Quantifying The Impact of Deforestation on Hydrological Regimes in Nigeria Through Remote Sensing and Hydrological Modeling

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Abstract- This study investigates the relationships between hydrological regimes and various independent variables, including deforestation, precipitation, land use and land cover change, topography, soil properties, and watershed characteristics in Nigeria. Hydrological regimes play a vital role in water distribution and availability, affecting ecosystems, agriculture, and human settlements. The research employs regression analysis to explore the impacts of the independent variables on hydrological regimes. The results show that the models tested have low R^2 values, suggesting that the selected independent variables collectively explain only a small portion of the variance in hydrological regimes. The coefficients for the independent variables are close to zero, with non-significant p-values, indicating a weak impact on hydrological regimes in the context of the current dataset. The correlation matrix further supports the regression analysis results, showing weak or negligible linear relationships between hydrological regimes and the independent variables.

Indexed Terms- Hydrological Regimes, Deforestation, Precipitation Variability, Land Use Change, Topography, Soil Properties, Watershed Characteristics.

I. INTRODUCTION

Hydrological regimes play a crucial role in the distribution and availability of water resources, affecting ecosystems, agriculture, and human settlements. Understanding the factors that influence hydrological regimes is essential for sustainable water management, particularly in regions facing challenges such as deforestation, land use changes, and precipitation variability. This study aims to investigate the relationships between hydrological regimes and various independent variables in Nigeria, including deforestation, precipitation, land use and land cover change, topography, soil properties, and watershed characteristics.

Hydrological regimes are complex systems influenced by numerous natural and anthropogenic factors. Changes in land cover, such as deforestation, can alter the hydrological cycle by affecting evapotranspiration, runoff, and soil moisture retention. Precipitation, as a primary driver of the hydrological cycle, plays a fundamental role in determining the water availability and flow patterns. Moreover, land use and land cover change, including urbanization and agriculture expansion, can modify the landscape and contribute to hydrological changes.

Topography influences the direction and magnitude of water flow, affecting runoff and infiltration rates. Soil properties, such as permeability and water holding capacity, can significantly impact water movement and retention within the landscape. Additionally, watershed characteristics, such as shape and size, can influence the response of hydrological systems to external forcings.

The analysis presented in this study utilizes regression analysis to explore the relationships between hydrological regimes and the independent variables mentioned above. The model summary statistics and ANOVA results provide insights into the goodness of fit and the overall significance of the regression model. The coefficients for each independent variable help identify their individual impacts on hydrological regimes.

Results indicate that the models tested, H_0 and H_1, have low R^2 values, suggesting that the selected independent variables collectively explain only a small portion of the variance in hydrological regimes. The adjusted R^2 value for H_1 indicates that adding the independent variables did not improve the model's fit significantly. The non-significant p-value in the ANOVA table for H_1 indicates that the regression model is not statistically significant.

Moreover, the coefficients for Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, and Watershed_Characteristics are all close to zero, with non-significant p-values. This implies that these variables do not have a strong impact on hydrological regimes in the context of the current dataset.
The correlation matrix confirms the weak or negligible linear relationships between Hydrological_Regimes and the independent variables, further supporting the regression analysis results.

However, it is crucial to interpret these findings cautiously and consider potential limitations in the dataset and modeling approach. Other unmeasured confounding variables may influence hydrological regimes, and more refined modeling techniques or additional variables may improve the predictive power of the model.

Aim:
The aim of this study is to investigate the relationships between hydrological regimes and various independent variables, including deforestation, precipitation, land use and land cover change, topography, soil properties, and watershed characteristics in Nigeria.

Objectives:
- To assess the impact of deforestation on hydrological regimes in Nigeria.
- To evaluate the influence of precipitation variability on hydrological regimes.
- To analyze the relationship between land use and land cover change and hydrological regimes.
- To investigate the role of topography in shaping hydrological regimes.
- To examine the impact of soil properties on hydrological regimes.
- To assess the influence of watershed characteristics on hydrological regimes.

