The Effects of Recent Climatic Variations on Water Yield in the Sokoto Region of Northern Nigeria

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Abstract

This study examined the effects of recent climatic variations on water resources in the Sokoto region of northern Nigeria. In doing this, the study adopted the modeling approach, in which changes in the yield of surface water reservoirs were related to variations in the weather and climate of the region. The results showed that variations in the weather and climate of the region have significantly impacted on water yields in surface reservoirs, with over 80 per cent of the yearly variations in water yield in the Sokoto-Rima Basin being explained by variations in the weather and climate. To prevent any further deterioration of the situation, inter-basin water transfer from the southern rivers of Nigeria (where there are water surpluses) to inland basins in the Sokoto region is recommended. Household level, water-use adjustments have also been recommended for residents, as adaptation to diminishing water supplies. Finally, massive afforestation programme should be implemented in the Sokoto region so as to moderate the regional climate, improve the environment and ultimately increase the yield of surface water resources.

Keywords: Nigeria, climate change, drought, water resources, adaptation, afforestation

Introduction

Climate change due to global warming is likely to have significant impact on society and environment, and the consequences have already started to manifest in the higher frequency of extremes of unusual weather patterns such as recurrent droughts and sand storms in northern Nigeria. Recent climatic trends in northern Nigeria, which are characterized by increased temperature and declining rainfall encourage dryness and desiccation, which makes the ecosystem generally dry and harsh. For instance, the last 40 years since 1969 have witnessed four severe droughts in northern Nigeria, causing widespread dislocation to social and economic activities, substantial modification of ecosystems in the region, and general discomfort to the populace. Accordingly, water resources within the Sudano-Sahelian zone have been negatively impacted by recurrent droughts. In this regard, studies have indicated that the quantity and quality of water in some parts of northern Nigeria have been seriously affected by increased evaporation from rising temperatures and sedimentation of surface streams by mobile sand dunes, leading to a drop in the water table around the Fadama areas. The Munwadata Lake in Sokoto is a case in point, which has dried up, creating serious hydrological changes in the region (Sofo and Ali-Akpajiak, 2008; Odjugo, 2010). Equally, Lake Chad in the north-eastern part of Nigeria has decreased from 9,700 square miles (25,000 km^2) in 1963 to 485 square miles (1,250 km^2) in recent times (UCS and WRI, 1999; Foley and Coe, 2001; Mayell, 2001; Bomford, 2006).

The shrinking of the lake is blamed on reduced rainfall due to global warming, as well as, increased demand for water for irrigation and other human needs. The consequences of these ecological disruptions are dire as the inhabitants experience frequent crop failures, dying livestock, collapsed fisheries and continuous water shortages. N'Tchayi et al., (1994) have pointed out that the hydrological effects of climate change will bring problems associated with domestic water use, industry, power generation (hydroelectricity power, HEP), agriculture, transportation, future water-resource system planning and management, protection of the natural environment and, most importantly, change in regional precipitation. As climatic variability intensifies, changes in atmospheric conditions have altered land and water resources, their distribution in space and time, the hydrological cycle of water bodies, water quantity and, in more recent time, water supply systems and requirements for water resources in the Sokoto region, creating serious water shortages for household needs, agriculture and industry. With further significant variations in the climate of the Sahel being predicted by General Circulation Models (GCMs) (IPCC, 2007), it is important that scientific studies be undertaken at regional levels so as to provide society with accurate information on the real and potential impacts of climate change, as well as, the mitigation and adaptation options available.

It is the aim of this paper to examine the effects of climatic variations on water yield in the Sokoto region of northern Nigeria, and to proffer appropriate solutions toward solving the problem of water shortage in the region.

The Study Area

Location

The study area is Sokoto State which is located in north-western Nigeria. The area is found between latitude 13^0 04' N and Longitude 5^0 14' E. The area so defined covers a land area of approximately 32,038km^2 and shares its borders with Niger Republic to the north, Zamfara and Katsina States to the East, Niger State to the South-east, Kwara State to the South and Benin Republic to the west. The southern boundary is arbitrarily defined by the Sudan savanna (Fig. 1).

Topography

The topography of Sokoto state is dominated by the famous Hausa plain of northern Nigeria. It comprises extensive tracts of almost level to gently undulating landscape. This monotony is broken in the south and east by groups of rocky hills and inselbergs. The highest and most impressive massifs occur in the south- east. On the plains the general height difference between valleys and adjacent domes is only 10-20 meters. Typical cross-sections consist of a broad dome area; long, straight middle slopes of less than 2^0 and short, steep lower slopes showing signs of physical weathering (SCHULTZ, (1975). The vast floodplains (fadama land) of the Sokoto-Rima River systems dissect the Hausa plain into rich alluvial soils that is suitable for the cultivation of a variety of crops. There are also isolated hills (inselbergs) and hill ranges scattered all over the state.

