in the Lake Karla Aquifer, Greece, for the simulation period 1960-2058. Under the transient conditions, the hydrological and groundwater models were combined. The findings of a study showed that climate changes did not primarily affect the natural aquifer of Lake Karla. At the same time, human exploitation was intense and required a direct reassessment of water resources management practices.

Kashish Sadhwani and T. I. Eldho [12] intended to analyze the effect of climate change on water balance components at the river basin scale in a humid tropical region. A study considered the Periyar River Basin (PRB) in Kerala, and the temperature data were considered from 1989 to 2019 using the SWAT hydrological model. The study showed that there was a significant increase in streamflow (>65%) and runoff (>40%) in the mid (2041–2070) and far (2071–2100) future under both the SSP scenarios, indicating a potential vulnerability to future floods.

Pechlivanidis I.G et al. [13] focused on investigating the assessment of the impacts of climate change on the water resources of the Luni region, India. From the Asian Precipitation, daily precipitation inputs from 1971 to 2005 were obtained. The study finding was analyzed using the CORDEX South Asia framework. The result revealed a -20 to +20% change in the long-term average precipitation and evapotranspiration by climate change. However, results were subjected to the available data driving the hydrological model, whereas longer lengths of discharge series were not considered in this study.

Rashid Mahmood et al. [14] studied the impacts of climate change on the Kunhar River basin's water resource in Pakistan. A study data was collected from the Pakistan Meteorological Department (PMD) from 1961 to 2000. Here, a Hydrological modelling system development model was used to stimulate streamflow in the basin. Due to the projected increase in high flow and decrease in low flow, the Kunhar basin would face more droughts and floods. The study only considered two meteorological stations. Thus, there might be a cause for a lower level of performance due to the scarcity of data.

Wang Yuejianet al. [15] examined the climate change and human activities consequences on water resources in the Ebinur lake basin, Northwest China. Meteorological data from the National Meteorological Information Center (NMIC) of the China Meteorological Administration was studied from 1961 to 2015. Next, the climate-sensitive method was utilized to characterize the total change in runoff. The results revealed a significant increase in temperature and precipitation from 1961 to 2015. However, numerous human activities severely affected runoff at the Jinghe station.

Qingling Baoet al. [16] focused on exploring the effects of human activities and climate variability on runoff changes in Lake Ebinur, China's catchment, from 1964 to 2017. Thus, a variable infiltration capacity model was utilized to quantify these effects. The study found that runoff depth decreased by

108.80 mm in the impact period compared to the reference period due to human activities. However, it was increased by 110.5mm due to climate variability.

M.D. Teweldebrihan and M.O. Dinka [17] identified the impact of climate change on the development of water resources. The study was conducted in the Dhidhess River Basin using the indicator of hydrologic modification programs. The findings of a study showed that the basin experienced a decrease in water level and river flow due to climate change. Additionally, the degree of flow alteration was found to be relatively low throughout most of the months.

3. DATA AND METHODOLOGY

This section outlines the data sources and analytical approaches used in this study to investigate the impact of climate variability and human interventions on water resources in the Kallada River basin. The study relies on long-term datasets, including rainfall, reservoir levels, and river discharge, to examine how these factors have influenced the basin's hydrological system. Additionally, land use changes and infrastructure development are considered to understand the effects of human activities on water management. The analysis focuses on identifying trends, anomalies, and correlations within the hydrological data, such as rainfall and discharge rates, and how they relate to water storage in the reservoir. It also evaluates land use changes and human interventions and their impact on the basin's water resources.

3.1 Data Collection

This study utilizes multiple datasets spanning two decades (2000–2020) to evaluate the impact of climate variability and human interventions on water resources in the Kallada River basin. The datasets include rainfall patterns, reservoir water levels, river discharge data, and land use information. Each dataset is collected from relevant agencies and scientific sources, comprehensively understanding the basin's hydrological changes and human impacts.

