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IMPACTS OF CLIMATE CHANGES ON WATER RESOURCES IN AFRICA WITH EMPHASIS ON GROUNDWATER

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Climate change is likely to impact groundwater resources, either directly, e.g. via changing precipitation patterns, or indirectly, e.g. through the interaction of changing precipitation patterns with changing land-use practices and water demand. These changes may affect both groundwater quantity and quality. Climate change will affect groundwater recharge rates and groundwater levels. Any decrease in groundwater recharge will exacerbate the effect of sea-level rise in coastal areas. In inland aquifers, a decrease in groundwater recharge can lead to saltwater intrusion from underlying saline aquifers, and increased evapotranspiration in semiarid and arid regions may lead to the salinization of shallow aquifers. In Africa, climate change and variability have the potential to impose additional pressures on water availability, water accessibility and water demand. A 1°C increase in temperature could change runoff by 10%, assuming that precipitation levels remain constant. If such an annual decrease in runoff were to occur, the impacts could be equivalent to the loss of one large dam per year in a given watershed. Temperature and precipitation in the African Sahel are negatively correlated - seasonal warming was accompanied by late 20th century drying.

INTRODUCTION

Warming is very likely to be larger than the global annual mean warming throughout the African continent and in all seasons, with drier subtropical regions warming more than the more moist tropics. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins. There is likely to be an increase in annual mean rainfall in East Africa. It is unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve (IPCC, 2007)

Overall situation of water resources in Africa

Water access and water resource management are highly variable across the continent (Ashton, 2002; van Jaarsveld et al., 2005; UNESCO-WWAP, 2006). The 17 countries in West Africa that share 25 transboundary rivers have a high water interdependency (Niasse, 2005). Eastern and southern African countries are also characterised by water stress brought about by climate variability and wider governance issues. Significant progress has, however, been recorded in some parts of Africa to improve this situation, with urban populations in the southern African region achieving improved water access over recent years (van Jaarsveld et al., 2005). When water is available it is often of poor quality, thus contributing to a range of health problems including diarrhoea, intestinal worms and trachoma. Much of the suffering from lack of access to safe drinking water and sanitation is borne by the poor, those who live in degraded environments, and overwhelmingly by women and children. The relevance of the problem of water scarcity is evident in North Africa, considering that the average annual growth of the population is among the world's highest. The Water Exploitation Index is high in several countries in the sub region: >50% for Tunisia, Algeria, Morocco and Sudan, and total water abstraction per year as percentage of long-term freshwater resources is >90% for Egypt and Libya (Gueye et al., 2005). Until recently, these countries have adopted a supply-oriented approach to managing their water resources.

Impact of Global Climate Change on Water Resources in Africa

There has been very little research on the impact of climate change on groundwater, including the question of how climate change will affect the relationship between surface waters and aquifers that are hydraulically connected (Alley, 2001).

Climate projections for Africa suggest that land areas may warm by as much as 1.6°C over the Sahara and semiarid parts of southern Africa by 2050 (Giannini, 2007). Robust findings on regional climate change for mean and extreme precipitation, and drought are shown in Figure 1 which shows high correlation between precipitation and mean air temperature for the African Sahel. Further inspection of this Figure reveals that temperature and precipitation in the African Sahel are negatively correlated - seasonal warming accompanied late 20th century drying. The regression equation that best fit the relation can be expressed as follows:

$$T \text{ (deg C)} = -0.0137\, P \text{ (mm/mo)} \quad \text{(Giannini, 2007)} \tag{1}$$

Equatorial countries (Cameroon, Uganda, and Kenya) might be about 1.4°C warmer. Sea-surface temperatures in the open tropical oceans surrounding Africa will rise by less than the global average (i.e., only about 0.6-0.8°C); the coastal regions of the continent therefore will warm more slowly than the continental interior.

In southern Africa and parts of the Horn of Africa, rainfall is projected to decline by about 10%

