Can Land Use Decisions Alter the Water Cycle? The Case of the Ouémé River Basin, Benin

Executive Summary

The impact of LULC change on hydrological processes (water balance) including surface runoff, lateral flow, baseflow, aquifer recharge and evapotranspiration on land is not fully understood in data-scarce regions such as the Ouémé River Basin, yet is crucial for water availability, flood management and infrastructure design. This study examines how LULC changes affect hydrological processes across multiple temporal periods. Key findings show that:

- Forest and Savanna areas have decreased by 4 % and 24 %, respectively, while Agricultural and Settlements/bare land have increased by 1 % and 28 %, respectively from 1986-2023.
- These LULC changes increased surface runoff by 32 mm/y from 1986-2023, reducing baseflow (5 mm/y), lateral (6 mm/y) and groundwater recharge (22 mm/y).
- Settlements/bare land expansion and Forest loss are strongly linked with increased surface runoff, intensifying flood risks due to higher volumes of water from reduced infiltration, and limiting groundwater availability for domestic, farming and industrial activities.

To address these challenges, it is recommended that:

- The Ministry of Living Environment and Sustainable Development in collaboration with communities embark on the reforestation of degraded Forests with clear demarcation of the Forest areas and laws to handle encroachment. In addition, training on the benefits of Forests and the effects of deforestation should be provided to communities to improve their knowledge of sustainable Forest management.
- Also, the Ministry of Agriculture, Livestock and Fisheries (as part of the Government Action Plan (PAG 2021-2026) and the Strategic Plan for Agricultural Sector Development (PSDSA 2017-2025) build the capacity of farmers in sustainable agriculture intensification, and conservation agriculture practices (such as plant cover, crop rotation, minimum tillage, etc.), and support those implementing them.

The study underscores the crucial need for sustainable farming and urban planning to improve sustainable water resources management.

Introduction

Rapid population growth and urban expansion have increased the demand for food and water significantly (Olofintoye *et al.*, 2022). This increase in demand has led to the conversion of natural vegetation to cultivated lands to meet the food supply needs. This affects the overall ecosystem health and its ability to provide services. LULC change influences how a watershed responds to rain by controlling surface runoff concentration and generation, and flood routing (Mbaye *et al.*, 2015). It affects water availability and agricultural production, mainly rainfed in Benin (> 90 %), employing 60 % of the Benin workforce and contributing 26.9 % Gross Domestic Product. In extreme cases, it leads to floods.

Existing research on the Ouémé River basin, Benin's largest basin have used a single LULC map to assess water balance or predictions from socio-economic projections to relate LULC with water balance changes. There is a lack of evidence on the effect of changing LULC on water balance across temporal periods in the basin.

Therefore, LULC change impact on water balance in the Ouémé River Basin is assessed using multiple historical maps up to the recent past. The relationship between LULC types and hydrological processes including surface runoff, lateral flow, baseflow, aquifer recharge and actual evapotranspiration is examined. This understanding provides insights to evaluate existing policy decisions and National Action plans towards a sustainable environment and water resources, which are vital to the survival of the populace and improving agricultural productivity.

It is also integral to achieving SDG 6 and Target 15.1 towards access to water and conservation, sustainable use and restoration of terrestrial ecosystems including Forests (Perron-Welch *et al.*, 2023). It also aligns with Benin's National Action Plans towards the conservation and restoration of Forests (World Bank, 2020) and sustainable management of water resources to ensure universal access and sanitation for all (PAG 2021-2026), and sustainable cities (Massa *et al.*, 2024).

WASCAL West African Science Service Centre on Climate Change and Adapted Land Use
Bundesministerium für Bildung und Forschung
TUM
Université d'Abomey-Calavi

Approach

Assessing Land use/cover Change in the Past

The Ouémé River Basin (Bonou) is the largest basin in the center of Benin, West Africa with a total area of 49280.23 km^2. Landsat satellite images for four historical years were used to classify the LULC types in the basin into five main classes according to the key LULC types found in this West African region. The years 1986, 2000, 2015 and 2023 were considered based on the data availability and quality and alignment with efforts towards environmental sustainability such as the Millennium Development Goals adopted in 2000 and the Sustainable Development Goals adopted in 2015. The year 2023 also ensured that the most current state of LULC was incorporated to improve the study's relevance for current and future planning. According to the West African Land Cover Reference System, the LULC types used in this study include Forests, Savanna, Agricultural land, Settlements/bare land, and Water bodies (Di Gregorio et al., 2022). After the classification, the absolute, relative, and rates of change of the LULC types between the years were assessed to quantify the changes that occurred over the period.

