Hydro-climatic variability of the Hadejia-Jama'are river systems in north-central Nigeria

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Abstract The study investigates the hydrological fluxes and land-use dynamics of the Hadejia-Jama'are basin in north-central Nigeria for sustainable agricultural development. The empirical Thornthwaite model was used to determine the potential evapotranspiration (PE) loss taking into account the land-use dynamics obtained from change detection using Landsat TM of 1986 and 2006. Using the results obtained from land-use dynamics, multiplying factors were determined and future water balances computed for high and medium emission climate change (HCC; MCC) scenarios for 50 and 100 years. The results reveal that the basin is currently recording a water deficit and that this will increase by 0.52% for the 50-year MCC, 0.53% for the 100-year MCC, 7.25% for the 50-year HCC and 37.82% for the 100-year HCC in Nguru, relative to the 2006 water balance. Sustainable agricultural practices and appropriate dam optimization techniques to ensure eco-friendly developments were recommended.

Key words hydro-climatic; land use; water stress; climate change; Hadejia-Jama'are river systems, Nigeria

INTRODUCTION

The Hadejia-Jama'are River System (H-JRS) ecosystems and the human food production systems and livelihoods they support are threatened by the phenomenon of climate change, which over the years has resulted in a high level of variability and uncertainty in the annual flood regime (Yahya *et al*., 2010). The area faces further challenges due to the persistent poverty of its population, which is basically rural, the degradation of its natural resources, the loss of its biodiversity and the consequent climate change brought about by increase in temperature and evapotranspiration which compound the water stress (World Bank, 2010). Farmers in the area have, over the years, developed several adaptation strategies such as flood recession farming, but efforts to improve livelihoods and address the impact of high-level variation and variability in the hydro-climatic elements were institutionalized by the construction of the Tiga (storage capacity: 1492×10^6 m^3, 1992) and Challawa Gorge (972×10^6 m^3, 1992) dams. The agricultural activities within the H-JRS are shaped by and dependent on the timing, magnitude, duration and frequency of flow patterns as dictated by the two dams (Geos, 2001). The dams control 80% of the flows into the Hadejia-Nguru Wetlands. The primary function of Tiga Dam, is to store water for the Kano River Irrigation Project (KRIP) scheme. Overwhelmingly, the losses in environmental productivity are due to alterations of natural flows and fragmentation of rivers and their flood plains due to dams and water diversions. By constricting the flows, these irrigation dams reduce the extent of the inundation of the flood plain and wetlands during the wet season and increase it during the dry season. These desiccated lands that were formerly wetted on a seasonal basis for recession agriculture are now waterlogged low-lying lands, which no longer experience their natural drying-out cycle. Consequently, there is a reduction in the area inundated, a decline in the groundwater tables and a general shortage of water in the lower part of the basin (IUCN and HNWCP, 1999). Also, this change in flow patterns has created conditions that have caused a massive invasion of the exotic *Typha* weed into the waterways, which has greatly reduced the areas that can be used for agriculture, and has caused massive siltation of the waterways, that result in permanent standing water and poor drainage (Fortnam & Oguntola, 2004). Yet these water projects also provide important hydropower, water supply and flood control benefits. Therefore, the study investigates the hydrological fluxes and land-use dynamics of the Hadejia-Jama'are basin in north-central Nigeria for sustainable agricultural development.

