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Assessing the Hydrological Impacts of Land Use/Cover Change in the Ouémé River Basin, West Africa

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Abstract

Population growth, unsustainable land-use practices, and climate change pose significant challenges to agri-food systems. This study examined the relationships between land use/cover change and changes in water balance within the Ouémé River Basin, which are essential for developing sustainable agroecological strategies. LULC was categorised from Landsat imagery for 1986, 2000, 2015 and 2023 using a supervised classification in Google Earth Engine into five main classes: Forests, Savannah, Settlements/bare lands, Water bodies, and Agricultural lands. These historical maps and climate data from 1998 to 2016 were used to simulate water balance components, including surface runoff, lateral flow, baseflow, aquifer recharge, and actual evapotranspiration, using the Soil and Water Assessment Tool (SWAT). The SWAT model was calibrated using observed discharge data from 1998 to 2008. The relationship between the LULC types and average annual water balance components values at the entire basin scale was then analysed using Partial Least Squares regression. Between 1986 and 2023, Forests and Savannahs declined by 4 % and 24 %, respectively, while Agricultural land and Settlements/bare lands expanded by 28 % and 1 %, respectively. These changes were associated with an increase in surface runoff (32 mm/year) and reductions in baseflow (5 mm/year), lateral flow (6 mm/year), aquifer recharge (22 mm/year) and actual evapotranspiration (6 mm/year). These LULC change trends might increase flood risks, limit water availability, and threaten agricultural productivity. The findings underscore the urgency of promoting agroecological practices that integrate sustainable land management and climate adaptation to ensure resilient agricultural systems and environmental sustainability".

Keywords: Google Earth Engine, hydrological changes, Landsat, Ouémé River Basin, partial least squares regression, SWAT, West Africa

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Introduction

Alterations in land use and land cover (LULC) have significant effects on the water cycle. In tropical basins, such as the Ouémé River Basin, linkages between land surface changes and water balance are visible, with rapid LULC changes due to agricultural expansion activities and urbanisation (Annan *et al.*, 2024). These developments affect runoff patterns, water availability (Mbaye *et al.*, 2015) and the basin's ability to provide ecosystem services in the long term and under extreme climate conditions, a crucial part of planetary health. Studies in the Ouémé River Basin have found agricultural lands prone to soil erosion (Hiepe, 2008), and surface runoff and groundwater flow sensitive to LULC changes. Others have shown that water yield and evapotranspiration are sensitive to climate change (Bossa *et al.*, 2014) and that expansion in agricultural lands and clearing of natural vegetation enhance flood occurrence (Hounkpè *et al.*, 2019). However, these studies either predicted water balance without considering LULC change, as they used constant maps, or used LULC scenarios derived from predicted socio-economic scenarios to assess future changes in water balance. Those who assessed water balance using scenario-based LULC changes also did not explore the relationship between the LULC changes and changes in water balance, nor the consistency of the relationship across different time periods. Such analysis has been a challenge due to the unavailability of comprehensive LULC data for the entire basin and the lack of up-to-date hydrological and climate data (Bodjrènou *et al.*, 2023). This study evaluated the effects of LULC change on water balance by (1) simulating water balance using four LULC maps and (2) estimating the relationship between changes in LULC types and corresponding changes in water balance components.

Material and Methods

The Ouémé River Basin is the largest in Benin, West Africa. It is located between latitudes 6°30' and 10°00'N, and longitudes 0°52' and 3°05'E, with a total area of 49,280 km². The basin's annual rainfall ranges between 900 and 1200 mm, and the temperature between 25 and 30°C. The Ouémé River Basin's geology is mainly composed of metamorphic and crystalline rock with low permeability and mainly tropical ferruginous soils (luvisols) in the north and ferrallitic soils in the south. Observed climate (1998-2016), soil map, LULC maps (1986, 2000, 2015, 2023) from Annan *et al.* (2024), and a Digital Elevation Model (DEM) were used in the Soil and Water Assessment Tool (SWAT) model for the hydrological simulations. The model was calibrated and validated using the LULC map for 2000 and observed discharge data. Sixteen (16) SWAT parameters were used for calibration and validation in SWAT-CUP. The influence of LULC changes was isolated by keeping all other factors (climate and soil) constant. Statistical analyses were used to assess the strength and direction of the relationship between LULC changes and water balance changes.

