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Implications of climatic variability and climate change for water resources availability and management in West Africa

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Abstract

The paper examines: (a) trends in climatic variations and variability with particular emphasis on rainfall (b) the characteristics of climatic events, including floods and droughts, (c) seasonal variations in river flows, (d) mean annual trends in river flows and discharges, (e) local variations of extremes of rainfall and river discharges, (f) the effects of climatic variability and climate change on ground water variations, (g) the problems of acute shortage of freshwater, and (h) the prevalence of water stress whose characteristics would be worsened with the projected impacts of climate change. The results show that: (i) there are a lot of spatial and temporal variations in the characteristics of rainfall and the hydrological systems locally and regionally, although in general, there have been downward trends in rainfall and increases in water deficits and drought events, (ii) that flood events, which also have impacted adversely in many parts of the region, have also been witnessed. The paper then produces projections for future urban and rural water supplies in Nigeria, which is an epitome of West Africa and examines the two main categories of adaptation measures needed to improve water management, namely, those involving the water supply and water demand systems in the study region. Finally, the paper discusses the need to address a number of mechanisms for implementation of the various adaptation measures including: (a) building capacity and manpower, (b) promoting education and public awareness, (c) public participation and the involvement of stakeholders, (d) the establishment of both national and regional co-operation, and (e) the need for climatic and other environmental data collection and monitoring.

Introduction

In recent years, especially during the past three or four decades, there has been a lot of concern over the impacts of climatic variations and climate change on environmental dynamics and environmental change and their implications on the socio-economic and socio-cultural activities in West Africa. In particular, with the downward trends in rainfall since the late 1960s, the issues of climatic variabilities and climate change and their impacts have been topics for scientific discussions, a lot of which have centered on water resources availability and water resources management as there has been increasing realization of the importance of water in the continuing effective planning of socio-economic development in many parts of West Africa.

No doubt, it is becoming well known in West Africa that water is becoming a scarce resource, more expensive to develop. It is also becoming clearer that water requires more expertise and technological know-how for planning, design and implementation than before, and that water can no longer be considered a cheap resource, which can be misused, abused, or squandered without a lot of adverse consequences for the region. Thus, water in West Africa, which is becoming more and more a critical resource for the future in the region, requires attention particularly in the event of climate change. In particular, increasing scientific evidence has shown that the characteristics of variabilities and changes, which have been known to occur in weather and climate will continue in future and that these changes will continue to have implications for water resources planning and management. This evidence shows that there is urgent need to be concerned for the future of water resources availability and water resources management, and for developing policies for reducing, and if possible, eliminating the adverse impacts of climate change on the hydrological systems and water resources availability. It is, therefore, the purpose of this paper to examine and discuss some of the issues involved in the implications of climatic variations and variability, as well as climate change, on water resources systems with particular reference to hydrological systems, water resources availability and water resources management in West Africa.

Climatic variabilities and change in West Africa

West Africa spans a belt of low latitude areas between approximately 2° N and 30° N, and is generally characterized by precipitation which varies from less that 200 mm in the Sahara desert to the north, to over

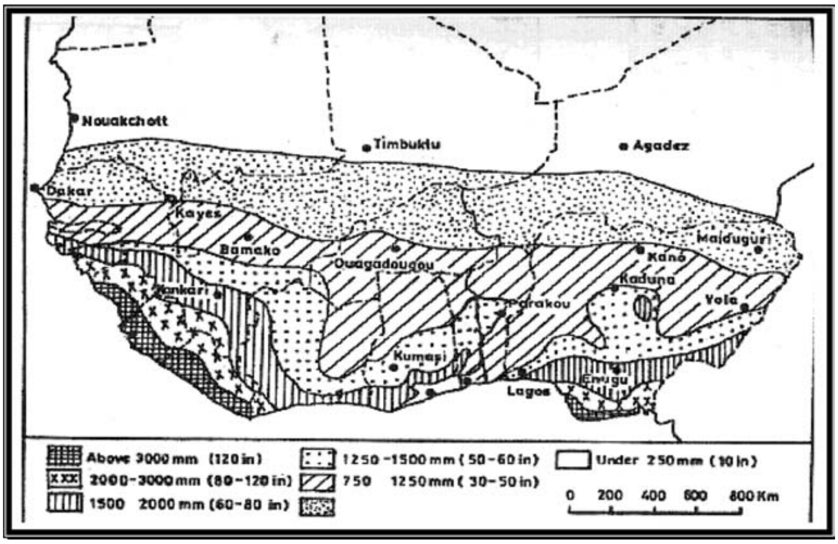

Figure 1. Mean annual rainfall of West Africa.

