



# Stream Discharge Reduction in Kenya's River Ruiru Sub-Catchment

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**How to cite this paper:** Onguru, P., Macharia, A.N. and Makokha, M. (2025) Stream Discharge Reduction in Kenya's River Ruiru Sub-Catchment. *Open Access Library Journal*, 12: e13713. <https://doi.org/10.4236/oalib.1113713>

**Received:** June 1, 2025

**Accepted:** July 13, 2025

**Published:** July 16, 2025

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## Abstract

Water resources in Kenya face escalating challenges from rapid urbanization, population growth, and anthropogenic activities that disrupt hydrological processes. This study investigated historical stream discharge trends in the River Ruiru sub-catchment of Kiambu County, Kenya, from 2006 to 2016. The research employed a descriptive quantitative research design using the Mann-Kendall trend test and Sen's slope estimator to analyse discharge data. The study conducted a comprehensive data validation process before the Mann-Kendall test, revealing 1.3% of the 10-year record as missing values and showing no temporal clustering ( $\chi^2$  test,  $p = 0.78$ ). These gaps were considered inconsequential, preserving the original series' statistical properties. Tukey's method identified four potential anomalies, two of which were confirmed as legitimate high-flow events. Results revealed a statistically significant declining trend in stream discharge (MK test statistic:  $-0.3079$ ,  $p$ -value:  $0.0086$ ) with an annual decrease rate of  $-0.0502$  m<sup>3</sup>/s over the 10-year period. An anomalous discharge pattern observed between November 2011 and January 2012 coincided with major infrastructure developments and extreme climatic events, demonstrating the complex interaction between anthropogenic and climatic factors. The declining discharge trend aligns with similar patterns observed in other Kenyan watersheds, suggesting regional watershed degradation, which may be linked to rapid urbanization, agricultural expansion, and increased water abstraction. These findings highlight the critical need for integrated watershed management approaches, including protection of forested areas in upper catchments, implementation of green infrastructure to increase infiltration in urbanized areas, establishment of sustainable water allocation systems, and development of climate-adaptive strategies to enhance resilience of water resources in the face of increasing environmental pressures and climate variability.

## Subject Areas

Stream Discharge, Mann-Kendall Test, Land Use Change, Hydrological Trends,

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Watershed Management

## Keywords

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## 1. Introduction

Water resources around the world are coming under pressure from anthropogenic uses, climate variability, and increases in population [1]. Rivers and streams, being important elements of the hydrological cycle, act as indicators of watershed sustainability and health. Freshwater represents about 2.5 percent of the total mass of water on Earth (around  $1.4 \times 10^9 \text{ km}^3$ ) [2]. Freshwater rivers and lakes, being the most readily accessible water sources for human utilization, are just 0.007 percent of the total water supply [2]. The average river discharge worldwide is about 36,000  $\text{km}^3$  yearly. This discharge is not equally shared, as Asia and Oceania together account for 55 percent (around 11,000  $\text{km}^3$  per year), while the Amazon River alone contributes about 8600  $\text{km}^3$  per year. The irregular distribution of water resources is dominated by atmospheric precipitation patterns, which are far greater within the latitudinal range of 20°N to 20°S [2], and therefore needs vigilant monitoring and management of water resources. Stream discharge is a cumulative consequence of hydrological processes in a river system, which carries runoff generated from rainfall. Moreover, stream discharge is a valuable indicator of the long-term hydrological characteristics of a drainage basin [3]. Stream discharge is a key hydrological parameter required for water resource management and planning as well as for ecosystem preservation.

Stream flow incorporates hydrologic processes across the entire landscape; thus, variations in discharge of big rivers can serve as a warning sign of pervasive changes within watersheds [4] [5]. Changes in river discharge also impact coastal and ocean chemistry, biology, and circulation [6]. Reference [7] applied the Mann-Kendall test when conducting a study to assess the decline in river discharge in Canada. The data revealed a 10% decrease ( $-125 \text{ km}^3 \cdot \text{yr}^{-1}$  or  $-22 \text{ mm} \cdot \text{yr}^{-1}$ ) in the total annual river discharge to the Arctic and North Atlantic Oceans from 1964 to 2003. This trend in river runoff was consistent with a  $21 \text{ mm} \cdot \text{yr}^{-1}$  decline in observed precipitation over northern Canada between 1964 and 2000. This suggests that changes in river discharge over northern Canada are driven primarily by precipitation rather than evapotranspiration [7]. Collectively, discharge from these 35 rivers, located primarily in northern and southern mid-latitude belts, declined by approximately 500  $\text{km}^3$ , 60% of their collective 1951 discharge [7]. On estimation, half of this loss may be due to decreased precipitation, the other half to anthropogenically induced water loss [7].