Assessing Water Balance Based on Historical LULC over Time

The classified LULC maps for 1986, 2000, 2015 and 2023 were each used to model the hydrological processes in the basin using the Soil and Water Assessment Tool (SWAT) model. Climate data including precipitation and temperature from 1998-2016 and a soil map from the FAO Soil Database were also used for the water balance simulation. Key components such as surface runoff, lateral flow, baseflow, aquifer recharge and actual evapotranspiration were analyzed for their changes across the four LULC maps. The same climate and soil data were used across the LULC maps to ensure that any changes in water balance were solely due to LULC change. A Partial Least Squares regression was used to assess the relationship between LULC and estimated water balance. The regression coefficients indicate the influence of the different LULC types on the water balance components, including surface runoff, lateral flow, baseflow, aquifer recharge and actual evapotranspiration over time.

Findings and Implications

LULC Change Assessment

The LULC assessment showed that the Oueme River Basin was initially covered by about 70 % of Savanna vegetation in 1986, followed by Agricultural land (23 %) and Forests (6 %), Settlements/bare lands (0.6 %) and Water bodies (0.1 %). Savanna and Forest areas have decreased considerably over time by about 24 % and 4 %, respectively, while Agricultural land and Settlements/bare land have increased by 28 % and 1 %, respectively. This indicates deforestation in the basin for agricultural activities and settlements as observed by Hounkpè (2016) and Bodjrenou *et al*. (2023).

The highest rate of change was observed between 2015 and 2023 despite the smaller number years than from 1986-2000 and 2000-2015. This trend can be attributed to the increasing population growth and urbanization in the basin and Benin. Consequently, this deforestation will result in the loss of certain species of trees, birds, reptiles and other organisms which play an important role in the overall health of the basin ecosystem since the Forest and Savannah serve as a habitat for diverse living things (biodiversity). The tree ecosystems also serve as carbon sinks, providing climate change mitigation. These changes in the land surface characteristics will also affect how rainfall flows in the basin, which is expounded on in the following section.

Figure 1: Deforestation in Benin (*Source: leconomistebenin.com)*

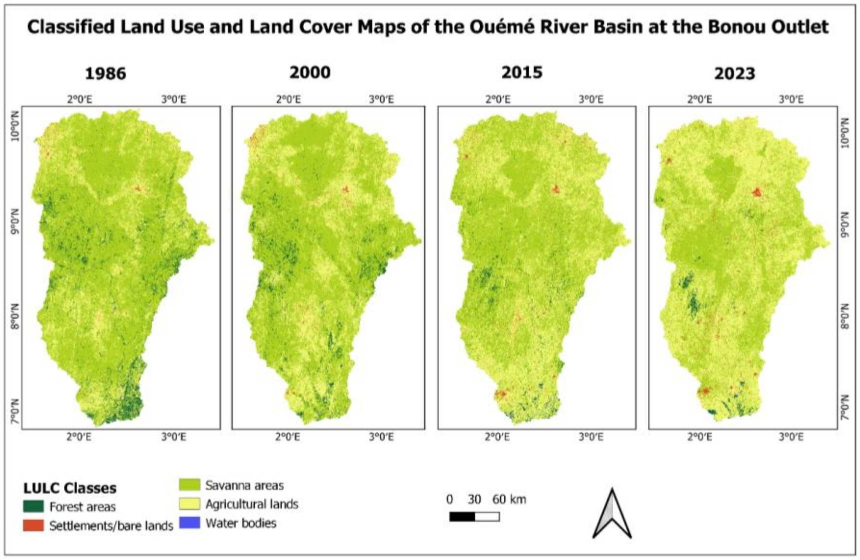

Figure 2: Classified LULC Map of the Ouémé River Basin from 1986 to 2023 (*Source: Annan et al., 2024)*

LULC Change Impact on Hydrology

The simulated water balance showed the highest surface runoff from the 2023 LULC, followed by the 2015, 2000 and 1986 maps in a reducing order. Lateral flow, baseflow and aquifer recharge decreased from the 1986 to the 2023. Actual evapotranspiration showed minute changes from 1986-2023. Linking this to the LULC change observed, it indicates that a decrease in Forest and Savanna areas, and the expansion of Settlements/bare land between 1986 and 2023 led to an increase in the amount of water flowing on the land surface and eventually ended up in rivers (and the sea). This is because vegetation cover, especially dense cover like that of Forests collects rain and slows the rate at which the rain falls to the ground, thereby slowing/limiting soil erosion. The litter on the ground of Forest areas trap rain, and slows water movement on the soil surface, allowing ample movement of the rain into the soil (infiltration). This makes water available for plant use, and groundwater available for abstraction for domestic, farming and industrial activities.