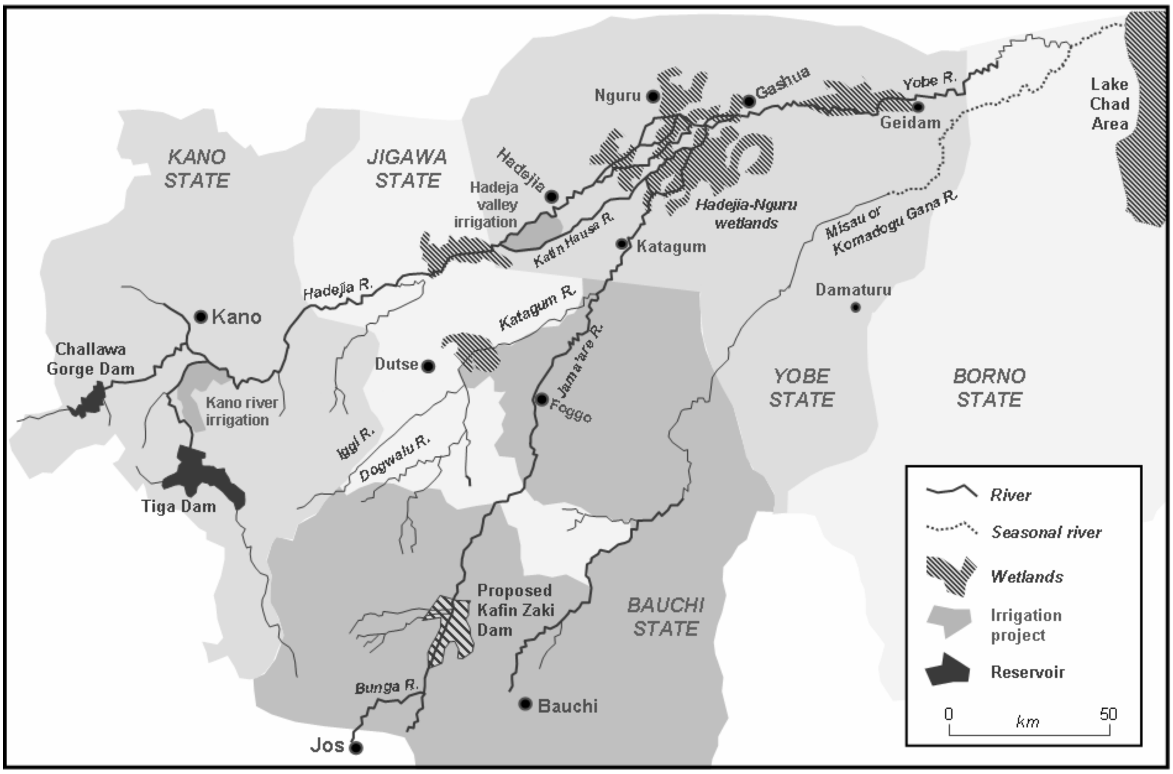

Fig. 1 Hadejia-Jamare River System (H-JRS).

STUDY AREA

The Hadejia-Jama'are River System (H-JRS) is part of the larger basin known as Komadugu Yobe River Basin. It is situated in the semi-arid northern part of Nigeria (Goes, 2001). The two major rivers of the H-JRS (Hadejia and Jama'are) meet in the Hadejia-Nguru Wetlands (HNWs) to form the Yobe.

The Hadejia take its source from the Kano highlands while the Jama'are takes its source from the Jos plateau. Apart from Tiga and Challawa gorge dams, other large-scale water resources management and irrigation projects are the Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and the Hadejia Nguru Wetlands (HNW) Conservation Project, which is the most extensive flood-plain area in the basin (IUCN-HNWCP, 1999). In addition to the ecological richness of the wetlands, the HNW also serve as groundwater recharge zones. The mean annual rainfall ranges from about 1100 mm in the upstream basement complex area, to about 400 mm in the middle part of the basin and less than 300 mm near Lake Chad.

METHODOLOGY

Mean monthly flow data were collected from the H-JRBDA while meteorological data were obtained from Nigeria Meteorological services NIMET. Landsat TM data for 1986 and 2006 were used for land-use/land-cover analysis. The land-use classification scheme for change detection was based on the Nigeria topographic maps classification. Land-use mapping was carried out using Arc Map 9.3. The rate and trend of land-use change were determined using overlay analysis. Based on the deforestation rate of the land cover, coupled with the Thornthwaite empirical model for potential evapotranspiration (PE), a water balance approach was used to determine the basin water resources under different climatic scenarios (50-year MCC, 50-year HCC, 100-year MCC and 100-year HCC). The storage capacity for all measuring points was assumed to be 100 mm. Surplus is the result of rainfall in excess of water needed to replenish the soil moisture storage. The balance is annual surplus less annual deficit. Based on the coefficient of correlation of land-use dynamics and water balance, multiplying factors of 0.01°C, 0.025°C, 0.03°C and 0.035°C increase in surface temperature as a result of deforestation and increase in evaporation were assumed for 50-year MCC, 50-year HCC, 100-year MCC and 100-year HCC respectively. The implications of increase in temperature and soil water deficit on agricultural activities within the region were discussed.

