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EFFECT OF LAND USE ON WATER DISCHARGE IN HUMID REGIONS: AN EXAMPLE FROM SOUTHERN NIGERIA

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ABSTRACT

The effect of land use on water discharge is one of the most important environmental problems of our times, particularly in the humid regions. However, there exists controversy over the hydrological effects of land use in the humid tropics. This paper therefore examines the effect of land use on water discharge in southern Nigeria. The study area is located in the Calabar River basin. Standard field and laboratory methods were adopted in obtaining the data on water discharge and land use, for the study. From the Pearson's Product Moment correlation analysis of the relationship between land use and total mean discharge measurement in the basin, the result shows a strong negative relationship with r = -0.717 and significant at the 0.05 confidence level. The regression analysis revealed an F-ratio of 7.733 which was again significant at the 0.05 confidence level. Since, p < 0.05 level of significance that was set for this study, the null hypothesis was rejected and the alternative accepted. It is therefore concluded that land use has negatively affected discharge. Re-vegetation has been recommended for the area.

KEYWORDS: Land use, Calabar river basin, hydrological effects, re-vegetation, water discharge

1. INTRODUCTION

The effect of land use changes on river flow is one of the most important environmental problems of our time (Kimaro, et al., 2003). According to Sahin and Hall (1996), the effect of land use change on hydrology and water resources is a problem which will not go away. Notably, changes in land use alter both runoff behaviour and the balance that exists between evaporation, groundwater recharge and stream discharge in specific areas and in the entire watershed, with considerable consequence for all water users (Sahin & Hall, 1996; Defries & Eshleman, 2004).

Land use change has been found to have affected the hydrology of a river basin. In fact, man exercises some influence on the hydrological cycle through the way he uses the land. Although the impact of man on the environment is quite clear in urban areas, it is no less important in rural areas. According to Ayoade (1988), through man's arable and pastoral farming activities, as well as lumbering, he can and does exert some influence on the local and even regional hydrological cycles.

Speculations about the effects on runoff of felling a forest, or one of the other land use changes brought about by man's activities has continued for many centuries. Only at the end of the nineteenth century were experiments commenced to determine what hydrological differences resulted from alteration in land use (Rodda, 1969). However, the impact of land use changes on the hydrological system behaviour of watershed is a major interest to water resources management.

The hydrological effects of land use changes in the tropics have been a cause of controversy and debate for many years, especially the effects of deforestation and afforestation (Lørup & Hansen, 1997). In the tropics, the impact of deforestation and afforestation on the dry season flow are conflicting. For instance, in the Mbeya experiment, the dry season flow was higher from a catchment with traditional smallholder cultivation than with forest cover, even on steep slopes (Edwards, 1979). Similar results were observed after deforestation of woodland in Zambia (Mumeka, 1986) and montane hardwood

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forest in Taiwan (Hsia & Koh, 1983). Afforestation of dry grassland and scrubland in South Africa resulted in a highly significant decrease in low flows (Smith and Scot, 1992).

However, Hardjono (1980) showed that the dry season flow was higher from reforested catchment based on data from a seriously degraded upland catchment in central Java. Also, Sandström (1995) in a study in semiarid Tanzania claimed that base flow was considerably higher from a catchment covered by *Miombo* woodland than from a catchment with mixed grazing and cultivation. In Kenya, colonial reports stated that one of the benefits of forest reserves and plantation was conservation of soil moisture and permanent springs (Tiffen et al., 1994) whereas tree planting has been prohibited in certain areas in South Africa to avoid reduced streamflow (Pereira, 1973).

This uncertainty about the effect of land use on dry season flow in the tropics is well illustrated by the following quote from Bruijnzeel (1988): "in fact in a country like Indonesia the issue is as hot as it was some sixty years ago." This may have been as a result of limited number of carefully conducted catchment experiments in the tropical zone. As observed by Bruijnzeel (1987), there is a particular dearth of studies concerning the impacts on the streamflow of shifting cultivation or conversion of natural forest to annual cropping which are two of the major types of forest conversion in the tropics.