In most tropical basins, increasing stream discharge results in increased sediment yield [8]. The majority of the favorable relationship between stream and sediment yield occurs during stormy seasons [9] [10]. When measuring the relationship

between sediment output and stream discharge in Ethiopia, a coefficient of determination ( $R^2$ ) greater than 0.5 was obtained [10]. Another study found that LULCC has a considerable impact on watershed hydrology by modifying evapotranspiration, infiltration, and runoff processes [1]. For example, in India, a 28% drop in forest cover resulted in a 15% rise in runoff peak in the Kerala watershed [11], whereas hydrological modeling in Ethiopia's Gilgel Gibe watershed demonstrated a link between LULC variations and repeated hydrological drought [12]. In Kenya, changes in stream discharge in the Mara River Catchment and Narok's Kakia and Esamburmbur Sub-Catchments have been connected to deforestation and land degradation [13] [14].

Kenya, a water-scarce country with low mean annual rainfall and a rapidly rising population of over 40 million, places a premium on effective water resource management. The River Ruiru sub-catchment in Kiambu County is a microcosm of the issues that Kenyan watersheds face, as land use changes, urbanization, and agricultural intensification occur rapidly. The River Ruiru sub-catchment region, located in Kenya's fourth most urbanized area after Nairobi, Mombasa, and Kisumu, has witnessed significant changes throughout time. According to research, the River Ruiru is critical to the maintenance of ecological processes and human activities in the region [15]-[17]. Nonetheless, the fast population growth and urbanization in Ruiru Sub-County would have most likely brought about extensive Land Use and Land Cover Change (LULCC), possibly changing hydrologic processes and stream discharge patterns [16] [17].

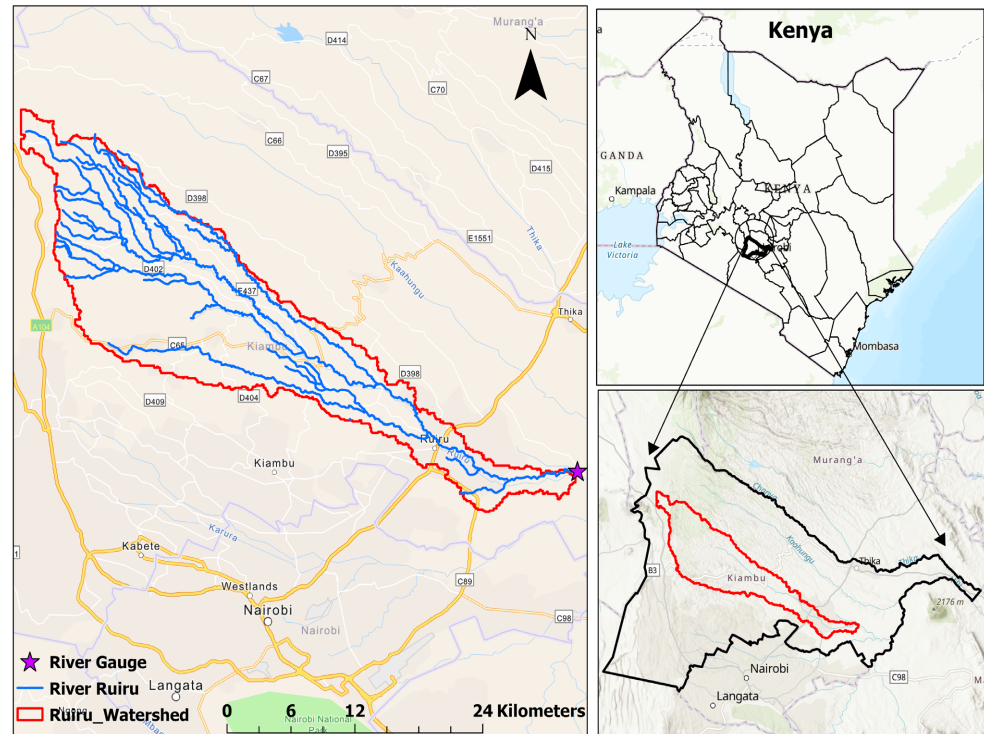
In spite of the patently clear significance of trends in stream discharge in order to manage water resources sustainably, comprehensive examinations of long-term discharge trends in most Kenyan watersheds, such as the River Ruiru sub-catchment, are surprisingly scant. The objective of this study was thus to determine the trend in stream discharge in the River Ruiru sub-catchment from 2006 to 2016, thereby offering insightful information on the hydrological processes in this valuable water resource. The study period was also determined by the availability of stream discharge records over this time due to vandalism at the monitoring station.