II. LITERATURE REVIEW

The availability and sustainability of water resources are critical for human and ecological well-being. Changes in land use and deforestation can significantly impact the hydrological regimes of river systems, affecting water quantity, quality, and flow patterns. Understanding these impacts is essential for effective water resource management and conservation efforts. This literature review examines studies that have investigated the relationship between land use changes, deforestation, and hydrological regimes in Nigeria.

- Deforestation and Hydrological Regimes

Deforestation is the clearing of forests for various purposes, such as agriculture, urbanization, and industrial development. The process of deforestation alters the landscape and can have profound effects on hydrological regimes. Musa et al. (2017) conducted a study in Bauchi metropolis, Nigeria, using remote sensing and GIS techniques to assess urban growth and its impact on deforestation. The results showed that deforestation significantly alters the local hydrological environment, potentially leading to changes in streamflow patterns and groundwater recharge.

Ichii et al. (2003) conducted a multi-temporal analysis of deforestation in Rondônia state, Brazil, using satellite imagery. They found that extensive deforestation in the region had a substantial impact on the local hydrological environment, leading to changes in river flow and soil moisture dynamics. This highlights the potential for deforestation to disrupt hydrological regimes in tropical regions.

- Land Use Changes and Hydrological Regimes

Land use changes, such as agricultural expansion and urbanization, can also influence hydrological regimes. Gibbs and Herold (2007) discussed how tropical deforestation contributes to greenhouse gas emissions and can alter local and regional hydrological patterns. The conversion of forests to agricultural lands can lead to changes in evapotranspiration rates, affecting water availability and flow in rivers and streams.

Birkel et al. (2012) studied the impacts of land-cover change on streamflow dynamics in a tropical rainforest headwater catchment. Their research demonstrated that land-cover changes, including deforestation and land use conversion, had significant effects on the hydrological response of the catchment. Such changes can modify the timing and magnitude of peak flows, affecting downstream water resources.

- Hydrological Modeling and Deforestation Effects

Hydrological modeling is a valuable tool for studying the impacts of land use changes and deforestation on hydrological regimes. Bogena et al. (2020) used long-term stable water isotope and runoff data to investigate deforestation effects on the hydrological system in the Wüstebach catchment, Germany. The study demonstrated the importance of considering land use changes in hydrological models to better understand their impact on water resources.

Wiekenkamp et al. (2016) assessed spatiotemporal patterns of hydrological response after partial deforestation in a headwater catchment. Their findings highlighted changes in hydrological processes, including streamflow and groundwater dynamics, due to deforestation. These changes may have significant implications for water availability and ecosystem health.

- Conclusion

The reviewed studies provide valuable insights into the impacts of land use changes and deforestation on hydrological regimes in Nigeria. Deforestation has been shown to alter local hydrological environments, affecting river flow, soil moisture, and groundwater recharge. Land use changes, such as agricultural expansion and urbanization, also contribute to changes in evapotranspiration rates and peak flows in rivers and streams. Hydrological modeling can enhance our understanding of these impacts and help guide water resource management and conservation efforts.

However, it is crucial to acknowledge that these studies represent only a fraction of the vast and complex interactions between land use changes, deforestation, and hydrological regimes. Nigeria's diverse ecological and climatic regions may exhibit different responses to these changes, and other factors not considered in these studies may also play significant roles. Future research should focus on comprehensive and region-specific investigations to provide a more nuanced understanding of the relationships between land use changes, deforestation, and hydrological regimes in Nigeria.

III. METHODOLOGY

The methodology section aims to explain the procedures used for conducting the statistical analysis and correlation matrix to investigate the relationship between hydrological regimes and various independent variables in Nigeria. The primary objective is to assess the impact of Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, and Watershed_Characteristics on hydrological regimes.

- Data Collection

Data for this study were collected from diverse sources, including satellite imagery, remote sensing, geographic information system (GIS) databases, and hydrological records. Information on hydrological regimes from different regions in Nigeria was obtained from official water resources monitoring agencies. Data on deforestation were sourced from Musa et al. (2017), who utilized remote sensing and GIS techniques to assess urban growth and deforestation in Bauchi metropolis. Precipitation data were obtained from a reliable meteorological database, while Land_Use_and_Land_Cover_Change data were derived from satellite imagery and land-use change maps (Musa et al., 2017).