Climate

Like the rest of West Africa, the climate of the region is controlled largely by the two dominant air masses affecting the sub- region. These are the dry, dusty, tropical- continental (cT) air mass (which originates from the Sahara region), and the warm, tropical- maritime (mT) air mass (which originates from the Atlantic Ocean). The influence of both air masses on the region is determined largely by the movement of the Inter-Tropical Convergence Zone (ITCZ), a zone representing the surface demarcation between the two air masses. The interplay of these two air masses gives rise to two distinct seasons within the sub-region. The wet season is associated with the tropical maritime air mass, while the dry season is a product of the tropical continental air mass. The influence and intensity of the wet season decreases from the West African coast northwards. Therefore, precipitation in the whole sub-region of West Africa depends on thunderstorm activity which occurs along disturbance lines called "line squalls" and, about 80 percent of the total annual rainfall for most places is associated with line squall activities which are prevalent between June and September (Nicholson, 1980; Dennet, Elston and Rodgers, 1985; Adefolalu, 1986; Kamara, 1986). In terms of climatic statistics, the annual rainfall for Sokoto ranges between 300 mm and 800 mm. The mean annual temperature is 34.5 ^{0}C, although dry season temperatures in the region often exceed 40^0C.

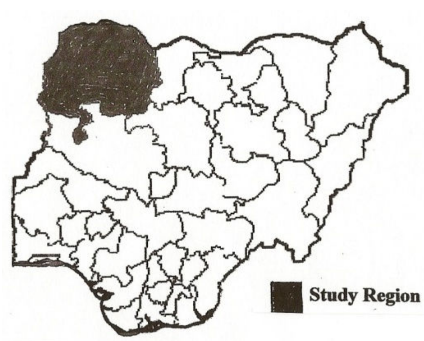

Fig. 1 Map of Nigeria showing the Sokoto region

Northern Nigeria experiences a short rainy period and a long dry season. The rainy season starts about mid-May in the southern fringes of the study area and about mid-June in the northern districts. The season ends about middle to late September in the northern districts, and early October in the southern districts. The dry season, on average, lasts between seven and eight months, usually from October to May. During the dry season, the climate is dominated by the north-east wind (harmattan) blowing Sahara dust over the land. When the dust hangs in the air, it causes serious air pollution which results in dirt virtually everywhere, and also reduces visibility.

Soils and vegetation

In general the soils of this region are well drained but poorly structured with texture ranging from coarse grains in the north to fine in the south. However, there are extensive areas where the soils contain considerable quantities of concretions and ironstone fragments.

The vegetation consists mostly of man-made, parkland tree savannas created through intense economic activity. Except for a limited area in the south-east where the topography restricts human activities, intensive cultivation, regular bush burning, firewood gathering and uncontrolled grazing, have prevented the natural succession of re-growth. On the periphery of these areas where cultivation and habitation are not dense, all stages of re-growth from shrub to tree savanna may be found through relics of former savanna wood land, which are becoming rare and confined to reserves (Sokoto State Ministry of Environment, 2009).

Materials and Methods

Broadly speaking, two main sets of data were utilized in this study. These were climate data and water yield data. The climate data consisted of temperature, rainfall, humidity and sunshine records for the period from 1978 to 2008 as recorded by the Nigerian Meteorological Agency (NIMET), while water yield data for the period from 1978 to 2008 was obtained from the Ministry of Water Resources and the Sokoto-Rima Basin Authority. Table 1 shows the records of climatic data and water yield data for the period 1978 to 2008.

Table 1 Thirty-one year data of variables involved in climate-water yield modeling