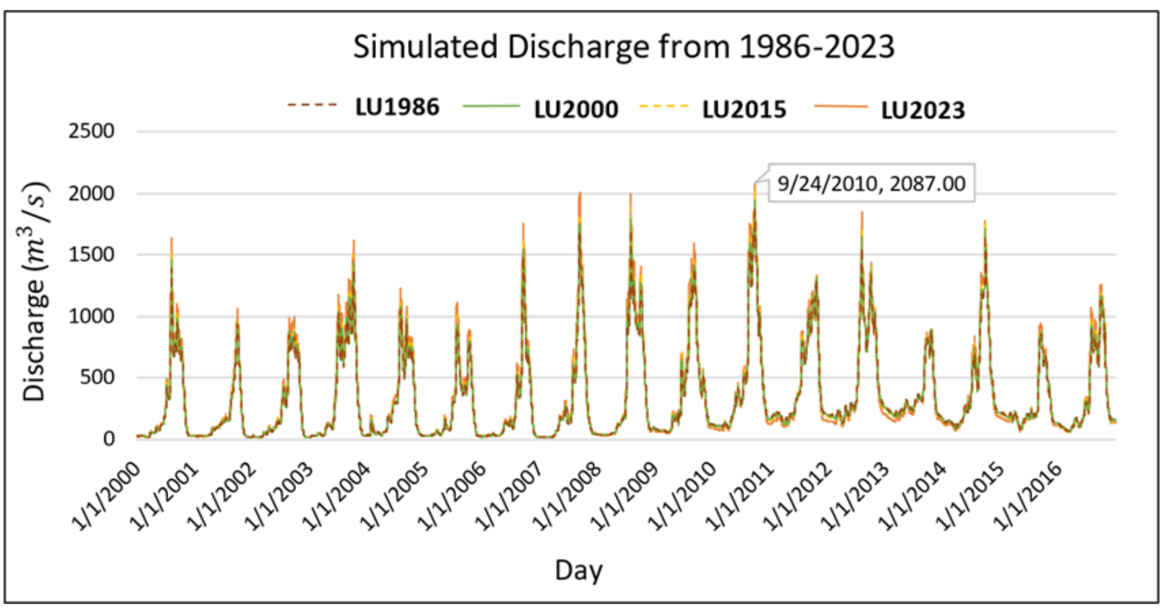

Figure 3: Simulated Discharge in SWAT model from 1986-2023 showing Increasing Peak Flows (*source: author's construct*)

Reducing lateral flow, baseflow, and total aquifer recharge means less water moves into the soil to improve soil moisture content and further downward to recharge groundwater. Plants use soil moisture for growth, which dissolves soil nutrients, making them available for plant uptake. Hence, a reduction in the amount of water entering the soil will limit the growth of plants (crops), and affect crop productivity, farmer income and food security in the long term. And since agriculture contributes to GDP and exports, the country's revenue would also be affected. The minute changes in actual evapotranspiration may suggest that the tree crops and plantations abundant in the basin can maintain similar actual evapotranspiration levels. Limited water availability for sanitation will increase disease outbreaks.

Figure 4: Water Scarcity (*Source: https://drop4drop.org/wp-content/uploads/2017/12/)*

Additionally, an increase in surface runoff will enhance soil erosion which carries soil particles, debris, fertilizer and other substances usually ending up in water bodies such as rivers, lakes, lagoons. Such pollution of water bodies makes them harmful for drinking. When there is a high amount of rainfall in a short period, as the soil moisture capacity is exceeded, it leads to floods which cause loss of lives and destruction to properties including croplands. The discharge simulated showed increasing peak flows from 1986 to 2023, with the highest peaks aligning with some flood events in Benin, such as that in 2008 (Office for the Coordination of Humanitarian Affairs, 2008) and 2010 which affected over 680,000 people from 55 out of 77 municipalities (Office for the Coordination of Humanitarian Affairs, 2010). The regression analysis shows that Settlements/bare lands and Forests are primary LULC drivers of changes in the basin's hydrology. While Settlements/bare lands increase surface runoff and decrease subsurface flow and groundwater storage, Forests do the opposite.