3.1.1 Rainfall Data

The rainfall data for the Kallada River basin are obtained from the Kulathupuzha station, covering the period from 2000 to 2020. The data consists of daily rainfall measurements recorded in millimeters at 08:30 AM. This dataset is crucial for analyzing annual and seasonal rainfall patterns, focusing on extreme weather events like heavy rainfall during the monsoon and drought conditions during the pre and post-monsoon periods.

3.1.2 Reservoir Data

The reservoir data for the Kallada Reservoir are collected from governmental hydrological agencies and span the years 2008 to 2020. The data include daily measurements of maximum and minimum water levels (in meters) and the corresponding storage volumes (in million cubic meters, Mm^3). This dataset is used to analyze the relationship between rainfall patterns and water storage capacity in the reservoir, particularly during years of extreme rainfall or drought.

3.1.3 River Discharge Data

River discharge data for this study are collected from the Punalur station downstream of the Kallada River. The dataset spans from 2000 to 2019 and includes daily measurements of the river's water level in meters and discharge rates in cubic meters per second (m^3/s). These records are crucial for understanding how river flow responds to changes in rainfall patterns, reservoir releases, and other factors. By analyzing discharge data, the study aims to identify periods of high flow that lead to flooding and low flow conditions that may indicate drought or water scarcity.

3.1.4 Land Use and Human Intervention Data

Data on land use changes and human interventions are obtained from government reports, satellite imagery, and other official records. These data cover changes in forest cover, urban development, and agricultural expansion between 2000 and 2020. This dataset is essential for analyzing how deforestation, urbanization, and changes in land use patterns have affected runoff, soil absorption, and water demand in the Kallada River basin.

3.2 Methodology

The methodology employed in this study is designed to analyze the impact of climate variability and human interventions on water resources in the Kallada River basin. This section outlines the approach used to process and analyze the rainfall, reservoir, river discharge data, and land use changes and evaluate their effects on water resource management.

3.2.1 Rainfall Data Analysis

The rainfall data are processed to examine trends and patterns over the study period. Daily rainfall data from the Kulathupuzha station are aggregated into monthly and yearly totals for 2000–2010, 2011–2018, and 2020. This aggregation allows for long-term trend analysis, identifying anomalies in precipitation patterns, such as significantly above or below-average rainfall years. Additionally, the data are segmented into seasonal periods (pre-monsoon, monsoon, and post-monsoon) to assess seasonal variability and its impact on water resources. Seasonal analysis is crucial in understanding water scarcity or surplus periods, particularly during the monsoon season. Deviations from long-term averages are identified to highlight extreme weather events, such as droughts or years of heavy rainfall.

3.2.2 Reservoir Data Analysis

The reservoir data, spanning the periods from 2000 to 2007, 2008 to 2018, and 2019 to 2020, are analyzed to evaluate water management's storage capacity and efficiency in the Kallada reservoir. A time series analysis of daily reservoir levels is conducted to visualize long-term trends in water storage. Key indicators, such as the maximum, minimum, and average reservoir levels, are calculated yearly to assess the reservoir's response to varying rainfall patterns. The reservoir data are correlated with rainfall data from the same periods to determine the direct impact of precipitation on water storage.

3.2.3 River Discharge Data Analysis

The river discharge data from the Punalur station, covering the period from 2000 to 2019, are analyzed to understand how changes in rainfall and reservoir levels influence downstream river flow. Hydrographs are generated from daily discharge data to visualize seasonal and yearly variations in river flow. These hydrographs are useful in identifying peak flow periods and assessing potential flood risks. By correlating the discharge data with rainfall and reservoir levels, the study aims to evaluate periods when flood risks are highest and document the frequency and magnitude of such events.

3.2.4 Land Use and Human Intervention Analysis

Human interventions, such as deforestation, agricultural expansion, urbanization, and reservoir management, are examined using secondary data sources, including government reports and satellite imagery. The study focuses on detecting major land use changes and mapping their effects on natural water flow, runoff patterns, and soil absorption capacity. Additionally, the role of infrastructure developments, particularly the construction and management of reservoirs and dams, is analyzed. The impact of these human interventions, including controlled dam releases and water storage management, is evaluated regarding flood mitigation and overall water resource management in the basin.

