Possible impacts of climate variability/change and urbanization on water resources availability and quality in the Benin-Owena River basin

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Abstract In this study, monthly rainfall and temperature from four Nigerian meteorological stations in the Benin-Owena basin covering the period 1940–2002, and evaporation (1960–2003) and river discharge (1980–2004) data were obtained and analysed to investigate the impact of climatic variability and urbanization on the water resources of the basin and the socio-economic implications. The Benin-Owena basin is heterogeneous in nature and located in the southwest of Nigeria. The study area covers a total land area of 59 787 km^2 and has a human population of over 13 million. Population data, the volume of solid waste generated in the region and water quality data from 32 boreholes distributed across the area were obtained from the UNICEF water and sanitation (WATSAN) project office and also analysed. The analysis showed that climatic variations exist over the region that appear as fluctuations of wet and dry periods every 2–3 years in terms of rainfall and the river flow. Also an increasing temperature trend was observed, rising at the rate of 0.37°C/decade. This, coupled with the high rate of evaporation, will cause increasing water loss in the basin. The borehole results showed that the aquifers are productive with relatively high potential water yields. Their water quality is within the World Health Organization (WHO) acceptable standards in terms of the physico-chemical and bacteriological composition, except for a few boreholes located in the unplanned densely populated areas of the basin; there, abnormal concentrations of chloride (297 mg L^{-1}), turbidity (20FTU), iron (0.43 mg L^{-1}) and faecal coliform counts of 3 per 100 ml of water, occur. Re-assessment of the water quality 10 years after commissioning of the boreholes showed that 18% out of the 96% of boreholes initially with good water quality, now had poor quality due to the high rate of unplanned urbanization.

Key words climatic variability; urbanization; river basin; discharge; borehole; water quality

INTRODUCTION

Human life and socio-economic activities have been subjected to many challenges in the recent time among which climate change/variability is the most important and of great concern. Unfortunately, the rapidly growing population of most cities is the most vulnerable to this climate change. Until recent decades, most water resources projects in Nigeria were planned and designed with the assumption of a stationary climate, whereas climate and hydrology have become both non-stationary stochastic processes. At present, water resources planners in river basins are facing increased uncertainty in evaluating the hydrological condition of the basins under the changing climate. According to the Third IPCC Assessment Report (2001), precipitation will intensify during the 21st century. In some low latitude areas there will be decreases in total quantities (and drought) and increases (and flooding) in others. In addition, many research projects in Nigeria have confirmed that there is a changing climate in Nigeria. For instance, Udoeka (1998) and Udoeka *et al*. (1998a) in their recent work over the six climatic zones of Nigeria showed that there is a steady rise in evaporation and steady decrease in rainfall throughout the country. Okpara *et al*. (2004) also observed that increased "land-use intensity" due to the rapid rate of urbanization and industrialization was a key factor responsible for the unsustainability of groundwater resources in the country, since it leads to imbalance and social malaise in the society. Also urbanization does not only ensue in climatic variations, but leads to inadvertent weather modification of a place as well as creating a micro-climate over the region. Gbuyiro & Aisiokuebo (2003) observed an average temperature increase of 0.4°C across the country in the last 20 years.

According to Obasi (2003), projected temperature increases are likely to lead to increased open water and soil/plant evaporation. As a rough estimate, potential evapotranspiration over Africa is projected to increase by 5 to 10% by 2050. Also, with Africa being the continent with the lowest conversion factor for precipitation to runoff (averaging 15%), the dominant impact of global warming has been postulated to cause reduction of soil moisture in the sub-humid zones, as well as reduction in the runoff. It is against this backdrop that this study tries to investigate the