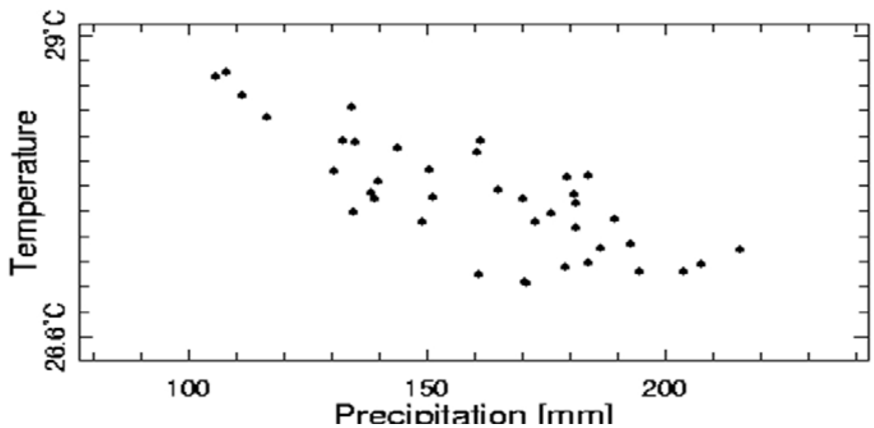

Figure 1. Cross plot of mean air temperature versus mean monthly precipitation over African Sahel in the period from 1950-1990 (Giannini, 2007)

by 2050. All of these changes could increase the drought frequency. Changes in sea level of about 25 cm might be expected by the year 2050 (IPCC, 2001-2007). Climate change impacts on the decrease of runoff by 10 to 30% include the Mediterranean, southern Africa, and western USA/ northern Mexico (Milly et al., 2005).

These effects could mean locally severe, groundwater-related impacts on water supplies, on property and on ecosystems that depend on groundwater. The impacts of climate change could increase the cost of providing water supplies, already rising as a result of deteriorating groundwater quality. Groundwater, of course, cannot be considered in isolation - impacts of climate change not necessarily related to groundwater, such as changing land use and population density, will have an effect on groundwater.

IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES

Lowering in Groundwater Levels

A water level in an aquifer are often observed to respond consistently to precipitation, although the nature of the response can be complex and depends on time of year and prior conditions, etc. Groundwater levels correlate more strongly with precipitation than with temperature, but temperature becomes more important for shallow aquifers and in warm periods.

Case study 1: Aquifers Recharged from Niger River Basin (NRB)

The Niger River basin, located in western Africa, (Figure 2) covers 7.5% of the continent and spreads over ten countries (FAO Land and water Bulletin 4, 1997). Algeria and Chad together cover about 9% of the total Niger River basin, Guinea covers about 6% and the sources of the Niger River are located in this country, Côte d’Ivoire (5%), Mali (26%), Niger (23%), and Nigeria (33%). The most important areas of the Niger basin are located in Mali, Niger and Nigeria. Mali and Niger are almost entirely dependent on the Niger River for their water resources. In the case of Niger, nearly 90% of its total water resources originates outside its borders (the Niger River and other tributaries from Burkina Faso and Benin) Burkina Faso (4%), Bénin (2%), Cameroun (4%), and Chad (1.0%) but there are almost no renewable water resources in these areas. The quantity of water entering Mali from Guinea (40 km^3/yr) is greater than the quantity of water entering Nigeria from Niger (36 km^3/yr), about 1800 km further downstream. This is due among other reasons to the enormous reduction in runoff in the inner delta in Mali through seepage and evaporation combined with almost no runoff from the whole of the left bank in Mali and Niger.