2000 mm along the coastal regions, especially in southern Nigeria and southwest Ghana. A large portion of the region consists of areas with rainfall between approximately 250 and 1000 mm of annual rainfall generally concentrated in the rainy season, in which about 75% or more of the rain falls and which lasts between 6 and 12 months south of about latitude 12°N (especially in the forests and the Guinea savanna regions) and less than 4 months in the Sahel and semi-arid regions of the north.

The rainy season in West Africa is mainly linked to the northwards and southwards movement of the Inter-tropical Convergence Zone (ITCZ) sometimes called the Inter-tropical Discontinuity (ITD). In general, the characteristics of the rainfall patterns consist of two equinoctial maxima in the forest areas located along the coast, and one single maximum in the central parts and in areas to the north. Rainfall over the forest regions tends to be spread over many months (Figure 1), while inland from the coastal areas, and especially towards the northern parts of West Africa, rainfall becomes more concentrated within three to 4 months. In addition to the short rainy season to the north, the rainfall characteristics also include relatively low annual rainfall and high to very high variability and unreliability in rainfall.

The climate of West Africa is also influenced by other factors such as atmospheric disturbances and medium to large-scale fluctuations in the atmospheric and oceanic circulation, land and sea breezes and relief. These factors are especially significant for sustainable environment and resources management futures because of their impacts on regional and local space scales. For example, the coastal areas are impacted locally and regionally by the characteristics of the coastal waters and land and sea breezes while relief factors play significant roles in influencing the climates of the Guinea highlands and the Cameroon highlands.

Methodology, data collection, and analysis

This study utilizes the climatic index, which emphasizes rainfall variability and is the time series of the normalized rainfall departures. For individual stations, normalization is achieved by using the following expressions as presented by Lamb (1980, 1983) and Ojo (1987):

$$Y_{ij} = (P_{ij} - P_i)/\sigma, \tag{1}$$

where Y_{ij} is the normalized departure of rainfall for station i, and j is the month or year. P is precipitation, P_i is mean precipitation at station i and σ is the standard deviation, which can be expressed in the form:

$$\sigma = J_i^{-1}[\Sigma_j(P_{ij} - P_i)^2]^{1/2} \tag{2}$$

where J is the number of months or years. When regionally averaged, the rainfall departure series can be expressed in the form:

$$R_{ij} = [N^{-1}\Sigma(P_{ij} - P_i)\sigma^{-1}] \tag{3}$$

where R_{ij} is the normalized departure of rainfall for station i and month/year j when regionally averaged, and N is the number of stations.

Equations (1)–(3) were computed using the database of the individual monthly rainfall for all the stations employed in the study region (Figure 2). The data used were collected from several sources. Data for the Nigerian stations were collected from the Nigerian Meteorological Agency (formerly the Department of the Nigerian Meteorological Services), while data for other stations outside Nigeria were collected from other sources including Gbuyiro (1998), Okoloye (1998) and Mohammed (2001). The runoff and discharge data used were also collected from several sources including those published by *Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM)* as reported by Ledger (1969), and the Federal Department of Inland

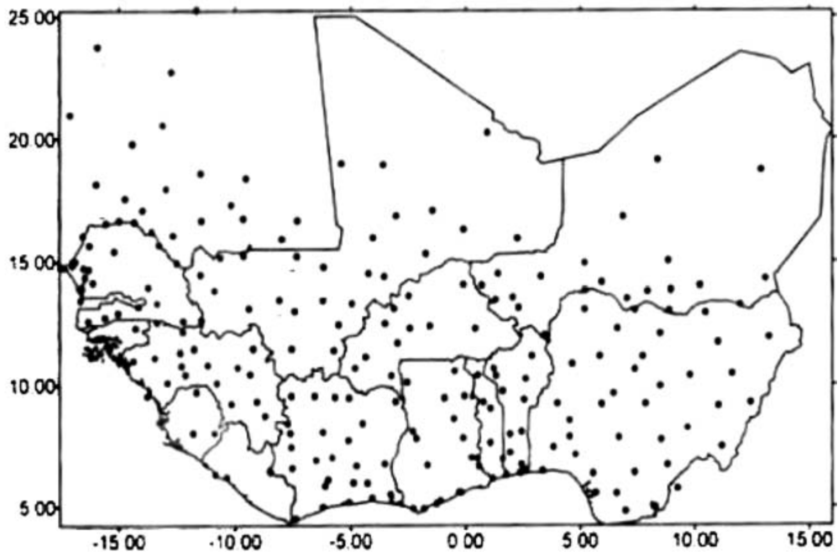

Figure 2. West African rainfall stations.