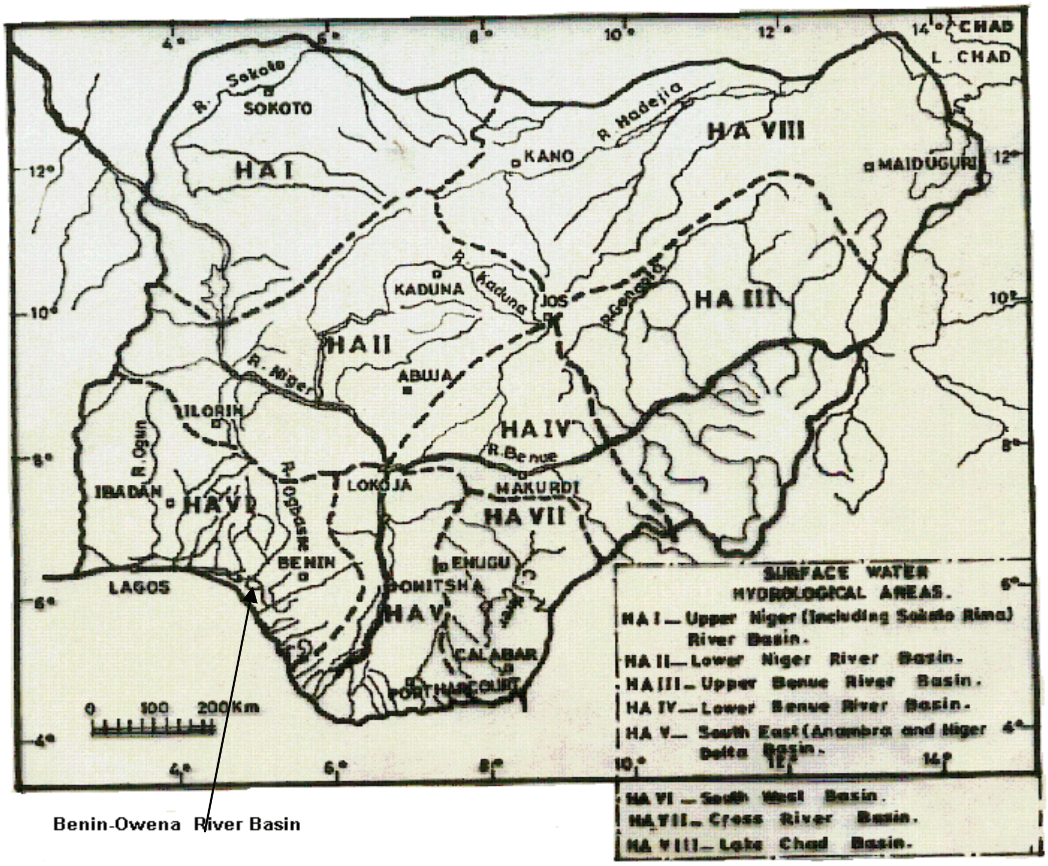

Fig. 1 Location of the Benin-Owena basin in southwest Nigeria.

impacts of climatic variability and urbanization on the available water resources of the Owena River basin, especially as NGOs and State government promote the sinking of shallow boreholes through the UNICEF assisted Water and Sanitation (WATSAN) project.

STUDY AREA

The study area is the Benin-Owena River Basin Area that lies between the west bank of the Niger River in the east and the Oni River in the west, and occupies the territory covered by Ondo, Ekiti, Edo and Delta states (Fig. 1). The basin has a total area of 59 787 km^2, with a human population of over 13 million. The settlement pattern shows compactness in the towns and cities, with the major occupation of the rural population being agriculture; there are a few growing industries scattered across basin. The main north–south flowing rivers/streams of the basin are from west to east namely; Oni, Siluko, Benin, Escravos, Forcados, Ase, Niger and many other streams. Topographically, the basin can be divided into two belts; namely the northern highlands and southern plains or lowlands. It has an undulating land surface that descends gradually from an altitude of over731.52m in Ekiti state to the lowlands. The Ishan plateau of the basin rises steeply from the Niger valley and has such striking characteristics as level topography, easily worked sandy soil and paucity of surface drainage which calls for extensive hydrological study in terms of groundwater occurrences.