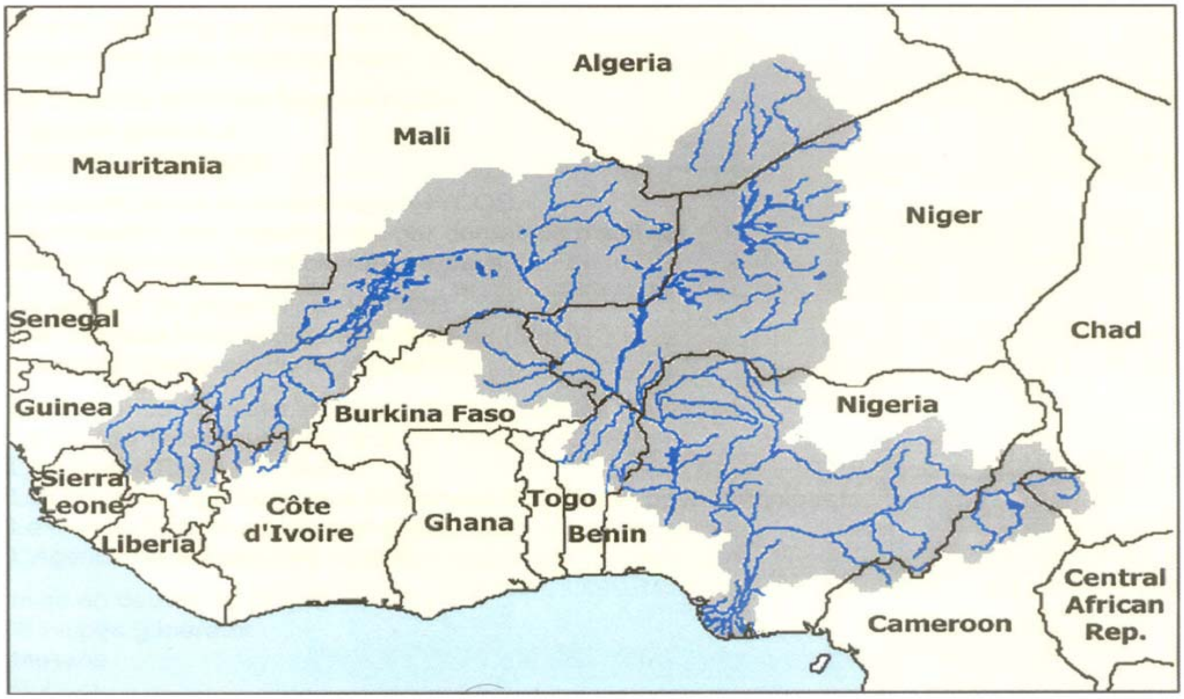

Figure 2. Location map of the Niger River Basin.

The Niger River Basin is very vulnerable to future climatic change due to: 1) the manifest impact of the changes that have already occurred and are exemplified by displacement in the position of rain belts (Figure 3), and the great variability in precipitation patterns and intensities as expressed by scattering around the mean value (Figure 4), 2) reduction in the flow of Niger River and 3) lowering in water table of nearby shallow aquifers as shown in Figure 5. The further inspection of Figure 3 reveals the shifts of isohyetal contour lines of 200, 500, 700 and 1000 mm for at least 100 km southward in the Sahelian part of Niger River Basin.

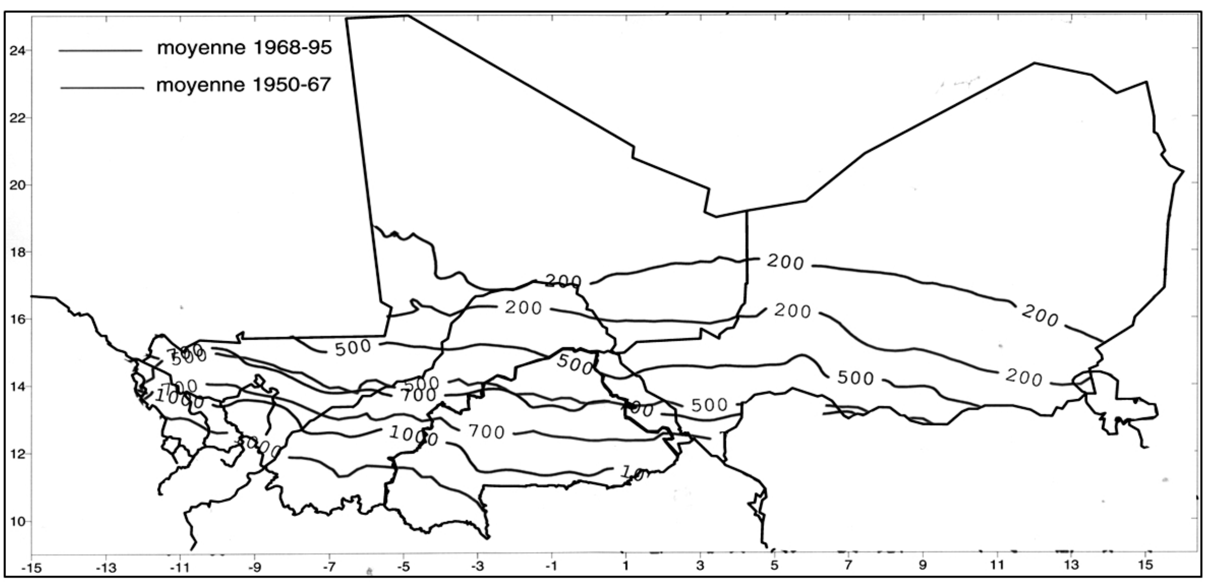

Figure 3. Shift in rain belts in the Niger Basin as a direct consequence of climatic change (R.Dessouassi and G. Mahé, 1997).