Table 1: Partial Least Squares Regression Coefficients of Historical LULC Impact on Water Balance

	PLS1 coefficients of LULC types per water balance component				
LULC type	Surface runoff (10^{-3}mm/y) per km^2 ΔLULC	Lateral flow (10^{-3}mm/y) per km^2 ΔLULC	Baseflow (10^{-3}mm/y) per km^2 ΔLULC	Total aquifer recharge (10^{-3}mm/y) per km^2 ΔLULC	Actual evapotranspiration (10^{-3}mm/y) per km^2 ΔLULC
FRST	-3.08	0.63	1.15	2.37	0.61
STB	14.47	-2.82	-5.55	-11.49	-2.95
SAV	-0.37	0.13	0.26	0.59	0.14
AGR	0.58	-0.11	-0.23	-0.47	-0.12
Intercept	68.91	109.72	49.08	313.10	667.41
R^2	0.989	0.986	0.950	0.961	0.932
RMSE	1.223	0.278	1.038	0.473	2.548

FRST-Forest Areas, STB-Settlements/bare land, SAV-Savanna areas, AGR-Agricultural lands

Conclusion

This research has provided insights into the impact of land use/cover on hydrological processes including surface runoff, lateral flow, baseflow, total aquifer recharge and actual evapotranspiration. The changes in LULC generally showed an increase in agricultural and Settlements/bare land at the expense of natural vegetation. The specific findings are:

- LULC change from 1986 to 2023 revealed decreasing Forest and Savanna areas by 4 % and 24 %, respectively, and an increase in Agricultural and Settlements/bare land by 1 % and 28 %, respectively.
- The changes have been fastest between 2015 and 2023. The LULC change from 1986-2023 increased surface runoff (32 mm/y) and peak flows, suggesting high flooding vulnerability. Lateral flow (6 mm/y), baseflow (5 mm/y), aquifer recharge (22 mm/y), and actual evapotranspiration (6 mm/y) reduced, potentially leading to limited water availability for domestic and farming purposes.
- Changes in Settlements/bare land and Forests were key predictors.

Currently, the Forest management policy in Benin allows communities and individuals living close to the Protected Estate Domain (80 % of the natural forest and overseen by the communities) rights to use the forest land for agriculture and extraction of forest products subject to prohibition if environmental degradation is compromised (World Bank, 2020). The lack of documentation of these Forests (and other land uses) and their demarcations has also made protection enforcement difficult (World Bank, 2020).

Recommendations

It is recommended that:

- The Ministry of Living Environment and Sustainable Development (MCVDD: *Ministère du Cadre de Vie et du Développmement Durable*) embark on reforesting degraded Forest areas in collaboration with the communities (including the Village Forest Management Organization) with clear demarcation of the Forest areas and laws to handle encroachment. This aligns with the principles of Protection and Regulated Development, and Participatory Management, outlined in Benin's new Forestry Policy 2023-2032, strengthening the importance of forest restoration and protection.
- The MCVDD should offer training to communities on the benefits of Forests and sustainable agricultural intensification (such as minimum tillage, cover crops, intercrops, etc.) and the effects of deforestation to improve their knowledge of natural resources management.
- The Ministry of Planning and Development encourages vertical expansion of buildings in infrastructure design and incorporation of green areas around buildings in the land-use plan, which will be enforced by the new bill on Sustainable Urban Planning being adopted in Benin. This will help to manage the shortage of housing while protecting the area from floods.

These outputs have depicted the urgency of the need for sustainable forest and agriculture management, and urban development to manage water resources in the basin. They contribute to action plans of the FAO-Benin Country Programming Framework (*Cadre de Programmation Pays*) Output 2.2 towards improving knowledge of natural resources and their management and Output 2.3 aimed at restoring forest ecosystems.

Figure 5: Flood in Benin, 2017 (*Source: https://drop4drop.org/wp-content/uploads/2017/12/*)

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Author

Ernestina Annan (WASCAL Climate Change and Land Use, Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. Email: ernestinaannan39@gmail.com; annan.e@wascal.edu.org)

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