Year	Temperature (^0C)	Sunshine (w/m^2)	Relative Humidity (%)	Rainfall (mm)	Water yield (Masl)
1978	34.60	7.90	41.90	603.41	173.42
1979	34.90	8.00	41.00	600.00	172.38
1980	29.30	8.20	43.20	540.80	175.48
1981	34.80	8.00	39.00	580.90	167.12
1982	34.90	7.60	38.80	550.60	158.41
1983	31.90	6.90	38.57	610.40	175.00
1984	36.00	7.10	36.30	280.90	80.45
1985	35.40	6.70	37.60	440.80	126.29
1986	36.10	7.60	39.50	480.73	138.31
1987	36.00	6.11	36.00	370.20	116.40
1988	34.64	6.07	41.50	715.30	194.65
1989	34.28	5.09	42.00	680.80	194.37
1990	35.40	5.03	41.70	660.90	188.55
1991	34.85	6.18	45.10	780.50	222.68
1992	34.68	6.40	42.10	770.30	218.92
1993	34.74	6.60	39.60	380.20	107.60
1994	34.90	5.90	45.50	540.10	172.36
1995	35.60	6.20	42.20	620.80	174.69
1996	35.90	6.08	44.10	670.20	188.59
1997	35.40	7.01	47.00	710.50	200.01
1998	35.70	6.43	46.80	770.90	200.21
1999	35.50	7.21	45.10	760.10	213.89
2000	35.10	7.15	42.50	770.60	216.85
2001	35.40	7.00	43.40	790.70	222.34
2002	35.40	7.56	45.00	731.20	205.54
2003	35.70	8.12	45.40	768.70	216.16
2004	35.70	8.43	45.00	649.50	185.57
2005	35.90	8.00	43.90	634.60	178.45
2006	35.10	8.20	43.10	716.90	202.31
2007	35.90	7.90	42.80	636.20	170.36
2008	35.50	8.00	41.40	667.60	189.40

Source: Climatic data was supplied by Nigerian Meteorological Agency (NIMET), while water yield data was obtained from the Ministry of Water Resources and the Sokoto-Rima Basin Authority.

Climate-water yield modeling

A model, within the context of this study can be viewed as a system which receives and translates a set of input variables into a set of output variables through a number of processes. Climate-water yield models may be defined as simplified representations of the complex relationships between climate and water yield in surface reservoirs. These models attempt to isolate and quantify the effects of the various factors that influence water yield. The input variables in climate-water yield models include any combination of climatic elements such as rainfall, temperature, humidity, evaporation, wind speed and sunshine. Other input variables include the size of the basin, the geologic structure and off-channel water uses. In the present context, only the climatic variables were considered in model construction, while the other variables were held as constant.

Two sets of variables were used as inputs in the construction of the regression model. These were water yield data (acting as the dependent variable) and climatic data (representing the independent variables). As an aid to model construction, a multiple correlation analysis between water yield and the climatic parameters (annual data) was conducted to establish the sensitivity of water yield to climatic variables. Table 2 shows the degree of association between water yield and the different climatic elements.

Table 2 Multiple correlation between water yield and climatic parameters in the Sokoto-Rima basin in northern Nigeria (p-values in parenthesis).

	Rainfall	Temperature	Humidity	Sunshine
Water yield	98.3 (.000)	-6.8 (.715)	76.0 (.000)	-0.01 (.994)

Based on the strengths of the correlation coefficients as depicted in table 2, rainfall, temperature and humidity were selected for modeling the impact of climatic variations on water yield. It should be emphasized that the main concern of the climate-water yield model in this study was with the role of weather in determining the yield of surface reservoirs. The preliminary analysis with multiple correlation technique has shown that rainfall, temperature and humidity are the major climatic parameters that impact on water yield. While rainfall and humidity play positive roles in reservoir yields as can be inferred from their positive correlation coefficients, temperature plays negative role of reducing reservoir yields. Sunshine was dropped as input in the regression model because its correlation coefficient was virtually nil and highly insignificant. Accordingly, rainfall, temperature and relative humidity were chosen for modeling the relationships between climate and water yield.The relationship between the dependent variable (in this case water yield) and the independent variables (rainfall, temperature and humidity) was examined through equation of the form:

$Y = a + b_1X_1 + b_2X_2 \ldots. + b_nX_n + e$

Where Y = the dependent variable (representing observed crop yield);

a = the intercept on y-axis

$b_1 - b_n$ = partial regression coefficients of the independent variables

$X_1 - X_n$ = the independent variables (representing climate data)

e = random error term representing the proportion of unexplained variation.

The model was constructed in accordance with the suggestions by Koustoyiannis (1977) and Gujarati (1995), as applicable to time–series data, so as to simultaneously determine the impact or otherwise of the selected climatic variables on water yield in the area. More so, the independent variables were transformed using logarithms to see if the level of explanation provided by the multiple regression models will be better. However, working with raw data proved to be quite useful as the level of explanation provided by the independent variables jointly was quite impressive, as can be seen from the coefficient of determination. The climatic parameters were expected to give details of their impact on water yield in terms of their regression coefficients. Similarly, P-values were used to check the 'goodness-of-fit' or otherwise of the relationships. The result of the regression analysis is presented in Table 3.