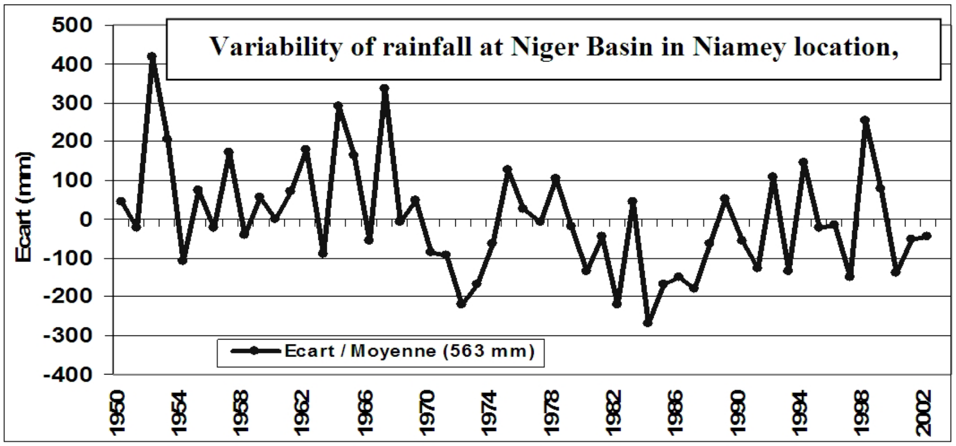

Figure 4. Variability of precipitation in Niger River Basin at Niamey for 52 years (R. Dessouassi and G. Mahé, 1997).

The shallow aquifers in nearby locations to the Niger River (in Mali) have shown a very strong correlation with both the reduction in precipitation as well as the reduction in the flow of Niger river as a direct consequence of climatic change in West Africa (Figure 5).

The manifest impact of climatic change can be illustrated and confirmed using another data set of piezometers located in Dantiandou and Gogo localities (bounded by longitude 02° 45' 30" and latitude 13° 24' 40"), where the water level has responded to the 1994 reduction in precipitation (Figure 6). The correlation is positive. However, the response is slightly delayed in the aquifer, attenuated with depth, and is more pronounced in unconfined than in semi-confined aquifers (OSS int. report). The same fact remains true for the abnormal rise in the water level of piezometers at the Gogo location which corresponds to the heavy rainfall that occurred in 1996 and 1999 (Figure 6).

Case Study 2: Iullemeden Basin

The Iullemeden Aquifer System (IAS) is located in the arid and semiarid zones of West Africa (Figure 7). The IAS extends between latitudes 10° 30’ and 19° 40’ north and longitudes 0° 50’ and 9° 20’ east. It is shared by Mali, Niger and Nigeria and covers a total area of 520,000 km^2 (30,000 km^2 in Mali, 430,000 km^2 in Niger and 60,000 km^2 in Nigeria). The IAS is part of the hydrographic Niger River basin.

Precipitation in the IAS varies greatly from north to south: less than 150 mm in the Saharan zone, between 150 mm and 300 mm in the nomadic Sahelian zone, between 300 mm and 600 mm in the

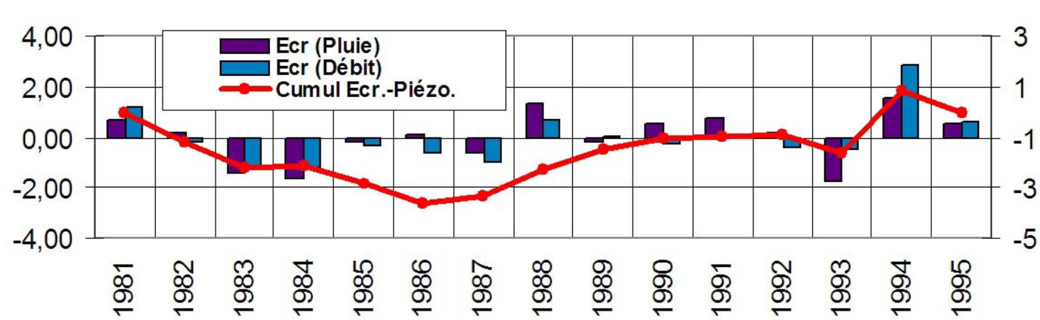

Figure 5. .Corresponding lowering of the water table for piezometers tapping the shallow aquifer in the Niger River Basin as direct consequence of climatic change (R. Dessouassi and G. Mahé, 1997).