Some studies suggest that river discharge may increase as much as 50 per cent as a result of forest removal (Edwards et al., 1999; Sahin & Hall, 1996; Mustard & Fisher 2004, Galster et al., 2006; Nelson et al., 2008). However, Bevan (2000) notes that a few studies have resulted in contradictory findings, though this may be explained by variations in the intensity and extent of soil compaction during logging operations. Also, most case studies originate from smaller watersheds where water discharge variations due to land cover change are easier to quantify as a result of more homogeneous weather conditions, soil types and land use (Costa et al., 2003).

In his study on channel and morphological response of two watersheds to urbanisation in Benin City, Aziegbe (2006) has shown that changes in stream flow regime were brought about by the conversion of natural cover to different land uses as a result of urbanisation in Benin City. Also, Jimoh and Iroye (2009) discovered that total runoff positively correlated with percentage built-up area (r = 0.93) in Illorin, Nigeria. While dry season discharge correlated positively with percentage forest area (r=0.99), there was a negative correlation between the rainy season runoff and percentage forest area (r=-0.95). Hence, the more the built-up area, the less the discharge in the dry season while the reverse was the case with the rainy season.

Most flooding is often attributed to land use change or outright removal of forest. For instance, Eze (2001) attributed most flood occurrences in Lagos State to the increased forest removal in the Ogun watershed. According to the author, the Ogunpa flood disasters in 1973, 1978 and 1980 were attributed largely to the clearance of forest along the banks of the rivers. Similarly, flooding has become an annual occurrence in Ekureku community in Abi L.G.A of Cross River State ever since the villagers wiped out the rainforest completely from the area in 1987 through a deliberate action (Eze, 2001).

From the literature, change in land use produces a corresponding change in the discharge of the river or stream. Particularly, forest conversion to other land uses increases the runoff immediately after rainfall, hence, increases the discharge and the possibility of flooding in a particular area. However, during the dry season, removal of forest has been accompanied by low discharge. This work is the author's contribution to the understanding of the effect of land use on water discharge in a humid tropical watershed.

2. Study area

2.1. Location

This study was carried out in the Calabar river basin in southern Nigeria. The Calabar river is a major tributary of the Cross river. The river basin is located in the south-south geopolitical zone of Nigeria. It spans approximately between Longitudes 18^0 10'E and 18^0 35'E of the Greenwich Meridian and Latitudes 5^0 00'N and 5^0 40′N of the Equator.

2.2. Climate

Rainfall in the study area is continuous throughout the year, but with two maxima and to periods of less rain. The average annual rainfall is above 2000mm. Temperature rarely falls below 19^0C and averages 27^0C all year round (Olaniran, 1987). The average daily maximum is above 24^0C with a range of 6^0C; and seasonal variation of the same amount between the hottest month (February) and the coolest month (August) (National Bureau of Statistics, 1993 and 2006). Expectedly therefore evaporation is high. The relative humidity is usually high, between 80 and 100 per cent with the air often being saturated with water vapour resulting in precipitation in the morning during the rainy season. Relative humidity drops with the rise in temperature to about 70 per cent in the afternoon during the dry season and rarely falls below that value. Vapour pressure of the air averages 29 millibars throughout the year (Cross River Basin Development Authority, 1995). With the above climatic characteristics, the area is considered as a humid tropical environment. The mean monthly climatic regime of thirty (32) years (1977 – 2008) for Calabar is shown in Table 1.

Table 1: Mean Monthly Climatic Regime between 1977 and 2008 in Calabar river basin

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall(cm)	38.96	40.59	139.11	210.46	254.30	376.13	427.43	382.13	386.81	305.50	145.09	78.14
Temperature(^{o}C)	26.89	28.32	27.46	27.62	26.97	26.30	25.32	25.11	25.79	26.41	27.12	27.46
Relative humidity(%)	78.55	79.56	81.70	82.50	83.29	85.10	87.25	87.70	86.64	85.00	84.53	81.25
Sunshine (hours)	3.80	3.76	3.33	3.60	3.76	2.93	2.10	1.30	2.09	2.80	4.13	4.33
Evapotranspiration (cm)	3.90	4.18	3.64	2.93	2.61	1.97	1.50	1.30	1.69	1.90	2.33	3.30