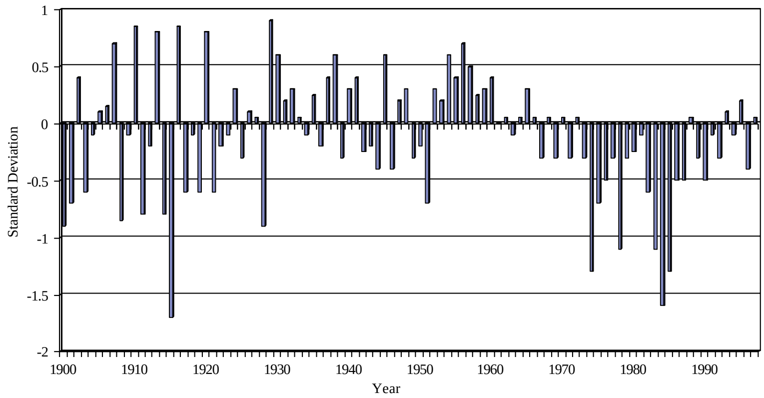

Figure 3. Climatic indices for West Africa 1900–1997.

Waterways also as reported by Ledger (1969). Other sources include those published by WMO/TD (1999).

Trends in rainfall variations in West Africa

Figures 3 and 4 show the rainfall variability for West Africa averaged for all the stations used in this study, using the results obtained in Equations 1–3. It can be noted from the figures that in general, the 20th century began with a relatively long period of drought which lasted until about 1926, with breaks of relatively normal or wet periods which lasted 1 or 2 years each. Between 1901 and 1926, only three periods may actually be regarded as wet with climatic indices greater than $+\sigma/2$. On the whole, about 52% of the period may be regarded as normal with climatic indices between $\pm\sigma/2$.

The second period, 1926–1960, is a relatively wet period. For most of this period, two or three relatively wet years were generally followed by another two or three years characterized by near normal conditions. About 11 years of the 33-year period have climatic indices, which are greater than $+\ \sigma/2$ while only 3 years have indices which are $-\sigma/2$ or less. The remaining 19 years have climatic indices which are between $\pm\sigma/2$. During the six years from 1961 to 1966, conditions were near normal with indices between $\pm\sigma/2$. From 1967, droughts have been relatively persistent and the indices for most of the years are equal to or less than $-\sigma/2$.

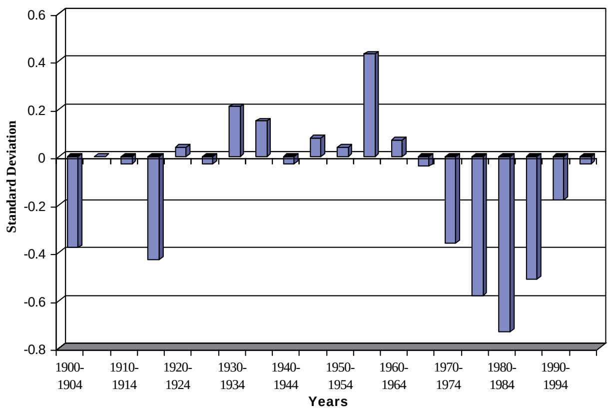

Figure 4. Climatic indices (Quinquinal) for West Africa.