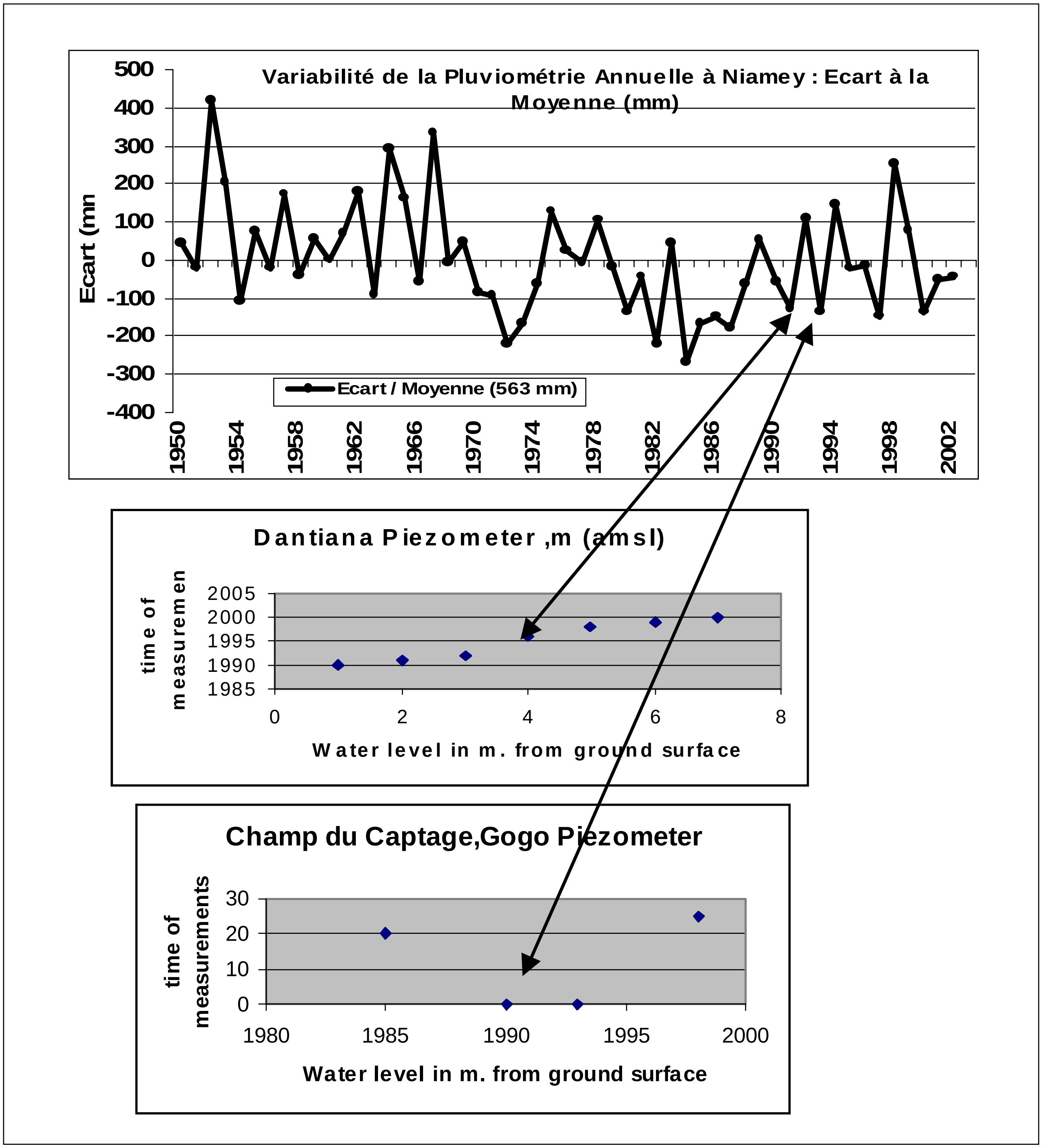

Figure 6. Change in water level of Dantiana and Gogo Piezometers as a direct consequences to climatic changes.

sedentary-Sahelian zone, and from 600 mm to 800 mm in the Sahel-Sudanese zone (OSS int.report). The IAS is very vulnerable to future climatic change due to: 1) the manifest impact of the changes that have already occurred: a 20% to 30% reduction of rainfall since 1968; 2) 20% to 50% reduction of runoff; and 3) silting and sand dunes establishment. Since 1968-1970, isohyetal lines expressing the same values have shifted southwards about 200 km from the earlier position (Figure 8)

Groundwater resources in Iullemeden Basin are represented by multilayered aquifer systems which encompass two major water bearing formations; the upper Cretaceous (Cenomanian)