RESULTS AND DISCUSSION

Rainfall variability in Hadeija-Jama'are

The data from the three NIMET observatory stations within the basin (Bauchi, Kano and Nguru) reveal that there is a decrease in rainfall amount from the upstream (the south of the basin) to the downstream northern part of the basin. The coefficient of variability (CV) of 41.86% shows an average spatial variation of rainfall distribution over the Hadeija-Jama'are basin. Spatially, PE decreases from north to the south, while its temporal variability between 1964 and 1996 reveals a CV of 15%, 18% and 20% for Kano, Bauchi and Nguru, respectively. The low level of temporal variability of PE over the basin shows that temperature has only marginally increased over the years. Figures 2 and 3 show the mean monthly rainfall and PE, respectively.

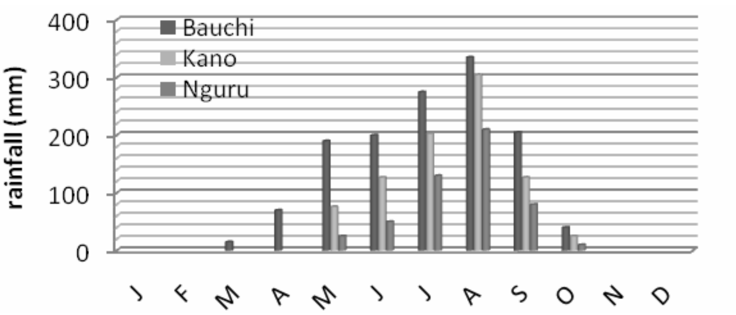

Fig. 2 Rainfall distribution in H-JRB.

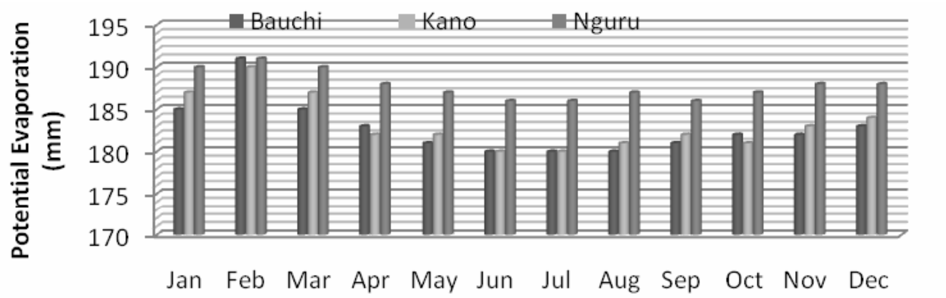

Fig. 3 Potential evapotranspiration.

Mean annual flow and discharge on the Hadejia and Jama'are

Flow analysis for the Hadejia River was carried out at Wudil (upstream), Hadejia (mid-Stream) and Gashua (downstream) stations. The Wudil record shows that mean annual flow on Hadejia River reduces from 1915 × 10^6 m^3 for the period 1964–1973 to 1004 × 10^6 m^3 for 1979–1989. This is about 47.57% decrease in the average flow records between the two periods. The mean peak discharge also reduced by 64.48% from 946 m^3 s^{-1} during 1964–1973 to 336 m^3 s^{-1} during 1979–1989. At Hadejia mid-stream gauging station, mean annual flow reduced by 27.16% from 718 ×

10^6 m^3 for 1964–1973 to 523 × 10^6 m^3 for 1979–1989, but then increased by 24.09% to 649 × 10^6 m^3 during 1993–1996. The reduction in flow between 1964–1973 and 1979–1989 is attributed to the construction of the dams (Tiga and Challawa), blockage of the river by *Typha* weeds, and droughts. The peak flow reduced by 34.34% from 99 m^3 s^{-1} during 1964–1972/73 to 65 m^3 s^{-1} during 1979–1989, but then increased by 36.92% to 89 m^3 s^{-1} for the period 1993–1996.