Climatologically, the basin area falls into the region of high temperature that ranges from 24.7–33°C on the long-term average and experiences mean annual precipitation of 6604 mm in any normal year and an estimated mean annual evapotranspiration of 4622.8 mm with relatively high humidity (>70%) .

DATA ANALYSIS

Monthly rainfall and temperature data (1940–2002), and evaporation data (1960–2003) from four meteorological stations in the basin, and river flow discharge data (1980–2004) were subjected to a time series and variability analyses. Also, data available for 32 boreholes were obtained from the office records between 1998 and 2002 of the Ondo State-UNICEF assisted water and sanitation (WATSAN) project on the rock formation and water quality of the basin, and subjected to descriptive analysis. Some of the parameters which could be determined immediately, i.e. temperature, pH (measured with a Jenway model 3100 pH meter), and conductivity (measured with a Jenway 4070 conductivity meter) were done. Both meters had automatic temperature compensation. In the laboratory, the total hardness and calcium were determined using EDTA titration, and titration with EDTA using Eriochrome black T as the indicator. Magnesium was estimated as the difference between total hardness and calcium concentration. The coliform counts were determined by the most probable number method, after incubation of Mackonkey Broth-treated samples for 48 hours at 37°C (WHO, 1984). Population data from the Federal Office of Statistics/National Population Commission, and data on the volume of solid wastes generated in the region from the office of Federal Ministry of Housing and Environment, were also obtained and analysed to ascertain the rate of land-use intensity, urbanization and population pressure in the basin. Re-assessment results for the water quality 10 years after the commissioning of the boreholes were also carried out in July 2003.

RESULTS AND DISCUSSIONS

Results in Fig. 2(a) show an increasing temperature trend, with a general increase rate of 0.37°C/decade. The temperature increase of 0.37°C/decade over the basin is still within the increase of 0.5^{o}C/decade projected by the third IPCC Report. This will invariably create a high evaporative demand from the open water and the soil/plants in the basin as we can see from Fig. 2(b). Evaporation has shown an increasing trend since the 1980s, resulting in about 70% of the annual rainfall of the basin being accounted for by natural losses (evapotranspiration). According to Obasi (2003), with Africa being the continent with the lowest conversion factor of precipitation to runoff (averaging 15%), the dominant impact of global warming has been postulated to result in the reduction of soil moisture in the sub-humid zones, as well as reduction in the runoff. Consequently, since the field capacity of the soil has to be attained before recharging the groundwater, the rate of recharge is expected to be affected.

Figure 3 shows that climatic variations exist that appear as oscillations of wet and dry periods every 2–3 years; with increasing rainfall trend pattern. There are also more wet years in this basin than dry years unlike in other river basins of the country with decreasing trends (Fig. 3). However, indications that the trend is tending towards the negative with time is already in evidence. Very long periods of wet years was observed from 1948–1969, with 1949–1965, 1991, 1995, 1999 and 2002 been the wettest years. The only dry periods were 1944–1946, 1950, 1956, 1958, and