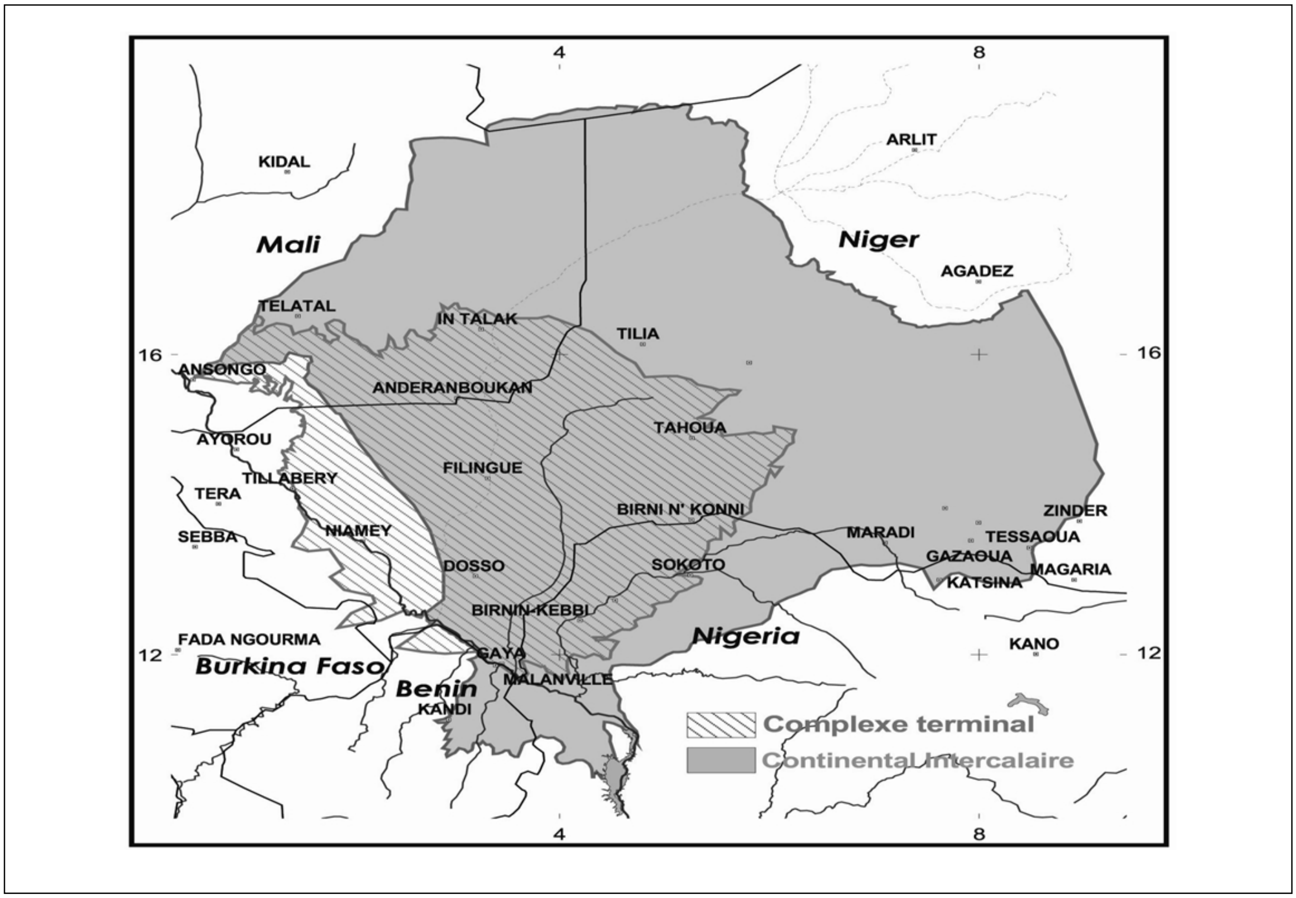

Figure 7. Geographical and hydrogeological setting of the Iullemeden Aquifer System.

argillaceous sandstones referred to as “Continental Intercalaire” and the Mio-Pliocene continental sandy facies known as “Complex Terminal”. Both aquifers constitute the major groundwater resources in the Basin.