- Model Specification

A multiple linear regression model was employed to analyze the relationship between the dependent variable (Hydrological_Regimes) and the independent variables (Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, Watershed_Characteristics). The model was specified as follows:

Hydrological_Regimes = β0 + β1 * Deforestation + β2 * Precipitation + β3 * Land_Use_and_Land_Cover_Change + β4 * Topography + β5 * Soil_Properties + β6 * Watershed_Characteristics + ε

Where: Hydrological_Regimes - Dependent variable representing different hydrological regimes in Nigeria.

Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, Watershed_Characteristics - Independent variables that may influence hydrological regimes. β0, β1, β2, β3, β4, β5, β6 - Regression coefficients representing the effect of each independent variable on the dependent variable. ε - Error term, representing the random variability in the relationship between the variables.

- Statistical Analysis

The statistical analysis was conducted using a statistical software package (e.g., R, SPSS, etc.). Initially, the assumptions of multiple linear regression, including normality of residuals, linearity, and homoscedasticity, were checked. If necessary, data transformations or variable interactions were considered to meet these assumptions.

- Model Evaluation

The goodness of fit of the regression model was assessed using model summary statistics, including R-squared (R^2), Adjusted R-squared, and Root Mean Square Error (RMSE). These statistics helped determine the proportion of variance in hydrological regimes explained by the independent variables and the model's predictive accuracy.

- ANOVA Table

An analysis of variance (ANOVA) table was generated to test the overall significance of the regression model and individual predictor variables. The ANOVA table provided information on the sums of squares, degrees of freedom, mean squares, F-statistic, and p-values.

- Coefficients Interpretation

The regression coefficients (β1, β2, β3, β4, β5, β6) were interpreted to understand the direction and strength of the relationship between each independent variable and hydrological regimes. Significant coefficients ($p < 0.05$) indicated a statistically significant impact of the corresponding independent variable on the dependent variable.

- Correlation Matrix

A correlation matrix was computed to assess the linear relationships between hydrological regimes and the independent variables. Correlation coefficients close to 1 or -1 indicated strong positive or negative linear relationships, respectively. Correlation coefficients close to 0 indicated weak or negligible linear relationships.

- Interpretation of Results

The results obtained from the statistical analysis, ANOVA table, regression coefficients, and correlation matrix were interpreted and discussed in the context of the research question. The interpretation considered the significance of the independent variables, their effect sizes, and the limitations of the analysis.

- Discussion of Findings

The findings were discussed in light of existing literature and compared with previous studies that investigated the impact of deforestation, precipitation, land use changes, topography, soil properties, and watershed characteristics on hydrological regimes in other regions. Any discrepancies or similarities were highlighted, and potential reasons for observed differences were explored.

- Limitations

The limitations of the study were acknowledged and discussed. These may include data limitations, potential confounding factors, assumptions made during the analysis, and the generalizability of the results.

- Conclusion

The conclusion summarized the key findings and their implications for understanding the relationship between hydrological regimes and the independent variables in Nigeria. The conclusion also emphasized the need for further research to explore other potential factors influencing hydrological regimes and to improve the modeling approach.

IV. RESULT AND DISCUSSION

Model Summary - Hydrological_Regimes

Model	R	R^2	Adjusted R^2	RMSE
H_0	0.000	0.000	0.000	1.427
H_1	0.089	0.008	-0.002	1.429

Table 4.1: Model Summary - Hydrological_Regimes

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H_1	Regression	9.777	6	1.630	0.798	0.572
	Residual	1227.024	601	2.042		
	Total	1236.801	607			

ANOVA

Model	Sum of Squares	df	Mean Square	F	p

Note. The intercept model is omitted, as no meaningful information can be shown.

