Cumulative environmental change in the lower Niger

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Abstract The Niger–Benue waterway, with a total water-route distance of about 2200 km, provides a natural artery and has great potential for water transportation from the coastal area of Warri and Port Harcourt to the middle belt and from there to the northeastern and northwestern frontiers of Nigeria. The long period of the neglect of the lower Niger has resulted in blockage of the channel of the waterway. The blockage and seasonal fluctuation of the river has confined the effective service of even small ferries to particular areas and periods of the year. In view of this, the present project of dredging was conceptualized to improve the navigability of the water route so as to promote both local and international economic integration. Statistical methods (regression) were used to aid understanding of the water resource dynamics of the lower Niger. Uncertainty in the water resource processes as a result of large scale deforestation, due to dredging activities, was reduced through the adoption of a water balance approach for the local catchments of three stations (Onitsha, Lokoja and Baro). Ranges of parameters of about 20–15% reduction in evapotranspiration contribution to rainfall at Onitsha, to 15–10% reduction at Baro were assumed. The response of the water resource to the expected change was estimated and the trend in water resources properly determined and suggestions made for sustainable use of the excess water resources.

Key words deforestation; evapotranspiration; environmental change; River Niger

INTRODUCTION

The last military government in Nigeria, through the Petroleum (special) Trust Fund (PTF), awarded a contract for the dredging of the lower Niger River for the purpose of developing the inland waterways and some river ports; a project that, inherently, is capable of causing great cumulative environmental change over time. It has caused perturbations to the hydroclimatic components in the area. Although the present civilian government temporarily halted the project, it has since given approval to the project and the debate on the benefits or otherwise of the dredging continues to rage without adequate attention to the constraints and uncertainty in quantitative estimates of the change in hydrological components such as rainfall, evaporation, runoff, water level (stage height) etc., all of which, if put together, will determine the effectiveness of the dredging for navigation and other uses (Henderson-Sellers & Gornitz, 1984).

AIM AND OBJECTIVES

This paper aims to assess how cumulative environmental change through deforestation affects the water resource potential of the lower Niger environment. The objectives are: (a) to use a simple water balance model and multivariate statistical analysis to estimate quantitatively the impact of human activities on water quantity and availability within the lower Niger environment; (b) to determine the trend of changes in water resources in the area; and (c) to identify a context relevant and eco-friendly water management strategy in the face of the dredging of the lower Niger.

STUDY AREA

The area is part of the lower Niger River in Nigeria. It extends for about 317 km along the waterways, southward, from Baro (6°25′E, 8°36′N) in Niger State through Lokoja (6°45′E, 7°47′N) in Anambra State. Within this reach of the River Niger, the rivers Benue and Guarara are the major tributaries. Lokoja is located at the confluence of the Niger and Benue. Upstream at Baro, the Kanji Dam, which greatly controls sediment transport from further upstream, is the major feature on the Niger. Southward after Onitsha, the Niger divides into a number of distributaries, which together form the Niger Delta, a fragile environment, highly susceptible to anthropogenic activities but of high economic value and political significance to the country of Nigeria because of its oil-rich deposits.

Climatically, the study area is located in the tropical sub-humid region of Nigeria. Baro is characterized by warm days (29–32°C) and moderately cool nights (~21°C). Humidity is usually high at night (70–80%), but reduced to 50–60% by day by mixing with the drier upper level air. Mean annual rainfall is about 1100 m with an average of 1 rain day per month.

Onitsha has high humidity ranging between 80% in January and over 90% in July. Average daily temperate is about 20°C. Mean monthly annual rainfall is about 1600 mm. With 3–10 months of rainy season, it has more than 90 rain days per year with an average monthly number rain days of 9.5.

Lokoja is located midway between Baro and Onitsha and, like Baro, is usually characterized by warm days (29–30°C) and moderately cool nights (about 21–22°). Humidity ranges between 75 and 80%. Monthly annual rainfall is about 1400 mm with two distinct seasons (dry and wet seasons). The climate of the entire study area is highly influenced by the two principal air masses blowing over the surfaces. These are the warm, dry and dusty tropical continental (CT), and the warm and moist tropical maritime (MT).