4. RESULTS AND DISCUSSION

This section presents the findings from the analysis of rainfall, reservoir levels, and river discharge and discusses their implications on water resource management in the Kallada River basin. The impact of climate variability and human intervention is highlighted, focusing on key patterns and extreme events over the two-decade study period.

4.1 Rainfall Variability and Trends

4.1.1 Annual Rainfall Trends

The annual rainfall trends in the Kulathupuzha region were analyzed from 2000 to 2020 to understand the variability and its impact on water resources in the Kallada River basin. The data were obtained from the Kulathupuzha station, which provided daily rainfall measurements, and were aggregated into annual totals. Table 1 presents the total annual rainfall recorded for each year from 2000 to 2020, along with significant observations and comments regarding drought, extreme rainfall, and average conditions. The trends indicated years of drought (e.g., 2001 and 2016) as well as years of heavy rainfall (e.g., 2002, 2018, and 2020), reflecting variability in precipitation, which had a direct impact on reservoir levels, river discharge, and overall water availability in the basin.

Table 1: Annual Rainfall Data (2000–2020)

Year	Total rainfall (mm)	Comments
2000	2414.5	Average Rainfall
2001	686	Drought year
2002	3054.7	High Rainfall
2003	2263.3	Average Rainfall
2004	4277.5	High Rainfall
2005	2901	Average Rainfall
2006	1994.5	Average Rainfall
2007	3492.4	High rainfall and flooding

2008	2081.7	Average Rainfall
2009	2948	Average Rainfall
2010	3450	High Rainfall
2011	3025.3	Average Rainfall
2012	2136	Average Rainfall
2013	2740	Below average
2014	3078.5	Average Rainfall
2015	2793	Average Rainfall
2016	1691.6	Drought year
2017	2345.2	Average Rainfall
2018	2504.4	Extreme rainfall and flood
2019	-	-
2020	3600	Heavy Rainfall

Figure 2 illustrates the annual rainfall trends for the same period, highlighting the years with extreme rainfall and those with drought conditions. The observed fluctuations in annual rainfall are critical for understanding the challenges faced by water resource management in the region, particularly in balancing water storage, mitigating floods, and addressing water scarcity during droughts.

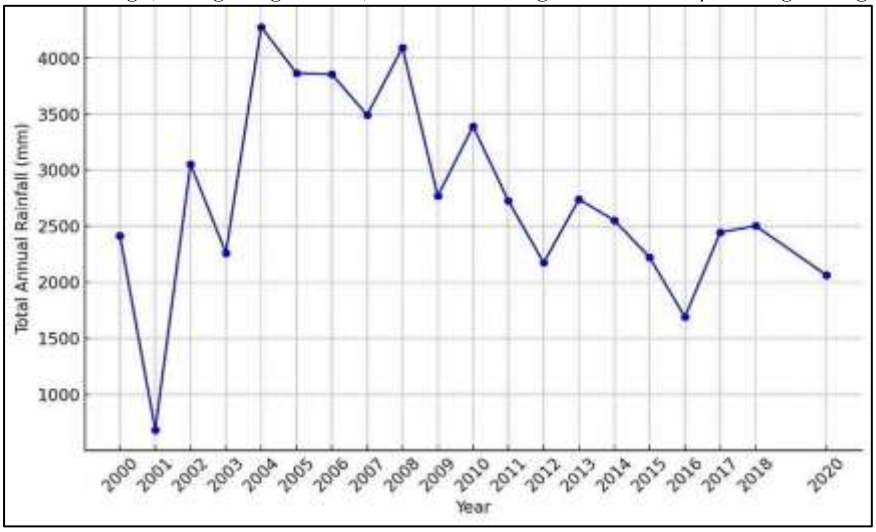

Figure 2: Annual Rainfall Trends in Kulathupuzha (2000-2020)

4.1.2 Seasonal Rainfall and Water Management

The seasonal rainfall data show that the monsoon (June–September) accounts for approximately 70–80% of the annual rainfall, which is crucial for water storage in reservoirs and groundwater recharge. In years with delayed monsoons or low pre-monsoon rainfall, such as 2016, the basin faced challenges maintaining adequate water levels in the Kallada reservoir.