Table 3 Result of multiple regression analysis between climate and water yield in the Sokoto region of northern Nigeria.

	a	Rainfall	Temperature	Humidity	R^2	R^2(adj)
Regression coefficient	2.99	21.33	-3.69	1.22	97.8	97.5
P-values	.006	.000	.001	.235		

Results and Discussion

The results in Table 3 show that the three climatic elements; rainfall, temperature and humidity, jointly provided a substantial explanation for the variations in surface reservoir water yield in the Sokoto region with a coefficient of determination (R^2) of 97.8 per cent, and R^2 (adjusted) of 97.5 percent. However, a close scrutiny of the Table reveals that rainfall made the highest contribution to the regression equation with a coefficient of 21.33, which is highly significant at the 0.01 level. This is not surprising as earlier studies have shown rainfall to be one of the most important parameters in reservoir yield and recharge, especially in semi-arid parts of northern Nigeria (Ekpoh, 1991; Mortimore and Adams, 2001). On the other hand, temperature shows an inverse relationship with water yield with a negative regression coefficient of -3.69, although the relationship is also highly significant at the 0.01 level. The inference that could be made from the "cat and mouse" behaviour of rainfall and temperature in relation to reservoir water yield is that while rainfall increases water yield, temperature subtracts through evaporation.

Udoeka (1995) had earlier observed that the rate of change of storage in water bodies, soil and groundwater in an area over a specified time interval, is equal to the rate of water supplied in the form of precipitation minus the combined outflow from the area in terms of runoff and evapo-transpiration.

Results in Table 3 also show that humidity has a slightly positive, but insignificant relationship with water yield.From the foregoing, it can be asserted that there is a relationship between climate variations and water yield in surface reservoirs in the Sokoto region. However, it should be noted that water yield in lakes and other surface reservoirs is not just a function of climatic parameters alone. Other parameters that could be significant in determining reservoir yields include: the basin size (i.e. the catchment area), the geological structure, off-channel uses and the management skills. To provide a holistic treatment of the question of diminishing water resources in the region, these other variables will need to be considered using an integrated, comprehensive simulation model. It will be interesting to see how future studies accommodate these issues. Also, working directly with evaporation data might enhance the level of explanation provided by the regression models, as opposed to using proxy variable such as temperature.

Previous studies have shown that there is continued increase in the temperature and a continued decrease in the rainfall, leading to desiccation in the study region (Oladipo, 1993; Nicholson and Tucker, 1998; Tarhule and Woo, 1998; Hulme, 2001; Biasutti and Giannini, 2006; Ojonigu, Edwin and Joseph, 2007). One study has even gone further to compute the rate of rainfall decline in this region as being 3.7mm per annum, while temperature increases at the rate of 0.03 per year (Udoeka, 1995). With global warming likely to continue as projected by general circulation models, the problem of water shortage in this region of northern Nigeria will also possibly continue since global climate change will adversely affect water resources and general water availability, especially in semi-arid regions (IPCC, 2007b). Therefore, recurrent droughts in these parts of northern Nigeria, together with rising temperatures and declining rainfall do not auger well for water availability in the region. The case of Lake Chad (earlier cited in this study) which is dying, is a classic example of what could happen to surface reservoirs in this ecological zone, if the "business-as usual" scenario continues.

Conclusion

The study has demonstrated that there is a strong, significant relationship between climatic variations and water yield in surface reservoirs in the study region. The study has also shown that rainfall made the highest contribution to the degree of explanation offered by climatic parameters in relation to water yields in the Sokoto region, and the positive contribution was found to be highly significant, statistically.. The implication of this finding for water yield is that good rainfall years will improve water yield in the Sokoto region while poor rainfall or drought years will diminish water yields. Since recent climatic trends in the region tend to suggest a pattern towards dryness, it is important that a number of strategies be developed towards solving the real and potential water shortage problems of the region. At the household level, individuals can begin to adapt to limited water supply by increasing their efficiency of water use. For instance, rather than filling our bath-top before taking bath, we can make do with a bucket of water. In the same vein, use of recycled water should be encouraged, such that we can recycle laundry water to flushing toilets. Similarly, dish-wash water could be recycled to water gardens and lawns.