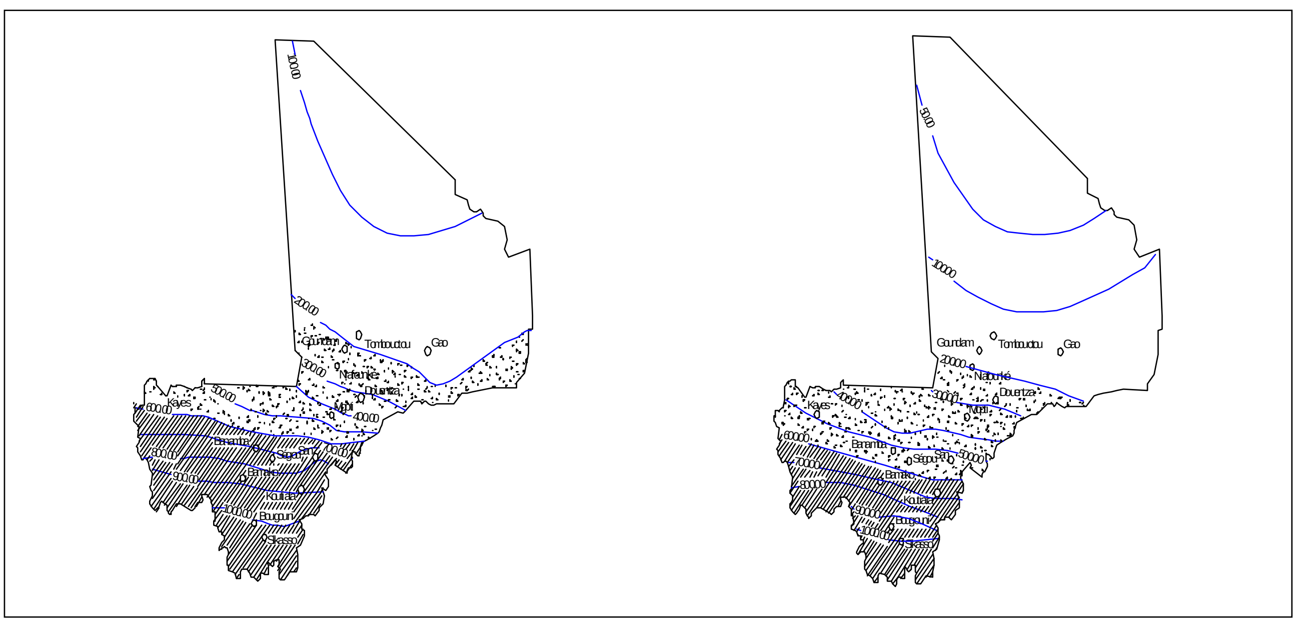

Figure 8. Displacement of isohyetal lines in the period from 1961-1990 (left) and from 1970-1985 (right) in the Iullemeden Basin, Mali (Source DNM).

As a direct consequence of climatic change, the water levels in both aquifers were lowered as evident from Figure 9. Further inspection of Figure 9 reveals the lowering in the piezometric head as well as the change in hydraulic gradient from a steeper gradient and higher groundwater velocity in 1970 to a more gentle gradient and slower velocity in 2004. The figure also shows a northward shift in piezometric head contour lines towards the basin water divide which reflects less recharge to the aquifer system.