4.2 Reservoir Water Levels

4.2.1 Long-term Reservoir Levels

Table 2: Kallada Reservoir Water Levels in Key Years (2008–2020)

Year	Max Reservoir Level (m)	Min Reservoir Level (m)	Avg Storage (Mm^3)	Max Storage (Mm^3)	Min Storage (Mm^3)
2008	114.79	113.38	470	490	440
2009	114.97	113.73	465	488	430
2010	115.32	114.43	467	489	432
2011	114.97	113.74	470	490	435
2012	114.38	112.55	471	493	438
2013	115.5	112.4	471	493	438
2014	115	112	465	488	432
2015	115	112	464	487	431

2016	114.8	112	460	484	430
2017	115.4	112.5	470	490	440
2018	116.5	113	475	495	445

Table 2 presents the Kallada reservoir water levels between 2008 and 2020, which show consistent annual fluctuations, with maximum levels ranging from 114.38 m in 2012 to 116.5 m in 2018, reflecting the impact of variable rainfall. In most years, minimum water levels remained close to 112 m, indicating a steady drawdown during dry periods. The average storage values also varied, with the highest in 2018 (475 Mm^3), corresponding to the year's extreme rainfall, while 2016 revealed lower average storage (460 Mm^3), reflecting drought conditions. Maximum storage exceeded 490 Mm^3 in wetter years, while minimum storage dropped to 430 Mm^3 during dry years, demonstrating the reservoir's role in balancing flood risks and water supply.

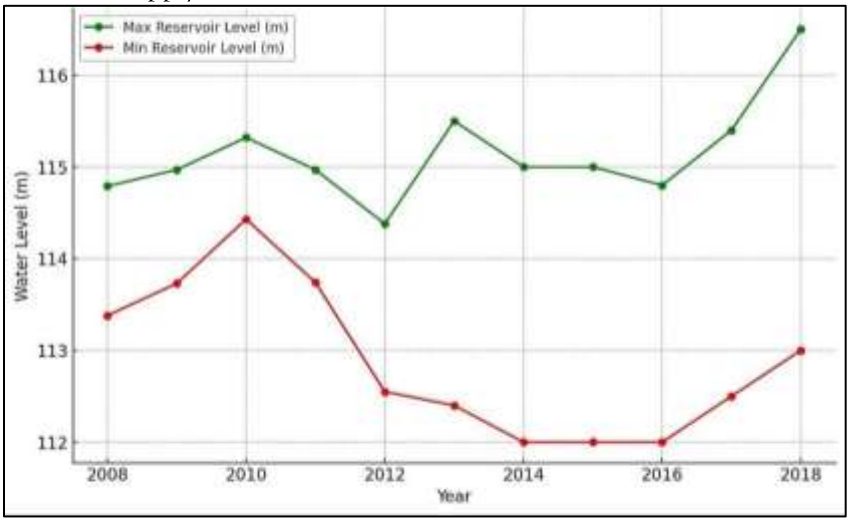

Figure 3: Kallada Reservoir Water Levels (2008–2020)

The analysis showed that the reservoir reached near-full capacity during high rainfall, posing overflow risks and necessitating controlled releases. Conversely, in drought years, the reservoir's levels dropped significantly, challenging water supply and storage strategies.

4.2.2 Water Storage and Release Strategies

The reservoir management strategies during extreme weather events were critical in balancing flood mitigation and water storage for dry periods. During 2018 and 2020, controlled releases were essential to prevent overflow; but, these actions increased downstream flood risks, as highlighted in the river discharge data.

4.3 River Discharge Patterns

The annual river discharge trends at the Punalur station were analyzed from 2000 to 2020 to understand the variability in river flow and its implications for flood risks and water availability. The data were collected from the Punalur station, which provided daily discharge measurements in cubic meters per second (m^3/s). These measurements were aggregated into annual totals to identify trends over the two-decade period.