Source: Nigeria Meteorological Station (NIMET), Calabar

2.3. Vegetation

The original vegetation of the entire Calabar river basin was the tropical rainforest. However, most of this vegetation in the study area has been removed as a result of agricultural, road construction, tree logging, industrial and residential activities. For instance, some of the original vegetation has been replaced by rubber and palm plantations. Though, the general vegetation can still be classified under the tropical rainforest, it is only in a few places that the structural organisation can be clearly distinguished. Various species of plants are found within the study area. The major ones are *Gmalina aborea* (Gmelina),*Pycnanthus anglolensis*(abakan), *Raphia vinifera* (raphia), *Brachystegia eurycoma, Piptadeniastrum africana, Guarea spp*., *Khaya spp*. and *Elaeis guineensis*(palm tree). Others are *Antiaris africana*, *Celtia spp*., *Staudtia stiptata* (Iyip Okoyo), *Poga oleosa* (Enoi), *Lovolatri chilliades* (cedar), *Rhizophora spp*. (red mangrove) and *Trema spp*. (charcoal tree).

2.4. Socio-economic activity

The major socio-economic activity in the study area is farming. This has resulted in the conversion of forests to farmland, with a possible alteration of the water discharge regime. Other socio-economic activities in the area include lumbering, trading and fishing.

3. Method of study

Data for this study include areal extent of land use and discharge. The drainage map of the basin was obtained from ortho-photomap of the area for the year 2005. Eleven (11) third order sub-basins were demarcated within the entire study area using the Stahler (1957) method. In geomorphology, third-order basins are considered to be mature for morphometric studies. This also provided a common base for discharge measurement and statistical analysis. Measurement of discharge was carried out in the field for all the sub-basins using the velocity-area technique as described by Chow (1964), Gregory and Walling (1973), Ayoade (1988) and Chup (2005). Water discharge measurements from streams were taken five times each, during the dry and wet seasons of 2009/2010.

Land use map of the basin for 2008 was obtained from Efiong (2010). The drainage map was superimposed on the 2008 land use map (Figure 1). The area covered by each of the land uses were calculated for the different sub-basins. Also, the percentages of each of the land uses were determined for the sub-basins. Fallow land/ scattered cultivation was the only land use that was found in ten of the eleven sub-basins, hence, it was chosen as the representative land use type to be related with discharge. The percentage change in this land use was correlated with the total mean discharge of respective sub-basins. A bivariate regression analysis was then conducted to examine the effect of land use (fallowland/scattered cultivation) on water discharge. The hypothesis is that water discharge is not significantly affected by land use in the humid tropics.

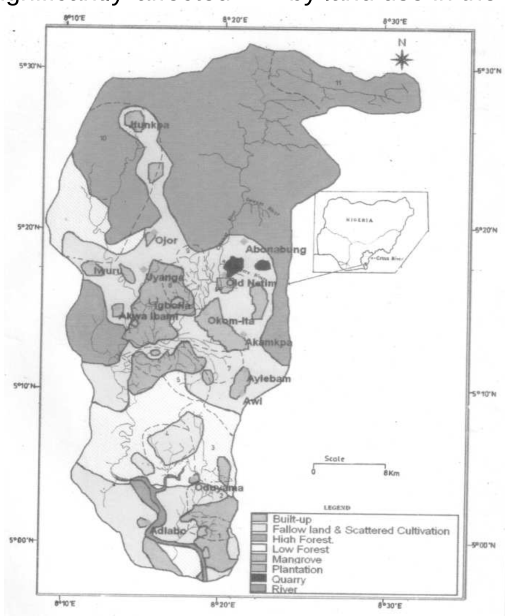

Figure 1. Superimposed drainage on land use map

4. Results

Table 2 presents the area and percentages of different land uses for each of the sub-basins in the Calabar river basin. Fallow land/scattered cultivation is the only land use type that is found in all the sub-basins except one (sub-basin 11). High forest is found in only three of the sub-basins while plantation occurs in six of the sub-basins. Also, built-up is found in six and low forest in five sub-basins.