Geologically the reach of the Niger River under study is made up of more resistant rocks of the Basement Complex, though the valley floor is made up of alluvial sediments which include gravels, salts, sits and clays. The major soils are hydromorphic and alluvial sedimentary. Vegetation is mainly riparian forest and wooded grassland. Human activities along the river includes fishing, peasant farming (agriculture) and quarrying. Apart from Lokoja which is the state capital and Onitsha which is a commercial city, most settlements along the Niger within the study area are villages whose inhabitants are principally engaged in primary activities.

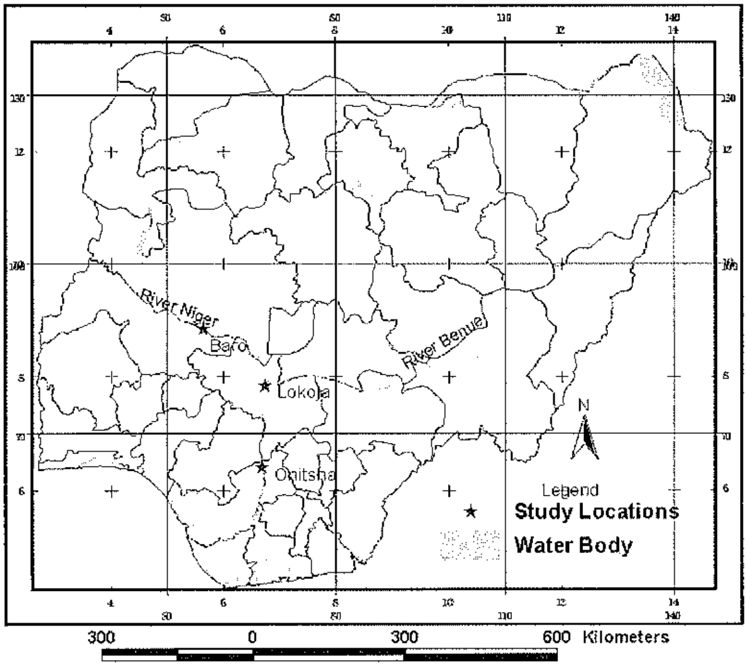

Fig. 1 Nigeria showing the study locations.

METHODOLOGY

The research used data from three stations (Baro, Lokoja and Onitsha). A simple water balance approach was used to analyse the effect of deforestation on the water resource. The potential evapotranspiration components for each of the three stations were established using the Thornthwaite empirical formula:

$$PE\ (\text{cm}) = 1.6F\,(10T_a / I)^a$$

where PE is potential evapotranspiration; F is the day length and month length factor; T_a is mean monthly air temperature; and a is a constant (cubic function of I) given by:

$$a = 10^{-6}\, I^3 \times 0.675 - 10^{-4}\, I^2 \times 0.771 + 10^{-1}\, I \times 0.1792 + 0.49239$$

and $I = E_i$ where $I = (T_a/5)^{1.514}$. The PE (cm) was converted to PE (mm).

The estimated potential evapotranspiration index was used to compute the water balance for the study area The storage capacity was assumed to be 100 mm for all sample stations (Onitsha, Lokoja and Baro). Surplus (*SUR*) is the result of rainfall in excess of water needed to replenish the soil moisture storage, and may percolate through the surface or flow as runoff into intersecting streams. Only 90% of the SUR for a given period would leave the catchments while the remaining 10% is held on the soil surface to evaporate, or to infiltrate into the soil after some time. Change in storage (D_s) is the current month's soil moisture storage minus the previous month's soil moisture storage. Actual evapotranspiration was derived by adding the values of change in storage (D_s) to the value of rainfall when rainfall (P) is less than potential evapotranspiration (PE), and using the value of PE when rainfall is greater than PE.

To identify and estimate the potential impact of deforestation on water sources, correlation and regression analyses were used. The coefficient of determination (R^2) which defines the proportion of the dependent variable (rainfall, *P*) that is accounted for by the independent variable (evapotranspiration), was determined for all the three stations. From this proportion of the evapotranspiration contribution to rainfall, a reduction fraction was assumed for potential evapotranspiration due to deforestation. In all, a 15% and 20% reduction in potential evapotranspiration and the evapotranspiration contribution to rainfall, respectively, were assumed for Onitsha, 17.5 and 12.5% for Lokoja, and 15 and 10% for Baro. The percentage assumptions were based on the denseness of the vegetation cover.