Flow analysis on Jama'are River, which is an uncontrolled river, was carried out using data from Bunga (upstream), Katagum (midstream), and from Gashua on the Yobe River downstream, along with flow from Hadejia River. The mean annual flow of Jama'are at Bunga reduced by 30.57% from 2061 × 10^6 m^3 for 1964–1972/73 to 1431 × 10^6 m^3 for 1979–1989, but then increases by 74.84% to 2502 × 10^6 m^3 for the period 1993–1996. The mean annual peak flow at Bunga on Jama'are reduced by 27.47% from 1227 m^3 s^{-1} for 1964–1972/73 to 890 m^3 s^{-1} for 1979–1989, and then increased by 58.88% to 1414 m^3 s^{-1} for the period 1993–1996. Though there was no record for Jama'are at Katagum for 1964–1973, the mean annual flow reduced by 8.14% from 1634 × 10^6 m^3 in 1979–1989 to 1501 × 10^6 m^3 for 1993–1996. The mean annual peak discharge decreased by 6.3% from 381 m^3 s^{-1} for 1979–1989 to 357 m^3 s^{-1} during 1993–1996. Unlike the Hadejia, the reduction in the flows of Jama'are is attributed to droughts, evapotranspiration and losses due to anthropogenic activities.

Gashua gauging on the Yobe River: the downstream station for both the Hadejia and Jama'are rivers

The mean annual flow at Gashua reduced by 33.79% from 1397 × 10^6 m^3 during 1964–1973 to 925 × 10^6 m^3 for 1979–1989, but then increased by 12.65% to 1042 × 10^6 m^3 between 1993–1996. There are strong indications that virtually no water (less than 1%) from the Hadejia reached Gashua in the 1993–1996 post-dam period. This is due to weed growth and siltation in the Hadejia River (IUCN, 1996). Consequently, the greater proportion of the flow recorded at Gashua is from Jam'are. Gashua peak flow reduced by 21.43% from 182 m^3 s^{-1} for the period 1964–1973 to 143 m^3 s^{-1} for 1979–1989, but then increased by 9.09% (from 143 m^3 s^{-1} between 1979–1989) to 156 m^3 s^{-1} during 1993–1996. In all, the natural flow regimes pattern of the Hadejia-Jama'are has greatly been modified by both natural and human developmental activities. Proper adaptation strategies to adjust to the changing pattern of year-round low dry season flow and wet season flood are necessary to combat hydro-climatic damage from drought and flood on agriculture.

Table 1 Hadejia-Jamare River System (H-JRS) flow.

River	Site	Area (km^2)	Pre-dams (1964–1973)		Post-dam (1979–1989)		Post-dam (1993–1996)	
			Mean annual flow (10^6 m^3)	Mean peak discharge (m^3 s^{-1})	Mean annual flow (10^6 m^3)	Mean peak discharge (m^3 s^{-1})	Mean annual flow (10^6 m^3)	Mean peak discharge (m^3 s^{-1})
Hadejia	Wudul	16 380	1915	946	1004	336		
	Hadejia	30 430	718	99	523	65	649	89
Jama'are	Bunga	7 980	2061	1227	1431	890	2502	1414
	Katagum	15 000			1634	381	1501	357
Yobe	Gashua	62 150	1397	182	925	143	1042	156

Source: IUCN (2006) and Goes (2001).

Land-use analysis

Table 2 shows the static land use in the basin for 1986 and 2006, while Table 3 shows the matrix of land-use change between 1986 and 2006. On average, the following annual rate of reductions in the total land area covered by different land use between 1986 and 2006 were identified: (flood plain complex (wetland) 73.32 km^2, water body 4.19 km^2, riparian forest 5.87 km^2, agricultural land 112.70 km^2 and shrub savanna 10.47 km^2). Grass savanna/bare surfaces were the only type of land use/land cover gaining at an average annual rate of 206.54 km^2. The massive loss in forest and other land uses and land cover was due to deforestation as a result of over-grazing and intensive agriculture, as well as the subsistence lifestyle of the inhabitants which means that they use firewood as their main source of energy. On average, a reduction in forest, wetlands and agricultural land at the rate of 20.65 km^2 per annum, leading to degradation of formally productive land, is being recorded. The diagonal (shaded) in Table 3 shows areas of stability where no changes have occurred (Adeniyi & Omojola, 1999; Odunuga & Oyebande, 2007).

