Climate and Land Use Change Impacts on Groundwater Quality in the Beninese Coastal Basin of the Transboundary Aquifer System Benin-Nigeria-Togo.

H.S.V. Totin[1], M. Boukari[2], S. Faye[3], A. Alassane[2], V. Orékan[4] and M. Boko[1 & 5]

(1) Laboratory Pierre Pagney, Climate, Water, Ecosystems and Development, University of Abomey-Calavi, 03 BP 1122 Cotonou, Benin, email: sourouhenri@yahoo.fr
(2) Laboratory of Applied Hydrology, University of Abomey-Calavi, BP 526 Cotonou, Benin, email: moussaboukari2003@yahoo.fr, aalassane@yahoo.fr
(3) Department of Geology, University Cheikh Anta Diop, BP 5005 Dakar, Senegal, email: fayes@ucad.sn
(4) Laboratory of Biogeography and Environmental Expertise, Universirty of Abomey-Calavi, 04 BP 1556 Cotonou, Benin, email: orekvin@yahoo.fr
(5) Multidisciplinary Centre of Training and Research in Environment for Sustainable Development, University of Abomey-Calavi, 03 BP 1463 Jericho, Cotonou, Benin, email: mboko47@live.fr

ABSTRACT

The coastal basin of Benin covers 12377 km² of the transboundary aquifer system shared by Benin, Nigeria and Togo. Groundwater is the mean water supply source of a population approximately estimated by 4 million inhabitants. Population rapid growth with the rate of 4.5% induces extension of human settlements which interaction with climate variability affect groundwater quality. Statistical analyses were used to highlight observed climate change. Seasonal analysis of 40 shallow and deep wells, boreholes and spring water sampling and land use land cover (data provided by LANDSAT ETM7+, MSS, and SPOT imagery for 1973, 1995 and 2005) diachronic analysis helped to emphasise environmental change impacts on groundwater quality. Furthermore, binary diagram method was used to interpreted geochemical process of water mineralization. Water quality is also appreciated from the drinking water quality standards of WHO. This study shows that groundwater mineralization is dominated by calcium, sodium, bicarbonates, nitrogen and chloride depending on ions exchange process in the wet or dry period. Bacterial polluting agents were numerous (total coliforms, *Escherichia coli* (in dry period) and fecal streptococcus (in wet period)). On the whole, depth of aquifers, land use, unhealthiness around the water supply sources, induced recharge from inadequate sanitation facilities and sea water intrusion interaction with hydroclimatic change are the mean factors of the strong deterioration of groundwater. Groundwater quality assessment could contribute to plan transboundary aquifers management based on local hydrogeological basin scale.

Key words: sedimentary coastal basin, groundwater, global change, quality, management.

1. INTRODUCTION

Groundwater is a valuable natural resource providing a primary source of water for agriculture, domestic and industrial purposes in many countries (UNESCO, 2006). It is a major source of drinking water across the world (UN/WWAP, 2006; IPCC, 2007). According to Hiscock and Tanaka (2006), global climate change is expected to have negative effects on water resources as a result of increased variability in extreme events such as droughts and floods. On the other hand, land use and land cover (LULC) changes are one of the main human induced activities altering the groundwater system (Calder, 1993). As consequence on the coastal sedimentary basin of Benin, physicochemical and bacteriological compositions of groundwater change in time and space (Totin, 2010). The objective of this paper is to analyse groundwater quality sensitivity to climate and land use patterns change.

The coastal hydrogeological basin of Benin is a part of the Transboundary Coastal Sedimentary Aquifer System (n° 414) that stretches from south-western Nigeria across southern Benin into southern Togo. It lies between latitudes 06°15'N and 07°38'N and longitudes 01°30'E and 02°50'E, with approximately 12377 km². This basin is sub-divided into four aquifers with the high water reservoirs mean unconfined aquifer of Continental Terminal and confined aquifer of Upper Cretaceous and the minor reservoirs like Quaternary and Lower Palaeocene aquifers (Dray *et al.*, 1989; Boukari &

Alassane, 2007). Fortunately, they have a large part (35%) of the whole groundwater resources of Benin.

2. RESULTS

2.1. Climate and land use change in the coastal sedimentary basin of Benin

At the annual scale, climate variability is marked by alternation of wet and dry seasons, corresponding respectively to recharge and discharge periods. Long-term variability and trend of annual rainfall show rainfall decrease of 17% over 1951-2005 with the range of 9 to 30% (Totin, 2010). Furthermore, observed change of average temperature (in the change rate of IPCC (2007)) was from 26.7°C in 1950 to 28°C in 2005 with the rate of 1.8°C over 1951-2005. So, modification of climate patterns affects hydrological process and water quality depending also on land use change.

From 1973 to 2005, the mean LULC patterns changes were shown in Table 1.

Table 1 LULC patterns change in the coastal sedimentary basin of Benin from 1973 to 2005.

LULC categories	Forest/Savannah land	Wetland	Agriculture land	Human settlements	Watershed	Beach land
Area_1973 (%)	35.89	16.29	40.02	1.47	4.33	2.01
Area_1995 (%)	14.86	12.51	62.43	2.95	3.66	3.59
Area_2005 (%)	8.30	6.91	72.20	7.69	3.01	1.88
Balance_1995-1973	-58.6	-23.2	56.0	100.7	-15.4	79.1
Balance_2005-1995	-44.2	-44.8	15.7	161.2	-17.8	-47.5

So, changing LULC is dominated by regression of forest/savannah land, marshy land and progression of agriculture and constructed land. This land use modification particularly extended of human settlements and cultivated land causes more damage to groundwater quality.