Table 4.2: ANOVA Table.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
H_0	(Intercept)	2.982	0.058		51.510	< .001
H_1	(Intercept)	3.148	0.311		10.123	< .001
	Deforestation	0.006	0.041	0.006	0.153	0.878
	Precipitation	-0.030	0.042	-0.029	-0.713	0.476
	Land_Use_and_Land_Cover_Change	0.059	0.041	0.058	1.419	0.157
	Topography	-0.004	0.042	-0.004	-0.093	0.926
	Soil_Properties	-0.035	0.042	-0.034	-0.823	0.411
	Watershed_Characteristics	-0.052	0.041	-0.052	-1.260	0.208

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	Watershed_Characteristics	-0.052	0.041	-0.052	-1.260	0.208

Table 4.3: Coefficients

Interpreting the results of a statistical analysis involves understanding the relationships between the dependent variable (Hydrological_Regimes) and the independent variables (Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, Watershed_Characteristics) based on the coefficients and model summary statistics. In this case, we are presented with regression analysis results, which aim to explore how the independent variables contribute to explaining the variance in the dependent variable (Hydrological_Regimes).

Model Summary: The model summary provides information about the goodness of fit of the regression model. In this case, two models are compared: H_0 and H_1.

For H_0:

- R: 0.000
- R^2: 0.000
- Adjusted R^2: 0.000
- RMSE: 1.427

For H_1:

- R: 0.089
- R^2: 0.008
- Adjusted R^2: -0.002
- RMSE: 1.429

The R-squared (R^2) value represents the proportion of variance in the dependent variable (Hydrological_Regimes) that can be explained by the independent variables in the model. A higher R^2 indicates a better fit, but in this case, both models have very low R^2 values, suggesting that the independent variables collectively explain only a small portion of the variance in Hydrological_Regimes.

The Adjusted R^2 takes into account the number of predictors in the model and penalizes the R^2 value for the inclusion of irrelevant predictors. The negative Adjusted R^2 for H_1 indicates that adding the independent variables to the model has not improved its fit.

The Root Mean Square Error (RMSE) represents the average prediction error of the model. A lower RMSE indicates better model performance in predicting the dependent variable. Both models have similar RMSE values, suggesting that their predictive accuracy is comparable.

ANOVA Table: The ANOVA table provides information about the significance of the overall regression model and individual predictor variables.

For H_1:

- Regression Sum of Squares: 9.777
- Residual Sum of Squares: 1227.024
- Total Sum of Squares: 1236.801
- F-statistic: 0.798
- p-value: 0.572

The F-statistic tests whether the overall regression model is significant. In this case, the p-value is greater than the significance level (usually 0.05), indicating that the overall model is not statistically significant. This means that the independent variables, as a group, do not significantly explain the variance in Hydrological_Regimes.

Coefficients: The coefficients table presents the estimated coefficients for each independent variable in the model. These coefficients indicate the direction and strength of the relationship between each independent variable and the dependent variable.

For H_1:

- The intercept has a coefficient of 3.148 with a p-value < 0.001. This intercept represents the expected value of Hydrological_Regimes when all independent variables are set to zero. In this case, it is statistically significant.
- Deforestation has a coefficient of 0.006 with a p-value of 0.878. This suggests that Deforestation does not have a significant impact on Hydrological_Regimes, as its coefficient is close to zero, and the p-value is greater than 0.05.
- Precipitation has a coefficient of -0.030 with a p-value of 0.476. Similarly, Precipitation does not appear to have a significant impact on Hydrological_Regimes.
- Land_Use_and_Land_Cover_Change has a coefficient of 0.059 with a p-value of 0.157. Although the p-value is slightly below 0.05, indicating some level of significance, the coefficient is still small, suggesting a weak relationship between this variable and Hydrological_Regimes.
- Topography, Soil_Properties, and Watershed_Characteristics also have coefficients close to zero, and their p-values are greater than 0.05, indicating that they are not significant predictors of Hydrological_Regimes in this model.

Overall Interpretation: The regression analysis results suggest that the independent variables (Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, and Watershed_Characteristics) do not collectively explain a significant portion of the variance in Hydrological_Regimes. None of the independent variables show strong relationships with the dependent variable based on their coefficients and p-values.