## 2. Research Methodology

### 2.1. Study Area

River Ruiru sub-catchment lies in Kiambu County, Kenya, between geographical coordinates  $1^{\circ}4'43.90''S$  and  $36^{\circ}50'54.24''E$  (Figure 1). The county has an area of about 2543 km<sup>2</sup> and is bordered by Murang'a, Nairobi, Nyandarua, and Nakuru Counties [15]. River Ruiru, whose length is 40 km, rises from the Gatamaiyo forest and has an average gradient of 0.057, with a drainage area of 400 km<sup>2</sup> [15] [17]. The climate of the study area is characterized by bimodal rainfall patterns, with long rains occurring from April to May, followed by a cool and dry season, and short rains between October and December. Temperature patterns vary across the region, with mean maximum temperatures ranging from 26°C to 28°C in the southern and eastern regions, while the northwest experiences temperatures between

18°C and 20°C [18]. The soils are generally well-drained, deep, mildly acidic, and range from dark red to dark reddish-brown [17]. Land use in the region is diverse, influenced by soil distribution and agro-ecological zones, comprising both small-holder farms (less than 5 acres) and large-scale agricultural operations (over 10 acres) [15] [17].



Source: Developed from shapefiles extracted from the Regional Centre for Mapping of Resources for Development [19].

**Figure 1.** Location of the River Ruiru sub-catchment.

## 2.2. Research Design

This study employed a descriptive quantitative research design to identify patterns and trends without necessarily generating new primary data [20]. This approach was appropriate for analysing historical stream discharge data and identifying trends over an extended period.

## 2.3. Stream Discharge Data Collection and Analysis

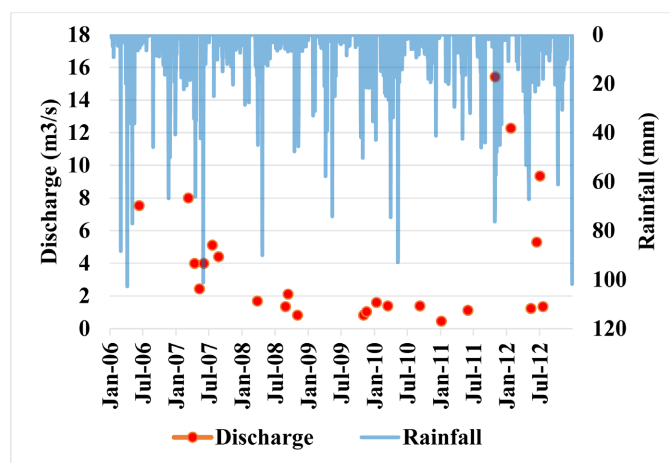
Historical stream discharge data for the River Ruiru sub-catchment spanning from 2006 to 2016 were obtained from the Water Resources Authority (WRA) monitoring stations. Before Mann-Kendall trend analysis, the dataset underwent systematic quality control procedures to ensure reliable results. Following standard hydrological practices [21], we conducted a comprehensive data validation process. Missing values comprised 1.3% of the 10-year record and showed no temporal clustering ( $\chi^2$  test,  $p = 0.78$ ). These gaps were considered insignificant, which preserves the statistical properties of the original series. Outlier identification using Tukey's method



0.05. This result indicates a downward trend in stream discharge that is statistically significant and unlikely to be attributed to random variation. Additionally, Sen's slope estimator quantified the average annual decrease in stream discharge at  $-0.0502 \text{ m}^3/\text{s}$ , providing a measure of the rate of decline over the study period.

The findings are consistent with those of [27], who found diminishing stream-flow in the Ruiru Sub-Catchment from 2005 to 2015. The study ascribed this loss to anthropogenic forces such as deforestation, increased water abstraction for home and agricultural purposes, and the rapid expansion of metropolitan infrastructure. These drivers are still significant in the current setting and may have increased over time, especially given the ongoing land use changes in Kiambu County, where the sub-catchment is located. While the present study did not directly quantify annual water abstraction volumes, existing studies have reported that licensed water abstraction permits in the Ruiru sub-catchment have increased markedly over the last decade. Moreover, other studies conducted in the same sub-catchment documented an increase in impervious land cover between 1987 and 2017 [16] and between 2005 and 2015 [17], which strongly supports the link between urbanization and reduced infiltration capacity.

Between November 2011 and January 2012, an interesting anomaly in the discharge statistics was found, with exceptionally high discharge levels deviating from the overall downward trend. This outlier period coincided with two significant developments: 1) the completion of the Thika Superhighway in 2010 [28] and the launch of the Tatu City development project in 2011 [29], which accelerated urbanization in Ruiru and surrounding areas, and 2) the 2011 East Africa drought, one of the most severe in decades [30], followed by heavy rainfall during the short rains period from November to December 2011 (Figure 3).