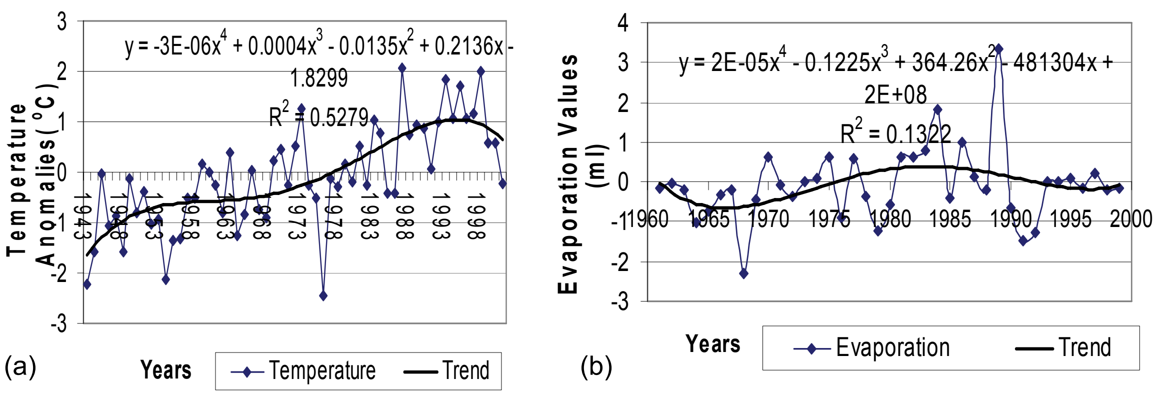

Fig. 2 Benin-Owena basin: (a) temperature variability and trends, (b) evaporation anomalies and trends.

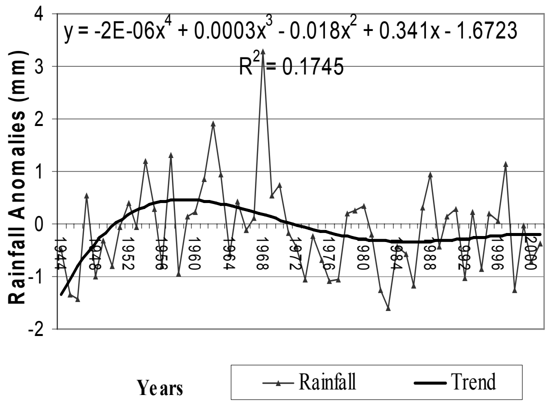

Fig. 3 Rainfall trend over the Ogun-Osum River basin.

1964, 1976–1978 and 1981–1984; most of which coincide with the El-Nino years. Changes in land-use due to urbanization and population pressure also created micro-climatic and inadvertent weather modification of the area; resulting in heat islands developing in the more devegetated and ill-planned urban areas of the basin, Tables 1 and 2. Some descriptive statistical properties of the rainfall for the two reference periods are also given in Table 3, which stresses the large differences in the data between the two periods. All the stations in the basin show statistically significant (95% level) differences in the means of the sub-period rainfall series. This suggests that the recent rainfall patterns of the region are not due to mere chance, but climate variability. This can be linked with intense rainfalls of short duration often experienced in the region causing increased runoff, sediment erosion and destructive flood flows.

Thirty % (1981.2 mm) of the mean annual rainfall (6604 mm) accounts for annual runoff in the basin. Figure 4 describes the Catchment response to the behaviour of the rainfall in terms of the river flow pattern over the basin. Hydroclimatological changes are also visible in the time

Table 1 Comparison of temperature distribution between ill-planned devegetated urban centre and well planned vegetated urban centre.

Time	Devegetated area	Vegetated area
0600Z	24.8	23.2
0900Z	28.0	26.9
1200Z	32.5	30.4
1500Z	31.6	29.9
1800Z	28.6	26.3

Table 2 Comparison of temperature increase in the urban centres of the basin with rural surroundings for both dry and wet season.

Land use	Temperature increase:	
	Wet season	Dry season
Medium class density	2.4	2.6
Low Class Density	3.4	4.6
Commercial areas	2.7	5.3

Table 3 Descriptive statistics for annual rainfall series in the basin.

Station	Reference period	Maximum (mm)	Minimum (mm)	Mean (mm)	Standard deviation (mm)	Reference period as % of long-term mean
Benin	1940–1970	3147.1	1334.3	2143.63	418.88	101
	1971–2002	2668.4	1228.4	2121.98	379.74	99
Warri	1940–1970	3390	2373	2877.53	282.82	101
	1971–2002	3436.8	2072.4	2774.74	318	98
Ondo	1942–1970	368	351	360.80	3.91	99
	1971–2002	385.5	354.1	368.75	6.0	101