Results and Discussion

Model Calibration and Validation, and Water Balance Trends

The calibration and validation of the SWAT model at Bétérou and Bonou outlets gave $NSE \geq 0.82$, $RSR \leq 0.42$ and $PBIAS \leq -12.8$ as outlined by Moriasi *et al.* (2007). The negative PBIAS indicates general overestimation of discharge by the model, although within acceptable limits. The LULC change effects on water balance components were analysed at the basin scale. The average annual water balance results showed that evapotranspiration accounted for the largest fraction of precipitation (57 %), followed by total aquifer recharge (27 %), lateral flow, baseflow and surface runoff. Additionally, between the 1986 and 2023 LULC maps, a reduction of forest by approximately 2,432 km² and 11,867 km² of savanna areas, coupled with an increase by 534 km² in settlements/bare land and 13,776 km² in agricultural lands, resulted in a 32 mm/year increase in surface runoff. At the same time, reductions of 12, 6, 26 and 5.9 mm/year in baseflow, lateral flow, total aquifer recharge, and actual evapotranspiration, respectively, were observed.

This can be explained by the absence of dense vegetation in forest and savanna areas, which can intercept rainfall and slow runoff, as well as their denser root system that increases infiltration rates compared to agricultural and settlements/bare lands.

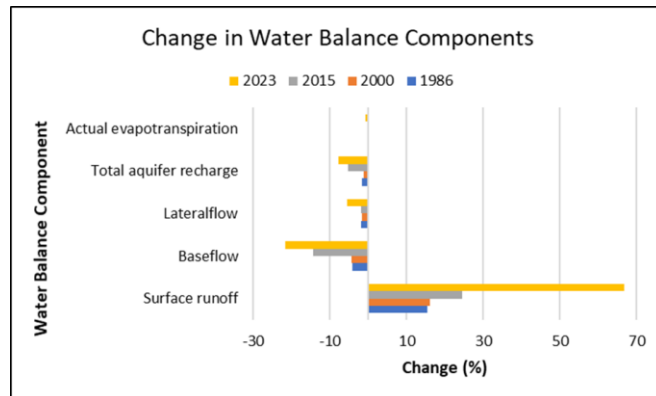


Figure 1: Change in Water Balance per LULC Type

Relationship between LULC Changes and Change in Water Balance Components

The correlation (R values > 0.80) and PLS regression (R^2 values > 0.75) analyses revealed a strong relationship between LULC change and water balance variations. The regression coefficients indicated a greater influence of changes in settlements/bare lands and forests compared to savanna and agricultural lands. A unit change in the area of settlements/bare land and agricultural land increased surface runoff and decreased the other water balance components, whereas a unit increase in forests and savanna areas decreased surface runoff and enhanced the other water balance components. This highlights the adverse impacts of extensive land degradation due to agricultural expansion and urban development, including increased soil erosion, flood risks, and reduced water availability for domestic, farming, and industrial activities.

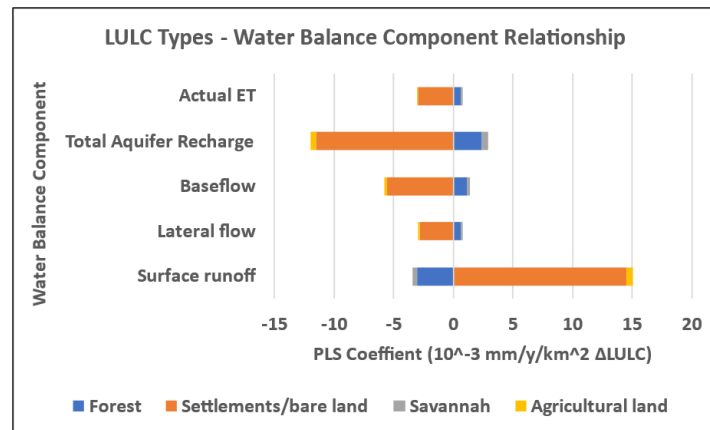


Figure 2: Magnitude of Influence of Changes in LULC Types on Water Balance Components

Conclusions and Outlook

This study assessed the relationship between LULC changes and changes in water balance in the Ouémé River Basin of Benin. The results showed a strong link where surface runoff increased by about 67 % when forest and savanna areas decreased and agricultural and settlements/bare land expanded. Baseflow, lateral flow, aquifer recharge and actual evapotranspiration decreased. The findings highlight the significant role of LULC changes in shaping hydrological processes, as well as the need for sustainable land management practices. Constraints of the study include the limited availability of long-term climate and observed discharge data to the researcher, which limited the extent of hydrological assessments, as well as the discrepancy between available

“LULC data” and “hydrological modelling data”, which may have contributed to uncertainties in the study. Future studies should explore the influence of LULC on water balance at the sub-basin scale and investigate seasonal variations in the LULC-water balance relationship.

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