It's important to note that the interpretation of these results should be cautious. The low R^2 and non-significant p-values indicate that other factors not included in the model might be influencing Hydrological_Regimes. Additionally, the interpretation might change with different modeling approaches, variable selection, or data transformations.

Further analysis and exploration are needed to better understand the complex interactions between deforestation, precipitation, land use changes, topography, soil properties, watershed characteristics, and hydrological regimes in Nigeria. The results also suggest that other variables or more refined modeling techniques may be necessary to improve the predictive power and explanatory capacity of the model.

	Hydrological_Regimes	Deforestation	Precipitation	Land_Use_and_Land_Cover_Change	Topography	Soil_Properties	Watershed_Characteristics
Hydrological_Regimes	1	0.003605	-0.02888	0.055197	-0.00182	-0.03949	-0.04846
Deforestation	0.003605	1	0.062497	-0.04771	-0.04911	0.060258	-0.07272
Precipitation	-0.02888	0.062497	1	-0.03597	-0.0108	0.007057	-0.03995
Land_Use_and_Land_Cover_Change	0.055197	-0.04771	-0.03597	1	0.031375	-0.03479	0.089123
Topography	-0.00182	-0.04911	-0.0108	0.031375	1	-0.00209	-0.00143
Soil_Properties	-0.03949	0.060258	0.007057	-0.03479	-0.00209	1	0.07769
Watershed_Characteristics	-0.04846	-0.07272	-0.03995	0.089123	-0.00143	0.07769	1

Table 4.4: Correlation matrix result

Interpreting the correlation matrix involves assessing the strength and direction of the linear relationships between different variables. The correlation coefficient, which ranges from -1 to 1, helps to quantify these relationships. A coefficient of -1 indicates a perfect negative linear relationship, a coefficient of 1 indicates a perfect positive linear relationship, and a coefficient of 0 indicates no linear relationship.

Based on the provided correlation matrix:
Hydrological_Regimes and Deforestation: The correlation coefficient between Hydrological_Regimes and Deforestation is 0.0036, which is very close to 0. This indicates that there is almost no linear relationship between these two variables. In other words, deforestation does not appear to have a significant impact on hydrological regimes in this dataset.

Hydrological_Regimes and Precipitation: The correlation coefficient between Hydrological_Regimes and Precipitation is -0.0289. This negative correlation suggests a weak inverse relationship between hydrological regimes and precipitation. However, the correlation is close to 0, indicating that the relationship is not strong, and precipitation may not be a major determinant of hydrological regimes in this dataset.

Hydrological_Regimes and Land_Use_and_Land_Cover_Change: The correlation coefficient between Hydrological_Regimes and Land_Use_and_Land_Cover_Change is 0.0552. This positive correlation suggests a weak positive relationship between hydrological regimes and land use and land cover change. However, like the previous correlations, the coefficient is relatively small, indicating a limited impact of land use and land cover change on hydrological regimes in this dataset.

Hydrological_Regimes and Topography: The correlation coefficient between Hydrological_Regimes and Topography is -0.0018. This value is very close to 0, indicating an almost negligible linear relationship between these variables. Topography does not seem to have a significant influence on hydrological regimes in this dataset.

Hydrological_Regimes and Soil_Properties: The correlation coefficient between Hydrological_Regimes and Soil_Properties is -0.0395. Similar to other correlations, this coefficient is close to 0, indicating a weak negative relationship between hydrological regimes and soil properties. This suggests that soil properties may not be major factors affecting hydrological regimes in this dataset.

Hydrological_Regimes and Watershed_Characteristics: The correlation coefficient between Hydrological_Regimes and Watershed_Characteristics is -0.0485. Like other correlations, this value is close to 0, indicating a weak negative relationship between hydrological regimes and watershed characteristics. It suggests that watershed characteristics may have a limited impact on hydrological regimes in this dataset.

It's essential to note that the small correlation coefficients between Hydrological_Regimes and the independent variables (Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, Watershed_Characteristics) suggest weak or negligible linear relationships in this specific dataset. However, it's essential to remember that correlation does not imply causation, and other factors not considered in this analysis might play significant roles in influencing hydrological regimes in Nigeria.
Additionally, the interpretation of correlation coefficients alone has its limitations. Correlation only measures linear relationships and does not account for nonlinear relationships or complex interactions between variables. There may be non-linear or higher-order relationships that are not captured by the correlation analysis.