4.3.1 Annual Discharge Trends

The annual river discharge trends at the Punalur station were analyzed from 2000 to 2019 to understand the variability in river flow and its implications for flood risks and water availability. These measurements were aggregated into annual totals to identify trends over the two-decade period.

Table 3 below presents the total annual discharge recorded for each year from 2000 to 2019. The trends indicate significant fluctuations in discharge volumes, which can be attributed to variations in rainfall patterns, reservoir releases, and other factors influencing the basin's hydrology. Years with high discharge, such as 2013, 2016-18, correspond to years of heavy rainfall and reservoir releases, which increased downstream flow and heightened flood risks. Conversely, years with lower discharge, such as 2000-2004, 2008, and 2012, reflect drought conditions and reduced rainfall, leading to decreased river flow and potential water scarcity.

Table 3: Annual River Discharge Data (2000–2019)

Year	Discharge in M3/s	Comments

2000	10289.76	Drought year
2001	13374.1	Drought year
2002	12577.2	Drought year
2003	10000.09	Drought year
2004	13855.79	Drought year
2005	17495.7	Average discharge
2006	25447.42	Average discharge
2007	32934.9	Average discharge
2008	11068.11	Drought year
2009	15676.2	Average discharge
2010	20862.19	Average discharge
2011	29288.59	Average discharge
2012	10247.92	Drought year
2013	58686.91	High discharge and flooding
2014	25856.21	Average discharge
2015	18190.68	Average discharge
2016	53305.67	High discharge and flooding
2017	53359.47	High discharge and flooding
2018	70759.76	High discharge and flooding
2019	32049.62	Average discharge

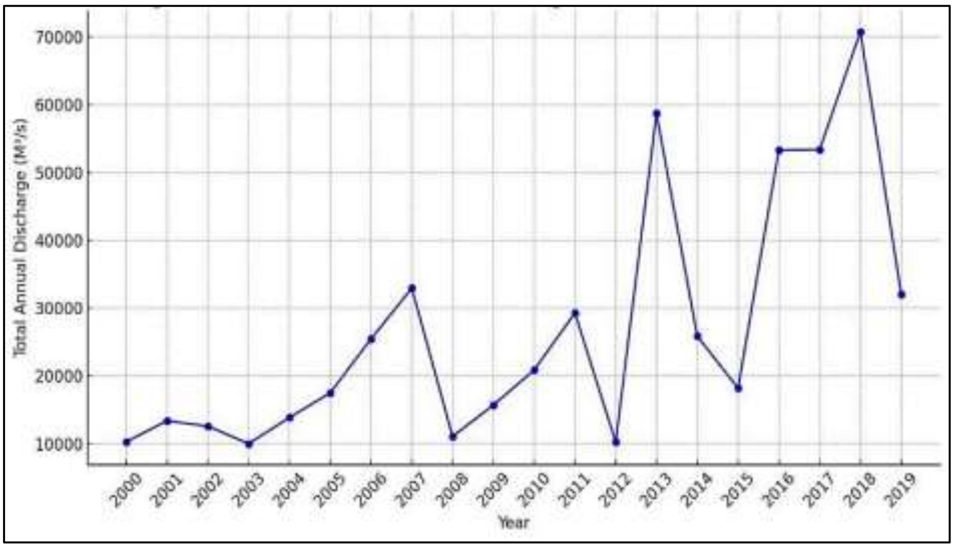

Figure 4: Annual River Discharge Trends at Punalur (2000–2020)

4.3.2 Correlation with Reservoir Releases

The correlation between reservoir releases and river discharge was evident during high-rainfall years when large volumes of water were released from the Kallada reservoir to manage flood risks. However, these releases contributed to downstream flooding in 2018 and 2020, demonstrating the need for better coordination between rainfall forecasts and reservoir operations.

4.3.3 Flood Risk Trends

The flood risk in the Kallada River basin was assessed by analyzing the river discharge data from the Punalur station from 2000 to 2020. The analysis revealed that when discharge exceeded 300 m^3/s, the flood risk threshold was considered as a critical level for potential flooding.