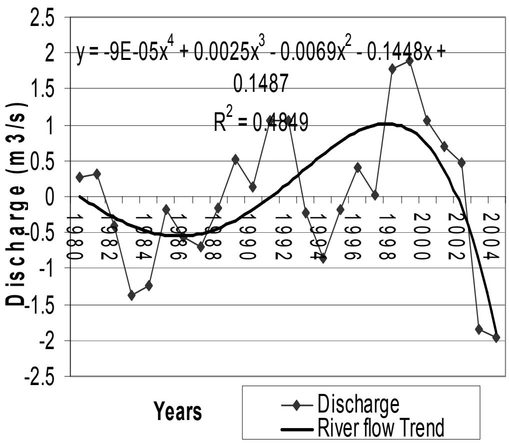

Fig. 4 Time series of Niger River flow over the Niger delta area.

series of the river discharges. The runoff of the Niger River (Fig. 4), the biggest in the basin, shows two climatic periods in the last two decades: a 10-year dry period, from 1980 to 1989, with an average interannual runoff of 51 946 $m^3 s^{-1}$.Then the wet period started, with an average interannual runoff of 62 087 $m^3 s^{-1}$. The driest and wettest years were only 16 years apart (1983 with 34 422 $m^3 s^{-1}$ and 1999 with 90 820 $m^3 s^{-1}$). The trend since 2003 is already tending towards another cycle of dry periods as we can see from the graph. Hence there is need for appropriate water resources management practices to be put in place in the region, so that no excess water is allowed to waste without being harvested. The river basin, unlike other basins in the country, seemed to be rich in water resources, strengthened by the increasing rainfalls; unfortunately, most of the waters are unfit for drinking and domestic uses due to indiscriminate disposal of wastes of all types from the towns and villages, unplanned densely populated settlements and uncoordinated land-use practices.

All these contribute to degradation of the quality of the available water resources. These contaminants are not only washed into the rivers after a heavy downpour but also get into contact with the water table through leaching. Another source of pollution observed is through pronounced sediment erosion and associated pollution. This has silted up and caused eutrophication in most of the reservoirs created for water supply purposes in the basin. The borehole analysis from the WATSAN project confirmed that the aquifers in the region are productive on average with relatively high yield of water potentials: 13 boreholes were categorized as high yield, 15 as medium/relatively high yield, and 4 as low yield. Most of the boreholes are developed within 30–36 m depth with varying water levels. The water quality is within the World Health Organization (WHO), acceptable standard for drinking and domestic use in terms of physical, chemical and bacteriological composition, Table 4.

Table 4 Groundwater quality assessment result of sampled boreholes.

Parameters	WHO prescribed standard (1984)	96% of sampled good bore holes	<5% of sampled bad bore holes
Appearance		Clear	Clear
Colour		Colourless	Colourless
Temperature (°C)		27.8	27.6
Turbidity (FTU)	<1 to 5	7.8	20
pH	6.5–8.5	7.0	7.0
Total Dissolved Solid(TDS) (mg L^{-1})	1000	0.27	0.47
Conductivity		0.56	0.96
Iron (mg L^{-1})	0.3	0.28	0.43
Chloride (mg L^{-1})	250	76.7	297
Nitrate (mg L^{-1})	10	2.1	12.1
Total Hardness (mg L^{-1})	500	95.4	695.4
Calcium (mg L^{-1})		40.7	40.7
Magnesium(mg L^{-1})		61.1	61.1
Copper (mg L^{-1})	1.0	2.2	2.2

On average, 96% of the sample points had good freshwater at the initial time of construction, with average total dissolve solid (TDS) as 0.27 mg L^{-1}, chloride 76.7 mg L^{-1}, nitrate 2.1 g L^{-1}, iron 0.28 mg L^{-1}, pH 7.0 and total hardness 95.4 mg L^{-1}, though the turbidity, 7.8 FTU, was slightly high. Less than 5% had poor water quality, with average turbidity values of 20 FTU, average faecal coliform count of 3 per 100 ml of water, average chloride values of 297 mg L^{-1}, average iron 0.43 mg L^{-1}, all these values are slightly higher than the WHO acceptable safety level. A few samples also have total hardness slightly above the tolerant level, and so is their colour, i.e. slightly brownish or turbid. Such boreholes could have their quality improved by treating and disinfecting them.