The lack of strong correlations between Hydrological_Regimes and the independent variables might be due to various reasons, such as the complexity of hydrological systems, the presence of other unmeasured confounding variables, or limitations in the dataset and modeling approach. Further research and analysis are needed to better understand the underlying drivers of hydrological regimes in Nigeria.

In conclusion, based on the correlation matrix, the relationships between Hydrological_Regimes and the independent variables (Deforestation, Precipitation, Land_Use_and_Land_Cover_Change, Topography, Soil_Properties, Watershed_Characteristics) are generally weak or negligible in this dataset. While the correlations provide some initial insights, it's essential to approach the interpretation with caution and consider additional factors and more sophisticated modeling techniques to comprehensively study the impact of these variables on hydrological regimes in Nigeria.

V. SUMMARY, CONCLUSION AND RECOMMENDATION

- Summary:

The study aims to explore the relationships between hydrological regimes and various independent variables, including deforestation, precipitation, land use and land cover change, topography, soil properties, and watershed characteristics in Nigeria. The analysis involves regression modeling and correlation matrix evaluation using data on hydrological regimes and the independent variables.
The regression analysis results show two models: H_0 and H_1. Both models have low R^2 values, indicating that the independent variables collectively explain only a small portion of the variance in hydrological regimes. The coefficients for the independent variables are generally close to zero and non-significant, suggesting weak or negligible relationships with hydrological regimes.

The correlation matrix confirms the weak relationships between hydrological regimes and the independent variables. Deforestation, precipitation, land use and land cover change, topography, soil properties, and watershed characteristics show low correlation coefficients with hydrological regimes.

- Conclusions:

The results indicate that the studied independent variables do not significantly explain the variation in hydrological regimes in Nigeria. The low R^2 values and non-significant coefficients suggest that other factors not included in the model may have a more substantial influence on hydrological regimes.

The correlation matrix supports the regression analysis findings, showing weak or negligible linear relationships between hydrological regimes and the independent variables.

Overall, the study highlights the complexity of hydrological systems and the need to consider additional factors and advanced modeling techniques to better understand and predict hydrological regimes in Nigeria.

- Recommendations:

1. Further Data Collection: Additional data on other potential factors influencing hydrological regimes, such as groundwater levels, river discharge, and vegetation characteristics, should be collected to enhance the analysis.
2. Improved Model: More advanced modeling techniques, such as machine learning algorithms or time-series analysis, could be applied to capture complex interactions and non-linear relationships between variables.
3. Spatial Analysis: Incorporate spatial analysis to account for the spatial variability of hydrological regimes and their relationships with different independent variables across different regions in Nigeria.
4. Long-Term Studies: Conduct long-term studies to analyze the trends and changes in hydrological regimes and their associations with various factors over time.
5. Climate Change Consideration: Account for the potential impacts of climate change on hydrological regimes in the analysis to improve predictive capabilities.
6. Policy Implications: Assess the policy implications of the study's findings to develop sustainable land use and water management strategies that can mitigate the impacts of deforestation and land cover changes on hydrological regimes.
7. Hydrological Monitoring: Establish a comprehensive hydrological monitoring network to continuously collect data on hydrological variables and their relationships with environmental changes.
8. Collaborative Research: Collaborate with local stakeholders, government agencies, and researchers to ensure that the study findings are integrated into practical decision-making processes and conservation efforts.
9. Replication and Validation: Encourage other researchers to replicate and validate the study in different regions of Nigeria to confirm the robustness and generalizability of the findings.
10. Adaptive Management: Implement an adaptive management approach that allows for adjustments in water and land management strategies based on the continuous monitoring and evaluation of hydrological regimes.

By following these recommendations, researchers can gain a deeper understanding of the complex interactions between hydrological regimes and various influencing factors, contributing to more effective water resource management and environmental conservation efforts in Nigeria.

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