**Figure 3.** Rainfall patterns in the River Ruiru Sub-catchment from 2006 to 2012.

The convergence of intensified urban development, which increased impervious surfaces and altered natural drainage patterns, with extreme climatic conditions created a unique hydrological situation that likely explains the observed discharge anomaly. The drought conditions would have reduced vegetation cover

and soil moisture, potentially leading to enhanced runoff when substantial rainfall occurred during the short rains period. Although the anomaly reflects the interaction of climate and urbanization, the persistent declining trend observed outside this period suggests that urban expansion and increased abstraction had a more sustained impact over the decade [16] [18] [27].

The declining trend in stream discharge observed in the River Ruiru sub-catchment is not an isolated phenomenon but appears to be part of a broader pattern of watershed degradation across Kenya. Similar trends have been documented in other catchments, including the upper Tana River Basin [31] and the Nyando River Basin [32], where streamflow declines have been linked to climate variability, catchment degradation, and expanding human settlements. Compared to the upper Mara River Basin, where an average during LU scenario analysis the streamflow a decline of approximately 3% when there was partial deforestation and its conversion to agriculture, and 2% when there was complete deforestation and its conversion to agriculture [33]. The Ruiru sub-catchment's decline of  $-0.0502 \text{ m}^3/\text{s}$  per year appears steeper. This suggests relatively higher watershed degradation pressure in Ruiru, possibly due to its proximity to Nairobi and rapid peri-urban development.

As suggested by [34], streamflow increases may be localized through land cover changes, like the removal of forests to grass or croplands, that minimize evapotranspiration and boost surface runoff. However, the prevailing trend within Ruiru is a decrease in streamflow. This decrease would be due to the additive impact of expanding impervious surfaces via urbanization, water abstraction from the groundwater, and the loss of vegetative cover, which adversely affect infiltration and baseflow, especially during dry seasons.

### 3.2. Implications of Declining Stream Discharge

The documented decline in stream discharge in the River Ruiru sub-catchment has several important implications for water resource management and environmental sustainability in the region. First, reduced streamflow undermines water security for downstream users, including households and agricultural operations that depend on reliable surface water supplies [35]. As water availability decreases, competition for limited resources may intensify, potentially leading to conflicts among different user groups.

Secondly, decreased discharge interrupts ecological processes in and around the river system [36]. Aquatic habitats can be damaged, affecting the river's biodiversity and ecosystem services [35]. In addition, riparian ecosystems, which rely on periodic water supply, can experience decreased resilience and performance, further promoting environmental degradation in the watershed.

Thirdly, considering the increasing water demand in the Nairobi Metropolitan and Kiambu regions, the trend of decreasing stream discharge as observed is an indicator of rising pressures on other water sources, namely groundwater [35]. This can initiate overdevelopment of the aquifers and result in declining water levels, rising pumping costs, and possible problems related to water quality [35].

Although direct measurements of groundwater levels were beyond the scope of this study, [37] reported potential declining borehole yields and increasing drilling depths in Kiambu County. These observations indicate a growing dependence on groundwater, corroborating the concern over potential overexploitation.

#### 4. Conclusion and Recommendation

The present research has confirmed a statistically significant declining trend in stream flow within the River Ruiru sub-catchment from 2006 to 2016, with a mean rate of decline of 0.0502 m<sup>3</sup>/s per year. The results point to the susceptibility of this water resource to anthropogenic pressures and climatic change, hence the necessity for targeting the implementation of sustainable management strategies towards guaranteeing water security in the area in the long term.

In this context, it is suggested that the Water Resources Authority (WRA) invest in the improvement of hydrological monitoring stations to avail quality, consistent data on stream discharge and associated parameters to facilitate early detection of change and decision-making. Its use has the potential to arrest the gradual reduction in stream discharge and promote more sustainable management of water resources in the River Ruiru sub-catchment and comparable watersheds throughout Kenya. Additionally, cost-effective interventions such as community-based rain harvesting projects and gardens have been implemented in Kiambu County under the Department of Water, Environment and Natural Resources in partnership with IWaSP, UKAID, and GIZ [38], demonstrating the viability of green infrastructure in this socio-economic setting.

#### Acknowledgements

This paper used discharge data from the Water Resources Authority Headquarters and rainfall data from the Kenya Meteorological Department, which are the custodians of these datasets.

#### Conflicts of Interest

The authors declare no conflicts of interest.

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