2.2. Groundwater quality: physicochemical and bacteriological characteristics

Table 2 shows that, in spite of the high concentration of the major ions in groundwater in the dry season, measured values are generally below the WHO (2008) guidelines for drinking water.

Table 2 Statistical summary of the physicochemical parameters in groundwater (40 samples) from the coastal basin of Benin.

Parameter	Wet season					Dry season					WHO (2008) Standard
	Min	Max	Mean	Medium	Std Dev	Min	Max	Mean	Medium	Std Dev	
pH	3.9	8.6	5.9	5.8	1.1	3.7	8.6	6.0	5.9	1.2	25
Temp	27.7	30.5	29.2	29.1	0.8	26.5	31.7	29.5	29.4	1.0	6.5 - 8.5
EC	24.7	3630.0	511.9	177.3	847.7	22.0	1540.0	394.9	177.2	481.1	2000
TDS	24.0	1477.0	336.8	149.0	425.0	14.0	1001.0	218.9	91.0	306.3	1000
Ca^{2+}	1.5	83.2	18.6	9.3	22.4	1.2	145.6	27.1	14.6	34.8	400
Mg^{2+}	0.1	16.2	3.3	1.5	4.2	0.3	39.2	9.0	4.3	10.9	50
Na^{+}	0.6	132.0	23.5	6.1	35.3	0.1	178.3	32.2	13.7	50.1	200
K^{+}	0.8	32.7	7.3	3.7	8.9	0.0	73.1	9.9	3.8	17.1	12
Cl^{-}	0.0	301.5	19.6	2.9	66.6	0.0	423.8	55.8	9.9	112.5	250
SO_4^{2-}	0.0	81.3	4.8	0.2	18.1	0.0	162.9	11.6	1.2	36.5	250
HCO_3^{-}	0.0	190.0	53.4	26.0	57.0	2.2	240.0	54.9	26.0	65.4	-
NO_3^{-}	0.0	48.5	10.1	4.6	14.1	0.1	88.2	25.7	14.2	25.7	50

Temperature (Temp.) in °C; Electric conductivity (EC) in µS/cm; Concentration values of ions in mg l^{-1}

Median values (meq/l) of major ions shows that groundwater mineralization is successively dominated by cations Ca^{2+}, Na^{+}, and K^{+} in the wet season and Mg^{2+} in the dry season. Relative abundance of the anions is $HCO_3^- > NO_3^- > Cl^- > SO_4^{2-}$ in both the wet and dry periods. Chemical composition change of groundwater in various climatic contexts is related to ion exchange, rocks dissolution or weathering, seawater intrusion, human pollution, etc. So, the main sources of NO_3^- in drinking water are certainly agricultural contamination (just as for K^+) in the wet period and induced recharge (by wastewater) in the dry period. Kortatsi *et al.* (2007) explain that NO_3^-, Cl^- and SO_4^{2-} loading positively together reflect common anthropogenic origin, perhaps pollution from human induced activities such as inorganic fertilizer and pit latrines, animal droppings. In the coastal basin of Benin, the main sources of NO_3^- are agricultural contamination in the wet period and induced recharge (by wastewater) in dry period. According to Hounslow (1995) bicarbonate is formed when carbon dioxide and water react with various minerals. In the coastal sedimentary basin, abundance of HCO_3^- in groundwater is linked to carbonate rock dissolution Boukari (1998).

On the other hand, the seasonal concentrations of bacteria, presented in Table 3, are in most cases higher than the standards recommended by WHO (2008).

Table 3 Bacteriological patterns of the groundwater in the coastal basin of Benin.

Sampling sites	Total coliforms		*Escherichia coli*		Fecal streptococcus		Maximum Allowable Value
	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	
Shallow and deep wells	160 – Innumerable	Innumerable	8 – 412	Innumerable	5 – 360	2 – 160	0 CFU/100ml
Boreholes	0 – 60	0 – 42	0	0 – 20	0 – 3	0	0 CFU/100ml
Spring	28	74	9	24	2	26	0 CFU/100ml

Results from seasonal water samples of 11 shallow and deep wells, 8 boreholes and 1 spring

Well water is more susceptible to bacteriological contamination than boreholes since the total coliforms were too numerous to count. The lower degree to which the boreholes are polluted can be explained by the depth of water table, the thickness of soil and geological layers (filters anti-pollutants) and their protected system. With regard to the sensitivity of the water supply sources to fecal contamination, it is clear that climate variability and land use affect groundwater quality.

3. CONCLUSIONS

Assessment of groundwater quality shows that the chemical elements concentrations are below WHO standards for drinking water while bacterial polluting agents exceed it both in rainy and dry seasons. Hydroclimatic change, depth of aquifers, land use and unearthliness around the water source are the mean factors of the strong bacteriological deterioration of groundwater. Therefore, in order to plan transboundary aquifers management, more attention should be paid to groundwater quality on the local hydrogeological basin like in Benin. So, studies from several sites in each country shared by the transboundary hydrogeological basin are needed to provide reasonable groundwater quality data for large scale use.

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