Table 6 Relationships between human population and water quality in Benin-Owena River Basin area.

	Urban Area	1991	1992	1998	2002
Population	Delta State	2 590 491		3 149 371	
	Edo State	2 172 005		2 640 600	
	Ondo State	3 785 338		4 601 990	
Water quality	Turbidity		7.8FTU		9.8FTU
	TDS		0.27		100
	Iron (mg L^{-1})		0.28		0.38
	Chloride (mg L^{-1})		76.7		307
	Total hardness (mg L^{-1})		95.4		580
	Faecal coliform		0		3 per 100 ml count

It is pertinent to say that the shallow nature and the location of most of the boreholes in the midst of dense settlements, coupled with the increasing rate of urbanization made some of the boreholes highly susceptible to contamination from septic tanks, pit latrines and solid waste dumping sites. These may have accounted for the abnormal concentration of chloride, faecal coliform counts and iron observed in the unplanned densely populated areas within Akure, Ilu-Oluji, Ilu-Abo and Ondo, Benin, Warri and Asaba. It was also noted that as the population grows, more wastes are generated in those places and the more their dumping sites become potential sources of groundwater pollution in the area (Fig. 5). The graph reflects the rate of solid waste generation growth in the basin. These solid wastes, apart from clogging up the drains and defacing the land area, also harbour all sort of pathogenic micro-organisms. Contaminants from these dumping sites often get into contact with the water table through leaching. Ten years after the construction of the boreholes, signs of serious groundwater contamination appeared in 18% of the supply wells in the region, in terms of chemical and biological (bacteriological) composition. Ironically, these same wells were among the boreholes that were initially of good quality. This result therefore explains the incessant outbreaks of diarrhoea in some of the towns in the basin.

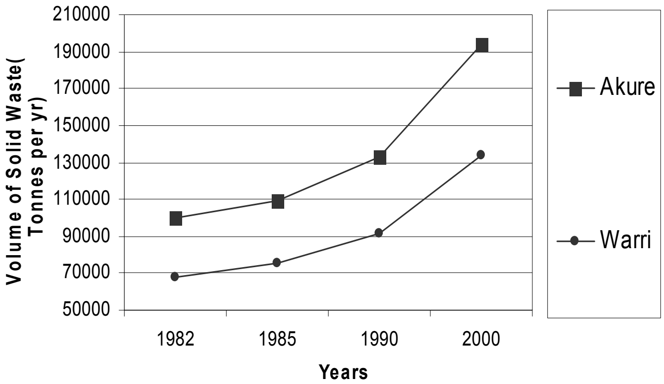

Fig. 5 Growing trend of solid waste generation in the Benin-Owena River basin area.

CONCLUSION AND RECOMMENDATIONS

The high evaporative demand observed over the basin due to rising temperature (0.37°C/decade) caused by changing climate portents danger to the available water resources of the region and a serious threat to the attainment of water security of the region. Also, the increase of intense rainfall of short duration due to observed climatic variations may have been responsible for the perennial ecological problems (flooding and sediment erosion) frequently experienced in the basin. Re-assessment of the quality of the existing borehole after 10 years showed that some have lost their initial good qualities, due to urbanization and increasing population coupled with poor sanitation systems, increasing use of nitrate fertilizers by farmers and change in land-use patterns. Therefore, for groundwater exploitation, determination of an optimum operating policy should be given high priority to take care of the following questions; (a) Where should the wells be located? (b) How many wells are actually needed? (c) How much should be pumped from each well and when? Due to the low travel velocity of groundwater, contamination may not be detected in real time and when detected rehabilitation may either be impossible or very costly. Also adequate sanitation systems should be put in place to meet up with the increasing population growth of the basin, so that domestic sewage and solid wastes can be properly disposed. Proper monitoring is one essential activity in the process of groundwater protection that must also be put in place.

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