Table 2 Static land use and land cover of Hadejia-Jamare River basin.

Land use/land cover	1986 (km^2)	% of total	2006 (km^2)	% of total	Annual rate of change (km^2)
Flood plain complex (wetland)	9 066.08	10.82	7 599.75	9.07	–73.32
Water body	5 697.72	6.80	5 613.93	6.70	–4.19
Riparian forest (*Khaya senegalensis* and *Syzygium guineense*)	5 773.13	6.89	5 655.83	6.75	–5.87
Agricultural land	49 167.97	58.68	46 914.02	55.99	–112.70
Grass savanna/bare surfaces	8 102.49	9.67	12 233.34	14.60	206.54
Tree/shrub savanna	5 982.61	7.14	5 773.13	6.89	–10.47
Total	83 790.00	100	83 790.00	100	

Table 3 Change matrix for land-use/land-cover change in Hadejia-Jamare River basin.

		Land-use and land-cover class 1986						
Land-use and land-cover class 2006		Flood plain complex (wetland)	Water body	Riparian forest *	Agricultural land	Grass savanna vegetal cover	Tree / shrub savanna	Total
	Flood plain complex (wetland)	7 599.75						7 599.75
	Water body		5 613.93					5 613.93
	Riparian forest*			5 655.83				5655.83
	Agricultural land				46 914.02			46 914.02
	Grass savanna/bare surfaces	1 466.33	83.79		2 151.42	8 102.49		12 233.34
	Tree/shrub savanna			117.31	102.17		5 982.61	5 773.13
	Total	9 066.08	5 697.72	5 773.13	49 167.97	8 102.49	5 982.61	83 790.00

*Riparian forest (*Khaya senegalensis* and *Syzygium guineense*).

Table 4 Water balance (deficit in mm).

	2006	MCC 50-year	MCC 100-year	HCC 50-year	HCC 100-year
Bauchi	–767	–772	–775	–855	–867
Kano	–821	–829	–832	–872	–881
Nguru	–952	–957	–957	–1021	–1312

Scenario analysis for climate change

Table 4 shows the results of the 2006 water balance (annual surplus less annual deficit) and the projected annual balance under medium climate change (MCC) and high climate change (HCC) scenarios for Bauchi, Kano and Nguru. When compared with the 2006 water balance, a sustained marginal increase in water deficit of about 0.65% for the 50 year MCC, 1.04% for the 100 year MCC, 11.47% for 50 year HCC and 13.04% for 100 year HCC was observed in Bauchi. In Kano, a water deficit increase of 0.97% for the 50 year MCC, 1.34% for the 100 MCC, 6.21% for 50-year HCC and 7.31% for 100 year HCC was observed while Nguru shows a deficit of 0.53% for the 50 year MCC, 0.53 % for the 100 year MCC, 7.25% for 50-year HCC and 37.82% for 100 year

HCC when compared with 2006 water balance. The long-term implication of the observed pattern is that if the current pattern of land-use activities continues, agriculture will only be possible during the short rainy season between May and August when the soil moisture storage is sufficient to support growth.

Implications of the results for agriculture

The spatial variation of rainfalls on H-JRS shows that rain-fed agriculture can be practised for a longer period in the upstream area than in the downstream area. The post-dam construction flow regime of Hadejia has been greatly modified; this has resulted in other problems such as weed growth and siltation in the Hadejia River that inhibit year round agriculture on the Hadeija flood plain. About 60% of the entire basin is under cultivation and if subsistence agricultural practise continues, further deforestation and land degradation will prevail. These have a long-term negative impact on the land productivity. The deficit recorded for 2006 and the projected water balance under different scenarios at Bauchi, Kano and Nguru stress the need for sustained dry season irrigation and wetland flooding.

CONCLUSION AND RECOMMENDATION

The water balance deficits for the different scenarios reveal a higher demand for soil moisture replenishments. This will be an additional stress on the water resources of the H-JRB and, if proper management and adaptation strategies are not put in place, it may lead to serious water crises and probably environmental refugees. Land conservation through mechanized farming supported by appropriate dam operations that not only ensures year round agriculture, but also mimics the natural flood regime, is recommended.

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