RESULTS

Potential evapotranspiration

Table 1 shows the potential evapotranspiration (*PE*) calculated for the study locations. The *PE* increases from the south where rainfall is in excess, to the north where rainfall is less. Annual *PE* values of 2019, 2068 and 2091 mm were calculated for Onitsha, Lokoja and Baro respectively. Onitsha had the smallest monthly *PE* (161 mm, November) while Baro had the highest *PE* (184 mm, February). This can be attributed to the fact that the highest recorded mean monthly temperature of 30.8°C was recorded in February at Baro, while the November mean monthly temperature was 26.7°C. The low variability of temperature is reflected in the calculated *PE* for the study area.

Table 1 Potential evapotranspiration for the three study locations.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	$\sum$	x
Onitsha	172	177	175	167	168	169	169	170	163	167	167	161	2019	168
Lokoja	178	180	178	175	169	170	170	172	169	171	171	170	2068	172
Baro	178	184	172	176	172	170	170	170	171	173	172	173	2091	174

Water environment

Tables 2, 3, and 4 shows the water balance computation before deforestation for the study locations. Onitsha recorded an annual deficit of 366.41 mm. Lokoja recorded 519.89 mm deficit while Baro also recorded an annual deficit of 692 mm.

Table 2 Water balance computation for Onitsha.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
P	18.7	38.1	101.6	177.8	203.2	208	215.9	173	254	228.6	50	18.2	1688
PE	172	177	175	167	168	168	169	170	163	167	161	162	2019
S	–	–	–	10.8	46	86.28	100	100	100	100	–	–	–
**S*	–	–	–	10.8	35.2	40.28	46.9	–	–	–	–106	–	–
AE	18.7	38.1	101.6	167	168	168	169	170	163	167	150	18.2	149.9
DEF	153.3	138.9	73.4	–	–	–	–	–	–	–	11	143.3	519.9
SUR	–	–	–	–	–	–	14.93	1.22	81.9	55.44	–	–	153
DET	–	–	–	–	–	–	1.66	0.14	9.1	6.2	–	–	

Balance = annual *SUR* less annual *DEF* = 153.49 – 519. 9 = –366. 41mm.

Table 3 Water balance computation for Lokoja.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
P	2.5	25.4	76.2	101.6	152.4	190.5	228.6	203.2	215.9	177.8	38.1	0	1412
PE	177	180	178	175	169	172	170	172	169	177	165	170	2068
S	–	–	–	–	–	18.5	77.1	100	100	100	–	–	–
**S*	–	–	–	–	–	18.5	58.6	22.9	–	–	–100	–	1350
AE	2.5	25.4	76.2		152.4	172	170	172	169	171	138.1	–	547.8
DEF	174.5	154.6	101.8	–	16.6	–	–	–	–	–	26.9	170	27.9
SUR	–	–	–	–	–	–	–	3.74	21.11	3.06	–	–	27.9
DET	–	–	–	–	–	–	–	0.42	23	0.34	–	–	–

Annual balance = annual surplus less annual *DEF* = 27.91 – 547.8 = –519.89 mm.

Table 4 Water balance computation for Baro.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep.	Oct.	Nov	Dec	Year
P	0	0	50.8	101.6	152.4	152.4	177.8	127	203.7	127	254	0	1397.5
PE	178	184	182	176	172	170	170	173	171	172	172	173	2091
S	–	–	–	–	–	–	48.3		48.3	84.3	84.3	–	–
**S*	–	–	–	–		–	32.7		2.3	82	82	–84.3	–
AE	–	–	50.8	101.6	152.4	152.4	170	170	171	173	172	84.3	1393.5
DEF	178	184	131.2	71.4	19.6	17.6	–	–	–	–	–	88.7	69.2
SUR	–	–	–	–	–	–	–	–	–	–	–	–	–
DET	–	–	–	–	–	–	–	–	–	–	–	–	–

Annual balance = annual surplus less annual *DEF* = 692 mm.