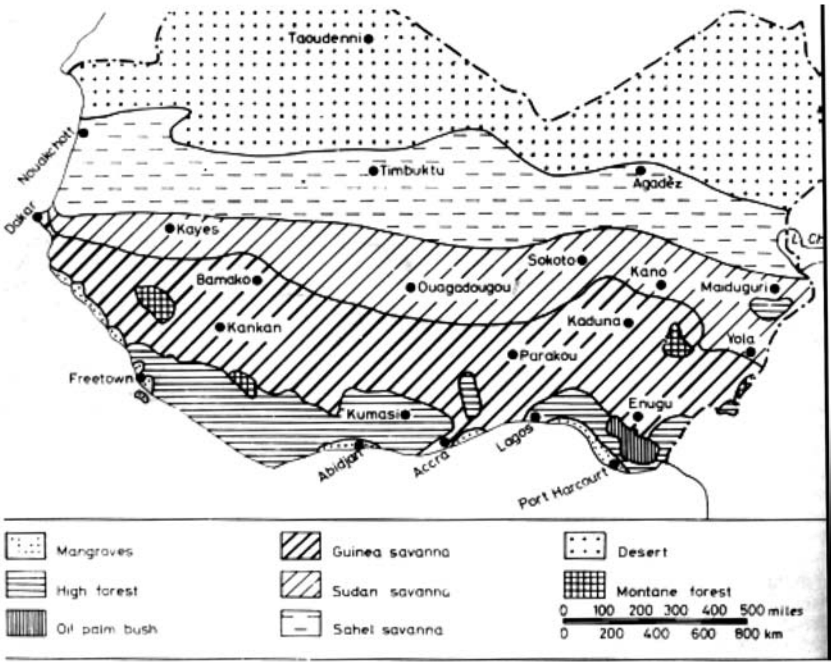

Figure 5. West African vegetation zones

Temporal variations also occur on the decadal and five-year scales. For example, the decades 1900–1909 and 1930–1939 were near normal. Similarly, 1960–1969 was near normal with a slight negative index. In contrast, 1950–1959 was a relatively wet decade while 1940–1949 and 1970–1979 were relatively dry decades. The worst conditions occurred during the 1970–79 decade, with an index of less than −0.62. On the quinquennial (five-year) scale, seven of the quinquennial periods have positive indices. Of the periods with negative indices, the worst were 1915–1919,1970–1974, 1975–1979 and 1980–1984 with climatic indices less than -0.4σ. The driest quinquennial period was 1980–1984 with a climatic index, which is less than -0.65σ.

Rainfall variations were also examined on a regional basis, using the five climatic zones based on vegetation regions of West Africa, namely, the tropical rainforest, the Guinea savanna, Sudan savanna, Sahel savanna, and southern semi-arid zones (Figure 5). The analysis showed that considerable variations also occur between the different climatic zones and even within the same climatic zone. For example, drought conditions were more persistent and more widespread in the Sudan Savanna, the Sahel Savanna and the Southern Sahara than in either the tropical rainforest region or the Guinea Savanna.

Impacts of climatic variations on West African hydrology and water resources

Seasonal variations in river flows

A lot of seasonal variations occur in the discharges of West African rivers and these vary with the type of rivers, the geology, physiography, soils, vegetation and the size of the catchment area. Over most areas of West Africa, rainfall is concentrated mainly in the rainy season, and potential evaporation losses are high especially during the dry season. Hence the flow of small rivers fall away very rapidly after the periods of rain and in most cases frequently cease during the dry season. In a few cases, however, most especially in the southern parts of West Africa, small rivers are capable of sustaining permanent flow during the dry season. In parts of the southern regions of West Africa with a long wet season, a large water surplus and relatively lower evaporation than in areas to the north, with a long dry season, the storage capacity is often sufficient to maintain a dry season flow of the order of 1–2 $l/s/km^2$ (Ledger, 1969).

In contrast to the smaller rivers, the characteristics of hydrographs of relatively large rivers depend to a large extent on the channel and floodplain storage capacity of the basins concerned. In part, the storage capacity is partly a function of basin size and partly a function of channel and floodplain morphology. In this respect, the rivers of West Africa fall into two distinct categories, namely, those of the northern plains with rainfall concentrated in 4–6 months and those to the southern areas with rainfall spread over 8–12 months of the year. In large rivers located in the northern parts of West Africa with rainfall concentrated in 4–6 months of the year, the pattern of flow is similar to the patterns of the smaller rivers which flow into them, for their discharges fall rapidly to very low levels once the wet season has ended. Examples of such rivers include the Niger, for example at Kouroussa and Niamey (Figures 6 and 7). However, while the over-all flow patterns especially during the dry season are similar, it is apparent that large rivers take

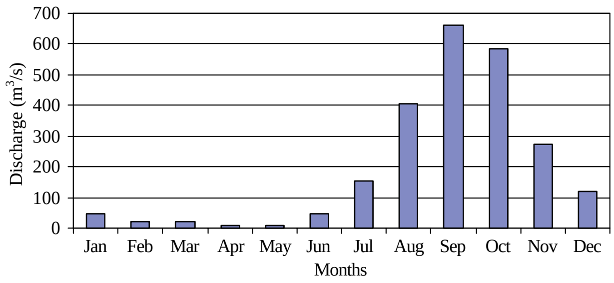

Figure 6. Mean monthly Discharges of River Niger at Kourousa.