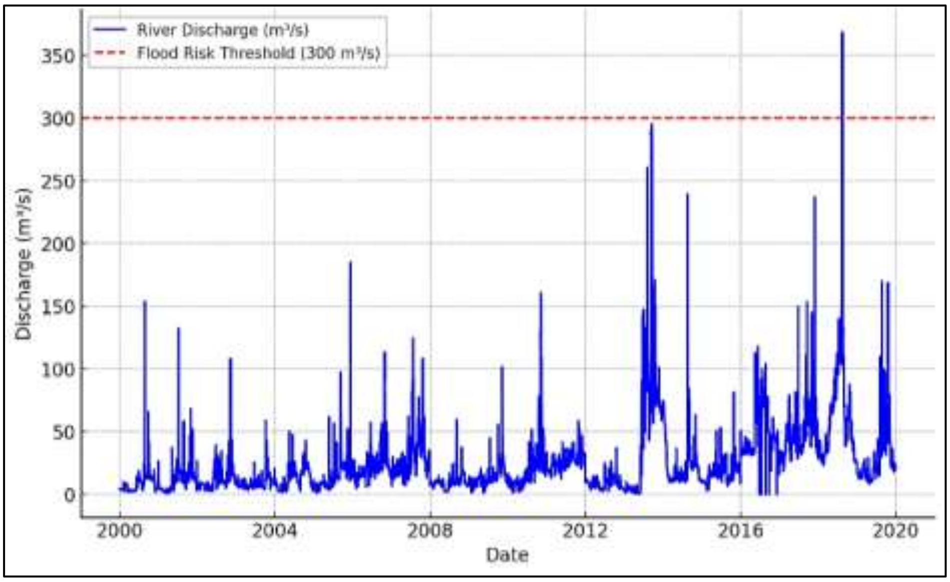

Figure 5: Flood Risk Trends Based on River Discharge at Punalur (2000–2020)

4.4 Impact of Land Use Changes and Human Interventions

4.4.1 Deforestation and Urbanization

The analysis of land use changes revealed significant deforestation and urbanization in the Kallada basin, with deforestation increasing by 15% and urban areas by 25% over the past two decades. These changes increased runoff and reduced soil absorption, exacerbating flood risks during heavy rainfall.

Table 4: Summary of Land Use Changes in the Kallada Basin (2000–2020)

Type of Change	Percentage Increase	Comments
Deforestation	15%	Increased runoff
Urbanization	25%	Reduced soil absorption
Agricultural Expansion	10%	Changes in water demand

4.5 Implications for Water Resource Management

The findings of this study had significant implications for managing water resources in the Kallada River basin. The increasing frequency of extreme weather events and human interventions required more adaptive management strategies. Key recommendations include:

- **Improved Forecasting**: Enhance weather and hydrological forecasting systems to better anticipate extreme rainfall and droughts.
- **Dynamic Reservoir Management**: Implement more adaptive reservoir release strategies to balance flood mitigation and water storage.
- **Integrated Land Use Planning**: Include land use changes into water resource management to mitigate the impacts of deforestation and urbanization on runoff and flooding.

5. CONCLUSION

The presented research examined the effect of climate variability and human interventions on water resources in the Kallada River basin, Kerala. The study concluded that the Kallada basin faced more floods during heavy rainfall and reservoir releases. However, from 2000 to 2004, 2008, and 2012, lower discharge reflected drought conditions and reduced rainfall, leading to decreased river flow and potential water scarcity. Human activities led to dramatically intensified urbanization (25%) and deforestation (15%). Moreover, some of the adaptive strategies of improved forecasting, dynamic reservoir management, and integrated land use planning had a significant implication for managing water resources. The findings of this study might help policymakers develop plans to recover adaptive capacity, lessen the effects of climate change and human intervention on water resources, and create robust water resources and demand in the long run. In the future, the study will consider a reference for long river catchments with varied topographical changes and reservoir operation constraints to deal with climate change and human intervention issues.

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