At the farm level, water conserving irrigation methods such as; point-drop, pitcher or water-can irrigations, should be adopted in preference to sprinkler irrigation which consumes more water. Mulching should also be widely practiced as a way of reducing evapo-transpiration from the soil.At the policy level, serious effort should be made by government to transfer water from southern basins (where there is surplus water budget) to the study region through inter-basin transfer using pipelines. The use of pipelines in the transfer is recommended because it reduces the risk of evaporation during transit, as opposed to canalization. Finally, it is recommended that massive afforestation programme should be embarked upon in the Sokoto region, and indeed the entire sudan-sahel zone of northern Nigeria, so as to moderate the regional weather and climate, stabilize the ecosystem, improve the hydrological regime, improve water yields in reservoirs, halt the southward migration of sand dunes, reduce the frequency of droughts and reverse the drying trend.

References

Adefolalu, D.O. (1986) Rainfall trends in Nigeria. *Theoretical and Applied Climatology*, 37:205-219.

Biasutti, M. and A. Giannini, (2006) A robust Sahel drying in response to late 20th century forcings, Geophys. Res. Letters, 11, L 11 706.

Bomford, A. (2006) Slow death of Africa's Lake Chad: BBC News, Lake Chad. http://news.bbc.co.uk/2/hi/4906692.stm

Dennet, M.D, Elston, Y. and Rodgers, J.A. (1985) A Reappraisal of rainfall trends in the Sahel Journal of Applied Climatology, 5: 353-361.

Ekpoh, I.J. (1991) The Effects of Climatic Variability on Agriculture in Northern Nigeria. PhD Dissertation, University of Birmingham, Birmingham B 15 2TT, United Kingdom.

Foley, J. A. and Coe, M. T. (2001) Shrinking African Lake offers Lesson on Finite Resources. Journal of Geophysical Research, 8: 122-127.

Gujarati,D.N (1995) Basic Econometrics. International 3rd edition, John Wiley and Sons Ltd., Chichester.

Hulme, M. (2001) Climate perspectives on Sahelian dessication; 1973-1998. *Global Environmental Change* 11; 19-29.

IPCC (2007a) Climate Change 2007: Fourth Assessment Report (AR4). WMO, Geneva.

IPCC (2007b) Climate Change 2007: Impacts, adaptation and vulnerability. WMO, Geneva.

Kamara, S.I. (1986) " The origin and types of rainfall in West Africa'' *Weather*, vol. 41, 48-56.

Kontsyiannis, A. (1977) Winston, Holt. Theory of Econometrics, 2nd Edition, London.

Mayell, H. (2001) The impact of global warming in Africa. http://news.nationalgeographic.com/

Mortimore, M. and Adams, W.M. (2001) Farmer adaptation, change and 'crises' in the Sahel, *Global Environmental Change* 11: 49 –57.

Nicholson, S. E. (1980) The nature of rainfall fluctuations in West Africa. *Monthly Weather Review*, 108: 473-487.

Nicholson, S. E. and Tucker, C. J. (1998) Desertification, drought, and surface vegetation: an example from the West African Sahel, *Bulletin of the American Meterological Society* 79.5, 815-829.

N' Tchayi, G. M., Bertrand, J., Legrand M. and Baudet, J. (1994) Temporal and spatial variations of the atmospheric dust loading throughout West Africa over the last thirty years, *Annalax physicane 12*, 265- 273.

Odjugo, P.A.O. (2010) General Overview of Climate Change Impacts in Nigeria. *Journal of Human Ecology,* 29(1): 47-55.

Ojonigu F.A., Edwin O. and Joseph, O.A. (2007) Are we Experiencing Drier Conditions in the Sudano-Sahelian Zone of Nigeria? *Journal of Applied Sciences Research,* 3(12): 1746-1751.

Oladipo, E. O. (1993) "Is the climate of Northern Nigeria becoming more arid?'' Paper presentation at the 36th Annual conference of the Nigerian Geographical Association, 18-22. Federal University of Technology, Minna, pp.13.

SCHULTZ (1975) Report on Hadejia Irrigation project, Lagos.

Sofo, C. A. and Ali-Akpajiak, T. P. (2008) Drought and Desertification. http://books.google.com.ng/

Sokoto State Ministry of Environment (2009) The Extent and Effects of Desert Encroachment and drought in Sokoto State. A Report submitted to the visiting Team from Switzerland.

Tarhule, A. and Woo, M (1998) Changes in rainfall characteristics in Northern Nigeria. *Int. J. Climatol.* 18: 1261-1271.

UCS and WRI (1999) Global Warming: Early Warning Signs. http://www.climatehotmap.org

Udoeka, E. D. (1995) Low Flow at Kainji: Climate change or hydrologic noise. In J. C. Omulo (ed) Global Climate Change: impact on energy development. DAMTECH Nig. LTD. Jos.