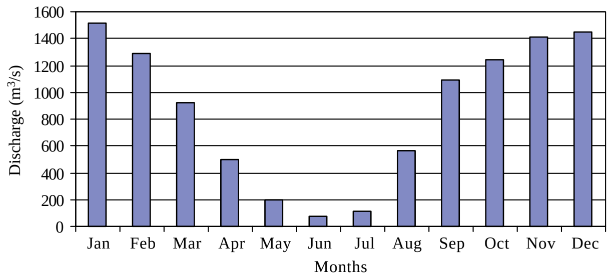

Figure 7. Mean monthly discharges of river Niger at Niamey.

appreciably longer than small ones to recede from high wet season to dry season flow. The period of such recession varies between 3 and 4 months, implying that the period of really low flow begins later and lasts for a shorter time than in small rivers.

The differences between large and small rivers are, however, slight compared with those arising from the differences between the northern and southern rivers. Because of the low gradient, many large rivers in the north of West Africa are able to carry only a small proportion of the water flowing into them from headwater areas. As a result, most of this water overflows into the surrounding plains, transforming them into huge, shallow lakes ranging in area from a few hundred square kilometres in a smaller basin, such as those of the Black Volta above Kouri and the Rima, to as much as 25,000 km^2 in the inland delta zone of the Niger Basin. Later, when the inflow rate begins to fall, much of the water stored in these plains is released back into the main channels, thereby sustaining flow at points downstream.

Variations in trends of mean annual river flow and discharges

Variations in the mean annual discharges of the rivers of West Africa show a general decrease especially during the past three or four decades. The only relatively long period of data for river discharges available to the present writer was for the River Senegal at Bakel, for which, as for rainfall, the 20th century began with relatively low discharges of less than 1000 m^3/s, for example, between 1904 and 1906 (Figure 8). The values increase slightly towards the end of the decade, with about 1230 m^3/sec in 1907. Thereafter, the values decrease until the 1920s and 1930s with values generally more than 700 m^3/sec. Occasional drought years are noticeable in the pattern of discharges. This is for example, true of 1921–1922 with about 431 m^3/sec and 1926 with about 521 m^3/s. Relatively low values which are generally less than 500 m^3/sec are also observed during the drought years of the early 1940s especially between 1941 and 1943 with 431 m^3/sec in 1941, 417 m^3/s in 1942 and 437 m^3/s in 1943. Relatively low values of about 330 m^3/sec also occurred in 1945 and 467 m^3/s in 1950. Since the late 1960s, the values of the river discharges had been decreasing and between 1980 and 1986, the values had decreased to 301, 402, 423, 303, 220, 205, and 356 m^3/sec respectively.

A lot of variations also occur in the characteristics of the discharges of the other rivers. From the few data available to the writer for example, it is evident that runoff data for the River Niger at both Koulikoro and Niamey, show that between 1969 and 1977, only 1969 experienced a positive variability index in the annual runoff. Negative variabilities prevailed between 1970 and 1977.

Local variations and extremes

It is significant to note that more detailed analysis of the variations of the occurrence, severity and

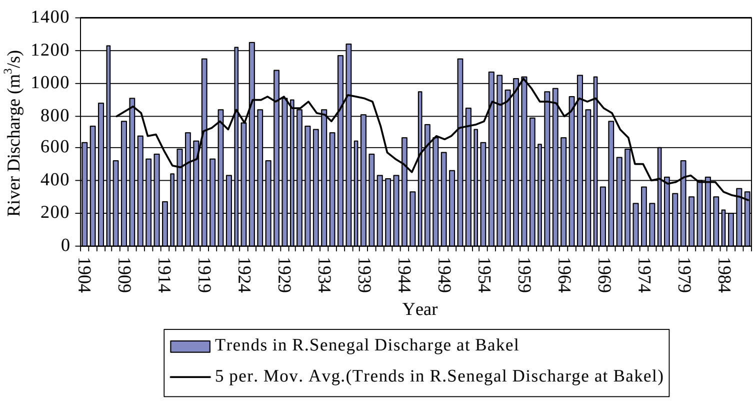

Figure 8. Trends of discharge for river Senegal at Bakel.