Impact of deforestation on the water resources

Impact at Onitsha At Onitsha, decreases of 20 and 15% in evapotranspiration were assumed, in order to capture the change scenario. The regression model (R^2) reveals that only 10% of the total rainfall is accounted for by evapotranspiration and that the characteristics of total rainfall in the area are a consequence of many multi-variable rather than simple linear cause-and-effect relationships between rainfall and evapotranspiration. Thus the expected new balance and water cycling of the environment reveals an annual surplus of 76.04 mm (Table 5) for the 20% decrease in evaporation and an annual deficit of 47.8 mm for the 15% decrease, unlike the situation before deforestation when a mean annual deficit of about 366.41 mm (Table 2) was recorded. At Onitsha, the effect of deforestation on the annual water budget shows that between 50 mm deficit and 80 mm surplus should be expected. This may mean that the more deforested the lower Niger basin around Onitsha, the higher the annual water surplus in the immediate surrounding areas.

Impact at Lokoja The coefficient of determination (R^2) reveals that evapotranspiration accounted for 14% of the total rainfall at Lokoja. This suggests an increase of about 4% when compared with Onitsha where only 10% of the rainfall is accounted for by evapotranspiration. It also reveals that the effect of tropical maritime winds coming from the Atlantic Ocean is gradually decreasing and that a greater percentage of rainfall is due to micro-climatic fluxes such as convectional rainfall and less to regional teleconnections. Because of the reduced vegetation cover when compared

Table 5 Expected water balance at Onitsha after deforestation for 20% decrease in evapotranspiration.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
P	18.3	37.3	99.6	174.2	1991.1	201.1	211.3	196.3	248.9	224	49	17.84	1652.3
PE	137.6	141.6	140	134.4	134.4	134.4	135.2	1.6	130	134	128.8	130	1615.2
S	–	–	–	40.2	100	100	100	100	100	100	20.2	–	–
**S*	–	–	–	40.2	59.8	–	–	–	–	–	79.8	20.2	–
AE	18.3	37.3	99.6	134	134.4	134.4	135.2	136	134	134	128.8	38.64	1260.0 –
DEF	119.3	104.3	110.4	–	–	–	–	–	–	–	–	91.96	355.96
SUR	–	–	–	–	4.9	69.7	176.4	130	218.9	190	–	–	434
DET	18.3	37.3	99.6	174.2	1991.1	201.1	211.3	196.3	248.9	224	49	17.84	1652.3

Annual balance = annual surplus less annual deficit = 434 – 355.96 = 76.04mm.

Table 6 Water balance at Lokoja after deforestation for 17.5% decrease in evapotranspiration.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
P	2.44	24.78	74.33	99.1	148.7	185.8	223	198.2	211	173.4	37.17	0	1377.9
PE	146	146.9	144.4	139.4	141.9	140.3	141.9	139.4	141.1	141.1	136.1	140	1706.7
S	–	–	–	–	9.24	53.14	100	100	100	100	1.04	–	–
**S*	–	–	–	–	9.24	4.39	46.86	–	–	–	–	1.04	98.96
AE	2.44	24.78	74.33	99.1	139.4	141.9	140.2	140.9	139.4	141.0	136.1	1.04	1181.8
DEF	143.6	124.2	72.57	45.28	–	–	–	–	–	–	–	98.9	484.61
SUR	–	–	–	–	–	–	35.89	56.32	71.57	130.3	–	–	294.1
DET	2.44	24.78	74.33	99.1	148.7	185.8	223	198.2	211	173.4	37.17	0	1377.9

Annual Balance = Annual Surplus less Annual Deficit 294.1 – 484.61 = –190.51 mm.

Table 7 Water balance at Baro after deforestation for 15% decrease in evapotranspiration.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
P	0	0	47.22	94.44	141.7	141.7	165.3	165.3	189.3	118	236.1	0	1313.1
PE	151.3	156.4	154.7	149.2	146.2	146.2	144.5	144.5	145.4	147.1	146.7	142	1777.4
S	–	–	–	–	–	–	20.77	41.67	85.66	56.96	100	–	–
**S*	–	–	–	–	–	–	20.77	20.9	45.99	–28.7	43.04	–100	–
AE	–	–	47.22	94.44	141.7	141.7	144.5	144.5	145.4	147.1	146.7	100	–
DEF	151.3	156.4	107.4	55.16	4.54	2.84	–	–	–	–	–	42.1	519.82
SUR	–	–	–	–	–	–	–	–	–	–	46.36	–	46.36
DET	0	0	47.22	94.44	141.7	141.7	165.3	165.3	189.3	118	236.1	0	1313.1

Annual balance = annual surplus less annual deficit = 46 – 519.82 = –473.46 mm.

with Onitsha, a 17.5% and 12.5% decrease in evapotranspiration were observed. Table 6 shows the adjusted water balance of the micro-environment after deforestation at Lokoja, assuming a 17.5% decrease in evapotranspiration.