Table 2: Percentage coverage of different land use types in each of the sub-basins

Sub-basin	Land use															
	High forest		Low forest		Plantation		Fallow land/ scattered cultivation		Built-up		Mangrove		Quarry		Total area	Total %
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%		
1	0	0	0	0	9.51	75.30	3.12	24.70	0	0	0	0	0	0	12.63	100
2	0	0	0	0	11.20	67.35	5.43	32.65	0	0	0	0	0	0	16.63	100
3	0	0	17.16	75.43	0	0	2.86	12.57	2.73	12.00	0	0	0	0	22.75	100
4	0	0	12.16	46.10	0	0	13.75	52.12	0	0	0	0	0	0	26.38	100
5	0	0	4.10	24.40	4.80	28.57	6.00	35.71	1.90	11.31	0	0	0	0	16.80	100
6	0	0	1.37	8.25	10.20	61.45	4.00	24.09	1.03	6.20	0	0	0	0	16.60	100
7	0	0	0	0	0.40	5.33	5.10	68.00	2.00	26.67	0	0	0	0	7.50	100
8	0	0	0	0	7.10	61.74	2.40	20.87	2.00	17.39	0	0	0	0	11.50	100
9	0	0	0	0	0.90	11.61	6.85	88.39	0	0	0	0	0	0	7.75	100
10	20.04	41.75	5.00	10.42	0	0	10.84	25.58	12.12	25.25	0	0	0	0	48.00	100
11	39.68	100	0	0	0	0	0	0	0	0	0	0	0	0	39.68	100

Source: Author's research (2009)

Table 3 shows the percentages of fallow land/scattered cultivation land use in each of the drainage sub-basins against the corresponding discharge (wet season, dry season and total mean discharge).

Table 3: Percentage of land use against discharge

Basin no.	% of Fallow land/scattered cultivation	Mean wet season discharge	Mean dry season discharge	Mean discharge
1	24.70	8.96	1.56	5.53
2	32.65	9.15	1.90	5.53
3	12.57	13.51	2.75	8.13
4	52.12	12.14	4.14	8.14
5	35.71	9.19	2.30	5.75
6	24.09	9.02	2.55	5.79
7	68.00	1.76	0.22	0.99
8	20.87	8.30	2.20	5.25
9	88.39	3.04	1.01	2.03
10	25.58	13.65	3.39	8.52
11	0.00	11.32	3.10	7.52

Source: Author's research (2009)

The results of the statistical analyses are presented in tables 4 – 7.

Table 4: Zero-order correlation matrix discharge and land use

	Land use (1)	Mean wet season discharge (2)	Mean dry season discharge (3)	Mean total discharge (4)
1	1	-0.741**	-0.498	-0.717*
2		1	0.855*	0.993**
3			1	0.896**
4				1

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)
Source: Analysis by author (2010)

Table 5: Regression model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.701[a]	.492	.428	1.88057

a. Predictors: (Constant), Land use
Source: Analysis by author (2010)

Table 6: Analysis of variance (ANOVA) for the regression

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	27.348	1	27.348	7.733	.024[a]
	Residual	28.292	8	3.537		
	Total	55.640	9			

a. Predictors: (Constant), Land use

b. Dependent Variable: Mean total discharge

Source: Analysis by author (2010)

Table 7: Regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.346	1.172		7.123	.000
	Land use	-.073	.026	-.701	-2.781	.024

a. Dependent Variable: Mean total discharge

Source: Analysis by author (2010)

5. DISCUSSIONS

From the Pearson Product Moment correlation analysis of land use with discharge measurements for the wet season, dry season and total mean discharge in the basin, the result shows (Table 4) that land use strongly correlated with the three discharge measurements. The correlation coefficients, r between land use on one hand and mean wet season, mean dry season and mean total discharge on the other hand were -0.741, -0.498 and -0.717 respectively.

The strong negative correlation coefficient implies that, the larger the percentage of sub-basin area under fallow/scattered cultivation, the lower the discharge. Invariably, the lower the percentage of forest cover, the lower the discharge. As forest cover increases, discharge also increases in the Calabar river basin. Hence, as land under forest cover increases, discharge increases also. This is also clearly shown on the regression plot of the relationship between discharge and land use in the area (Figure 2).