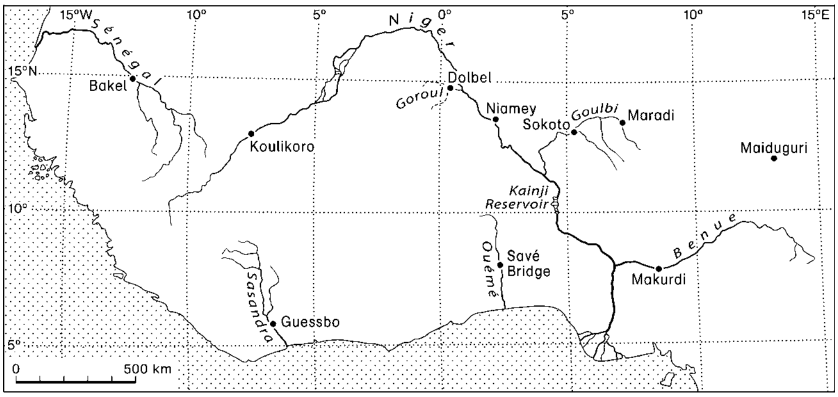

Figure 9. Some river locations in West Africa.

widespread nature of the hydroclimatic characteristics show that it is difficult to generalize for relatively large areas using information from a relatively small area. For example, in contrast to conditions at Save Bridge on the River Queme and at Bakel on the River Senegal, where the driest years of 1971–1980 decade were 1973, 1977, and 1978, the driest year at Quessaba on the River Sassandra was 1974. Variations also sometimes occur in the characteristics of the discharges along the same river. For example, although most of the years between 1969 and 1977 were characterized by drought conditions at Maradi and Dobel on the River Goulbi, the year-to-year variabilities in the percentage deficiency of annual discharges at both locations show that droughts were more persistent at Dobel, occurring approximately between 1970–1974 and 1976 with a slight recovery in 1975. At Maradi on the other hand, droughts occurred in 1972–1973 and 1976–1977. Also, the severity of droughts was greater at Maradi than at Dobel. It may also be noted that conditions at Maradi show that the years 1974–1975 were characterized by very wet conditions in contrast to Dobel where the years showed either negative variabilities or positive conditions near normal.

Extremely high discharges appear to have been more spectacular in the early part of the 20th century, when for example, values of more than 3000 m^3/s were usually recorded on the river Senegal. In some cases, extreme values of more than 4000 m^3/s were recorded. This is for example the case of the River Senegal at Bakel in 1907, 1910, 1917–1920, 1923, 1926, and 1928 with about 9340, 5490, 4200, 4960, 7300, 5630, 9070, 4670, 6350, 4610, and 6460 m^3/s respectively. Variations similar to those of the River Senegal at Bakel were also found for some other rivers in West Africa. For example, the standardized values of the mean annual discharges on the River Benue at Makurdi show a decrease from more than $+\sigma$ in the 1950s and early 1960s to less than $-\sigma$ in the 1980s. Relatively low values occur especially in the relatively remarkable years of 1973 and 1983. Over the past 5 or 6 years, observed trends in rainfall indicate a relative increase with possibly an increase in discharges, as for example shown in the 1994 value, with slightly above $+0.3\sigma$.

Groundwater

Groundwater resources always reflect the pattern of rainfall characteristics in West Africa in general. Over the past three or four decades, the impacts of the relative persistence of droughts in the region have been remarkable. Groundwater tables usually rise during years of relatively high positive rainfall variability and fall during years with negative deviations. This was the case, for example, with the Kano region of Nigeria as already noted by Ojo (1989).

Implications of climatic variability and change on climatic events

Other significant aspects of the impacts of climatic variations and climate change are related to floods and droughts, two major types of disaster that have caused considerable losses and damages and even death in many parts of West Africa, especially the Sudano–Sahelian region. The severity of these disasters, however, varies in time and space, but evidence from many countries shows that floods and droughts cause greater losses of lives and property in the region than any other disaster. In spite of the decreasing trends in rainfall and consequently, increasing frequency of droughts in the region, floods are still a significant occurrence. For example, in spite of the ravages caused by droughts in parts of Nigeria following the 1983–1984 events, downpours of rains were reported especially down the south of the country causing floods, loss of property and sometimes lives. Another example is in Senegal where, although, the drought was unusually severe in 1983–1984, over 150 mm of rain fell in 4 h of 19th June 1983 to the northeast of the country, causing floods which damaged property and left people homeless.