The annual balance of the Lokoja area shows a deficit of about 190.51 mm for the 17.5% reduction and a deficit of 283.8 mm for the 12.5% reduction in evapotranspiration. This is equivalent to about 63% and 45% increase in the water budget of the environment when compared with the period before deforestation. The reason for the increase in the water budget may be attributed to the following. Firstly, the influence of the tropical maritime wind is still effective; secondly, the marginal reduction in evapotranspiration due to deforestation results in increases in the available water resources. Also because of the tropical nature of the environment, any anthropogenic activities that would significantly alter the physiognomy of the vegetation cover reduces the water requirements for photosynthesis and evapotranspiration which will in turn bring about an increase in the available water resources.

Impact at Baro Statistical evidence shows that about 42% of the total rainfall in Baro is accounted for by evapotranspiration. This, however, is due to the fact that the tropical maritime wind that brings moisture laden winds is becoming weaker and the influence of the dry northeast trade winds is more prolonged and profound. Therefore, evapotranspiration constitutes a major source of atmospheric moisture, which condenses to bring rainfall. Any human activity that would significantly bring about a large-scale loss of vegetation and alter the process of evapotranspiration would have a major impact on the water resources of the environment.

Baro is not made up of dense tropical rainforest through which contributions from transpiration to atmospheric water could be much higher; marginal 15 and 10% reductions in evapotranspiration were assumed. Table 7 shows the expected water balance at Baro after deforestation based on 15% reduction of the 20% statistically significant contribution of evapotranspiration to rainfall at 95% level of confidence.

An annual balance of about –473.46 mm should be expected after deforestation for the 15% reduction. However, this is an increase of about 32% in the water budget of the environment when compared with the period before deforestation. An annual deficit of –515.6mm was computed for the 10% reduction. Also, unlike the period before deforestation when the field capacity is not met at all, the expected change analysis reveals that by October, all things being equal, the field capacity of the water environment at Baro would be attained and the surplus water would lead to significant contribution of overland flow to the Niger River runoff around Baro.

Although the cumulative long-term effect of regional change in the rainforest might cause much water deficit, the short-term impact on the hydrology due to deforestation of the micro-environments along the lower Niger trough is expected to increase the water resources potential of the environment through the reduction in evapotranspiration whose contribution to total rainfall, except at the northern extreme end, is statistically insignificant. Furthermore, an important question that remains to be adequately addressed is the issue of the length of time required for the system to adjust to the disturbances (Dickinson & Henderson-Sellers, 1988). It may take 3–4 months before the adjustment takes place. Even after the adjustment time, soil moisture content that is outside this analysis may not be in equilibrium with the prescribed atmospheric forcing and can take 1–2 years to stabilize completely. Thus, during the initial stages, following deforestation, the climate response might be somewhat transient rather than fully equilibrated. Therefore, precise timing of full equilibration is very difficult, as it would require complex modelling for proper understanding.

CONCLUSION AND RECOMMENDATION

The result reveals that the basin is well integrated ecologically and that cumulative environmental change due to deforestation would increase the water reserve of the area as a result of a decrease in evapotranspiration. In this type of setting, the possibility of flash floods, inundation of surrounding low land and other insidious excess water related problems are real. The following are therefore recommended:

- adequate networking and continuous monitoring of the water resource of the lower Nigeria basin should be put in place;
- provision for flood control measures to minimize losses during high flow;
- provision of bank stabilization measures so as to not only combat erosion but also ensure optimum utilization for transportation and other uses;
- adopting storage measures for the excess water resources during the wet season, especially around Onitsha, and ensuring inter-regional water transfer of such excess water to stressed areas during water shortage.

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