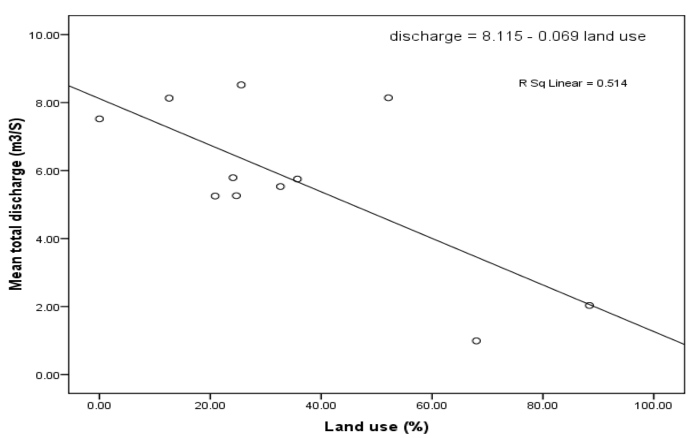

Figure 2. Regression plot of relationship between discharge and land use

The finding of this study is different from most of the other studies as reviewed. This may be due to the fact that base flow discharge is used in the present study while others considered both the quick flow (direct runoff) and base flow. Such may be more useful in flood management while the present study looks at water resource development. It is also noticed by the author that, many streams in the study area are drying up due to siltation. Siltation reduces the volume of water flow.

The model of the relationship is given by:

Discharge = 8.36 – 0.069 fallow land/cultivation

This relationship has a coefficient of determination (R-square) equal to 0.514 or 51.40 per cent (Table 5). This suggests that 51.40 per cent of variation in the dependent variable (discharge) may be as a result of or has been explained by the independent variable (fallow land/scattered cultivation). From the model, given a unit increase in fallow/ cultivated land, discharge will decrease by 0.069.

It should be noted that climatic factors were held constant in the present study. But the Calabar river basin falls within the humid tropical environment. This means that rainfall amount and intensity are generally high with the rain falling in almost all the months of the year (Table 1). Therefore, the effect of such on discharge cannot be denied.

Although the stream discharge decreases as forest land is changed to other land uses, flooding is enhanced as pore spaces are closed up resulting in reduced infiltration. Hence, during the rainy season, many segments of the lower part of the basin with little or no forest cover are flooded. Thus, if the current rate of change in land use continues, flooding problems currently being experienced in the basin particularly in segments along the Calabar-Itu highway might certainly be on the increase. This may worsen the already poor state of the road, posing more hardship to the road users and also threatening the life and property of its citizens. Also, Calabar Metropolis which is already faced with annual flooding problems usually associated with the wet season may suffer the more as whatever the ecological problem in the upstream segment is most likely to be transmitted to the downstream areas.

6. Test of hypothesis

H_o: Water discharge is not significantly affected by land use

H_1: Water discharge is significantly affected by land use

In testing the hypothesis, we make use of the F-ratio in table 6, where the F-ratio of 7.733 is significant at the 0.024 confidence level. Since, $p < 0.05$ level of significance that was set for this study, the null hypothesis is rejected and the alternative accepted. By rejecting the null hypothesis, it means that the variations in discharge did not occur by chance, but was as a result of the dependent relationship with land use. Hence, water discharge is significantly affected by land use (fallow land /scattered cultivation) in the humid tropics.

7. CONCLUSIONS

This study examined the effect of land use on water discharge in the humid region southern Nigeria with the Calabar river basin as a case study. The findings of this study show that water discharge is significantly affected by land use (fallow land/scattered cultivation) in the humid tropics. Also, there is a negative relationship between fallow land/ scattered cultivation and water discharge in the area. The negative correlation coefficient suggests that, the larger the percentage of sub-basin area under fallow/scattered cultivation, the lower the discharge. This finding is different from most of others reported in the literature. This may be due to the fact that base flow discharge is used in the present study while others considered both the quick flow (direct runoff) and base flow. Even though land development has shifted to the basin, it can still be done in a sustainable manner through re-vegetation.

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