From the above analysis, it is apparent that most years within the study period have been characterized mainly by water deficits and droughts, although flood events have also impacted adversely in many parts of the region. The characteristics of droughts and floods have also been influenced by human activities, such as increased rates of deforestation and desertification processes. These processes have resulted in rapid surface runoff and in many cases reduced water quality, which in turn have affected potable water availability. Because hydrology and water resources are inextricably linked to climate in the region, climate change will continue to have a lot of impacts on various components of hydrological systems and water resources aspects of the region, including the characteristics of both surface and ground water.

The impacts of droughts and floods form a relatively high proportion of disasters occurring in West Africa. For example, between 1963 and 1992 about 88% of the significant damage and 76% of the deaths were caused by droughts. The impacts of floods also took another 4% of the significant damage and 9% of the persons affected. It is also significant to note that epidemics, the occurrence of which to a large extent depends on climatic variability and change, account for about 79% of the number of deaths. In particular, following the occurrence of droughts over the past three or four decades, most lands especially in the Sudano–Sahelian region, tend to be completely barren, covered with loose sands, so that there were no pastures to graze in the drought affected areas. Also, with the acute shortage of water, sandstorms became a common feature especially before the arrival of another rainy season. There were frequent bush fires, and wind and water erosion occurred more frequently with a reduced vegetation cover.

Variations in the characteristics of the lakes and the catchment basins of West Africa also illustrate the variations in the characteristics of droughts and floods. For example, as with the rivers of West Africa, the lakes of West Africa were also considerably affected by the drought events which have been especially persistent in the region during the past three or four decades. In particular, the inflow into the lakes dropped sometimes by as much as 50%. This is, for example, true of the Kainji lake whose inflow in the first half of 1974 was down by as much as 50% and all year round downstream navigation was impossible. In addition, the fish catch in the lake went down from about 28,000 tonnes to only about 10,000 tonnes.

In a recent study by Adewale (2000), it was shown that the physical characteristics of the river basins of West Africa in general and the Sudano–Sahelian region in particular, have been declining. A decline of 50% was observable in some basin parameters of the area studied in the Sudano–Sahelian region between 1956 and 1975, while between 1975 and 1986 there was a decline of about 20%. Such parameters include stream length and stream numbers, the drainage density, stream frequency, and length of overland flow. These have significant import for the water resources planning and management of a basin. For example, the drainage basin decreased from 1.1589 km/km^2 in 1956 to 0.7576 km/km^2 and 0.6936 km/km^2 in 1975 and 1986, respectively. The stream frequency declined from 1.25 in 1956 to 0.31 in 1986. There was also a decline in drainage efficiency, and decreasing opportunity for infiltration as a result of the declining trends in rainfall and consequently increasing frequency of droughts. In general, the trend in the basin's linear characteristics shows a mean "percentage decline" of 35.5% in stream length between 1956 and 1975, and 42.2% between 1956 and 1986 showing an increase in decline of 6.7% between 1975 and 1986, using the 1956 data as base. For stream length, mean percentage decline rates were 27.5% (1975) and 34% (1986), giving an increase in decline of 6.5% between 1975 and 1986, or about 0.6% declining rate per year. These conditions would have serious implications on the water resources of the basin. For example, the declines in the basin characteristics imply that there would be declines in water availability in both surface and groundwater resources and consequently declines in water yields. These would have negative impacts on agriculture and the socio-economic sectors because there would be considerable water stress. No doubt, if the trends were to continue, many basins in the Sudano–Sahelian region would show almost completely dry characteristics with no surface water in the streams and other water bodies.

Response strategies

The impacts of climate change on hydrological systems and water resources management will be serious in West Africa. Presently, the ever-increasing population pressures have resulted in a sharp rise in requirements for clean freshwater which in many parts of the region are not available. Increasing water stress has particular implications on the economy of West Africa, and the acute shortage of freshwater experienced in most parts of the region indicates the need to plan for optimum utilization of coherent policies and programs for the development and management of water resources. This also implies the need for actions and response measures to adapt to climate change impacts, and especially as they affect water resources. The water supply-demand projection done for Nigeria (1996-2030) in a recent study for Nigeria shows that water demand deficits are relatively considerable and show increases between 1996 and 2030 (Table 1; Ojo, 2003). This situation stresses the need for effective water resources development strategies and for coherent and effective policies and programs of development and management of water resources.

Two main categories of adaptation measures may be noted. These include adaptation measures involving the water supply systems and those involving the water demand systems. The water supply adaptation measures can take any of the following forms: (a) construction of new structures, for example, building of reservoirs, hydro-plants, well fields, and possibly inter-basin water transfer, if found feasible (b) modification of existing

Table 1. Water supply-demand projections for rural and urban areas in Nigeria (1996–2030)

Year	Population (Millions)	Water supply (MLD)+		Water demand (MLD)+		Water demand Deficit (MLD)+	
		Rural	Urban	Rural	Urban	Rural	Urban
1996	39.6	363	2593.5	1596	4905.9	−1233	−2312.4
2000	44.7	407.7	3212.2	1792.5	6074	−1385	−2866.8
2005	51.6	470.6	4199.4	2069.2	7947.3	−1599	−37.7.9
2010	59.5	542.6	5488.4	2386	10386.6	−1843	−4898.2
2015	68.5	624.7	7166.1	2746.9	13561.7	−2122	−6395.6
2020	78.9	719.6	9386	3136.9	17762.8	−2444	−8376.8
2025	90.9	829	12776	3645.1	23232	−2816	−10956
2030	104.9	956.7	16040.6	4206.5	30356.5	−3249	−14315.8

Note: (a) Base year (1996) urban water supply: 51.15 l/person/day. (b) Base year (1996) urban water demand: 98.6 l/person/day. (c) Base year (1996) rural water supply: 51.15 l/person/day. (d) Base year (1996) rural water demand: 51.15 l/person/day. + Megalitres per day.

physical structures and (c) developing alternative management of existing water supply systems. This may, for example, be in the form of changing the operating rules, use of conjunctive surface/groundwater supplies, change in priority of release, or coordinating water supply/demand systems (Feenstra et al., 1998; Ojo, 2003). Water demand adaptation measures may also take any of the following forms: (a) conservation and improved efficiency (b) technological change and (c) market- or price- driven transfer activities (Feenstra et al., 1998, Ojo, 2003). For example, policies, which involve metering, water pricing, and restrictions as well as the use of conservation, will improve efficiency and promote reduced water loss through demand. The need for adaptation measures for water resources management should be a priority for West Africa in the event of climate change and its ensuing consequences. Possibly the most effective approach would be a combination of as many of the above listed approaches as possible in order to balance supply and demand of water, and involving the management of integrated management strategies.

In addition to measures for water-supply and water-demand systems, there is urgent need to address a number of mechanisms for implementation of the adaptation measures. For example, if there is an urgent need for building capacity and manpower development of water institutions in the region. In general, capacity building has three components. These include: (a) creation of an enabling environment with appropriate policy and legal frameworks, (b) institutional development, and (c) development of human resources. In particular, there is need for strengthening the institutions and development of human resources at all levels including development of qualified hydrologists and hydroclimatologists.

Some of these measures have been applied in West Africa, although they have not been effective mainly because of problems related to socio-economic and socio-cultural factors. Some other mechanisms which are significant for the implementation of the adaptation measures include: (a) promoting education and public awareness on the various measures to be used, (b) public participation and the involvement of stakeholders, (c) the establishment of both national and regional cooperation and (d) the need for climate and other environmental data collection and monitoring.

Conclusion

The impacts of future climate change on hydrological systems and water resources management in West Africa are expected to be adverse and extensive, and the environmental and socio-economic problems that would be associated with the potential impacts may prove to be among the major problems facing the region. The consequences would exacerbate the already critical situation in many parts of the region. Timely and effective adaptation strategies are therefore, necessary although there are constraints and problems facing the implementation of any response strategy that would be put in place. Such constraints include those related to legislation, institutional, and organisational development and economic and financial problems. West Africa has suffered enough from the consequences of climatic variability and climate change and therefore, it is necessary to introduce explicit consideration of climate and adaptations to climate and climate change into the formulation, development and implementation of the policies at all levels. It is particularly important to realize that climate is both a resource and a factor in hydrological systems and water resources planning and development. It is now urgent to begin to formulate and implement policies, which will prevent or minimize the adverse consequences of climate change on socio-economic sectors in general and hydrological systems and water resources planning and development in particular.

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