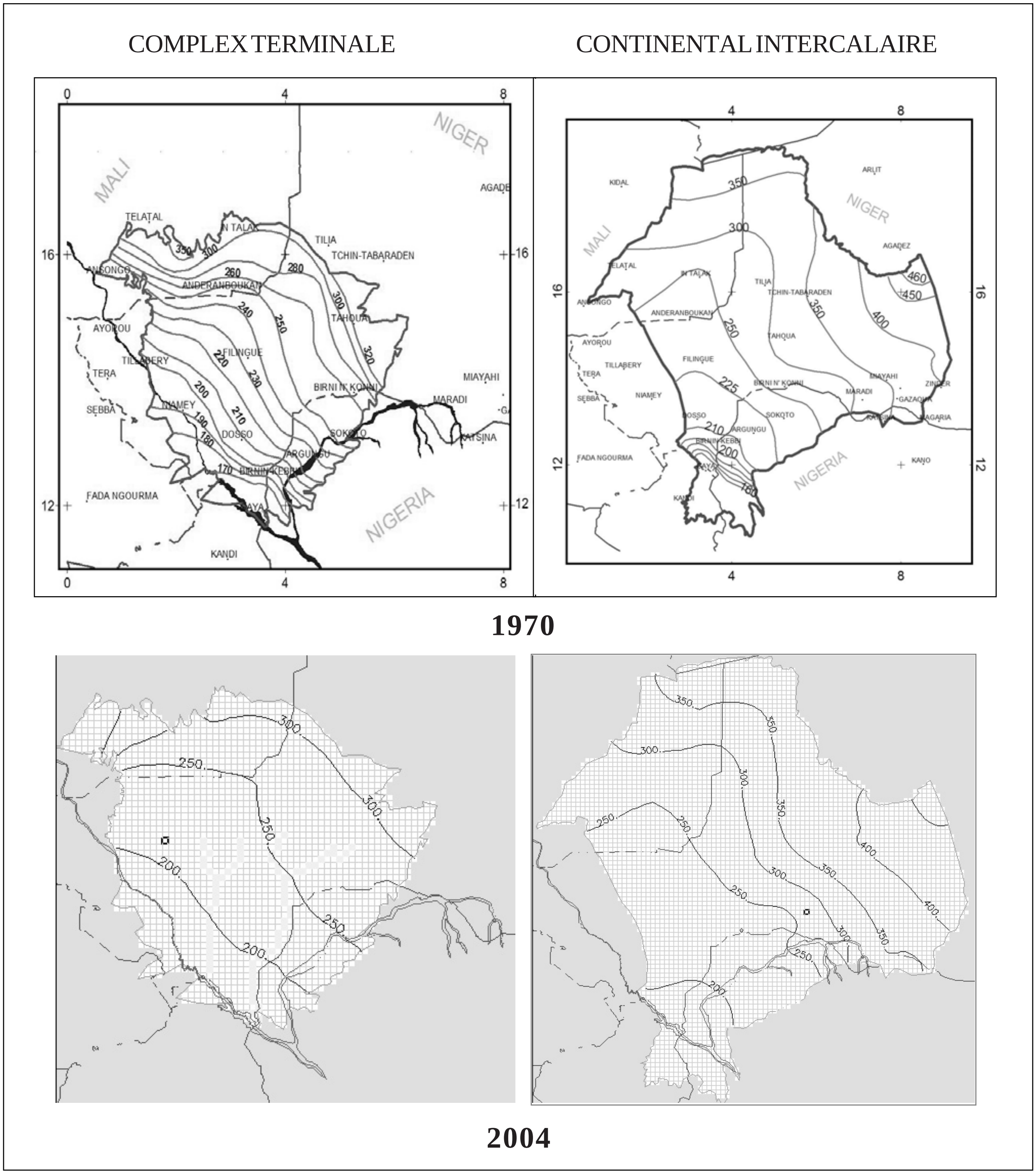

Figure 9. A comparison between the piezometric levels of the two major aquifers in Iullemeden Basin: 1) The Complex Terminal (left), 2) The Continental Intercalaire (right) during the periods in 1970 and in 2004 as a direct consequences to climatic change (OSS Int. Report).

INDIRECT EFFECTS OF THE IMPACT ON GROUNDWATER RESOURCES IN AFRICA: OBSERVED CHANGES

Variability in Rainfall Regime

The El-Nino-Southern Oscillation (ENSO) as well as Surface Sea Temperature (SST) in the Indian Ocean are the dominant sources of climate variability over eastern Africa (Goddard and Graham, 1999; Yu and Rienecker, 1999). Isolated secondary but significant patterns of regional climate variability has been identified and isolated by Schreck and Semazzi (2004). The trend pattern in their analysis is characterized by positive rainfall anomalies over the northeastern sector of eastern Africa (Ethiopia, Somalia, Kenya and northern Uganda) and opposite conditions over the southwestern sector (Tanzania, southern parts of the Democratic Republic of the Congo and southwestern Uganda).

This signal significantly strengthened in recent decades. Warming is associated with an earlier onset of the rainy season over the northeastern Africa region and a late start over the southern sector.

Regional Variability in Time (1930-2005)

It is possible to distinguish between monsoonal and equatorial climates based on seasonality considerations and hence three African subregions can be defined, western (0_to 20_N, 20_W to 20_E), eastern equatorial (10_S to 10_N, 20_E to 50_E), and southern Africa (25_S to 10_S, 20_E to 40_E) (Giannini et al., 2007). These regions are broadly consistent with those chosen by Hulme et al. (2001), who also presented the state-of-the-art. The history of annual mean (July to June) rainfall anomalies averaged over these regions is shown in Figure 10. Comparison of the three panels in this Figure highlights the qualitative difference between the West African time series on one side, and its eastern equatorial and southern African counterparts on the other. West African rainfall is characterized by a high degree of persistence, of anomalously wet (e.g. in the 1930s, 1950s and 1960s) and dry (e.g. in the 1970s and 1980s) years. Arguably, the shift in Sahel rainfall is unparalleled globally, in magnitude, spatial extent and duration (Trenberth et al., 2007). In eastern equatorial and southern Africa interannual variability is more conspicuous. According to Giannini et al. (2007), when observations of precipitation over Africa are analyzed with a view to their global linkages, two continental-scale patterns, related to variability in the oceans, appear to dominate African climate variability: (1) a continental-scale drying pattern related to enhanced warming of the southern compared to the northern tropics and to a warming of the tropical oceans, (2) the impact of ENSO on the tropical atmosphere and oceans around Africa.

CONCLUSIONS

The response of groundwater systems is often difficult to detect because the magnitude of the response is may be small and delayed. However, the effects of climate change on groundwater resources in Africa include the following facts:

- A long term decline in groundwater storage
- Increased frequency and severity of groundwater droughts
- Increased frequency and severity of groundwater-related floods
- Mobilization of pollutants due to seasonally high water tables
- Saline intrusion in coastal aquifers, due to sea level rise and resource reduction.

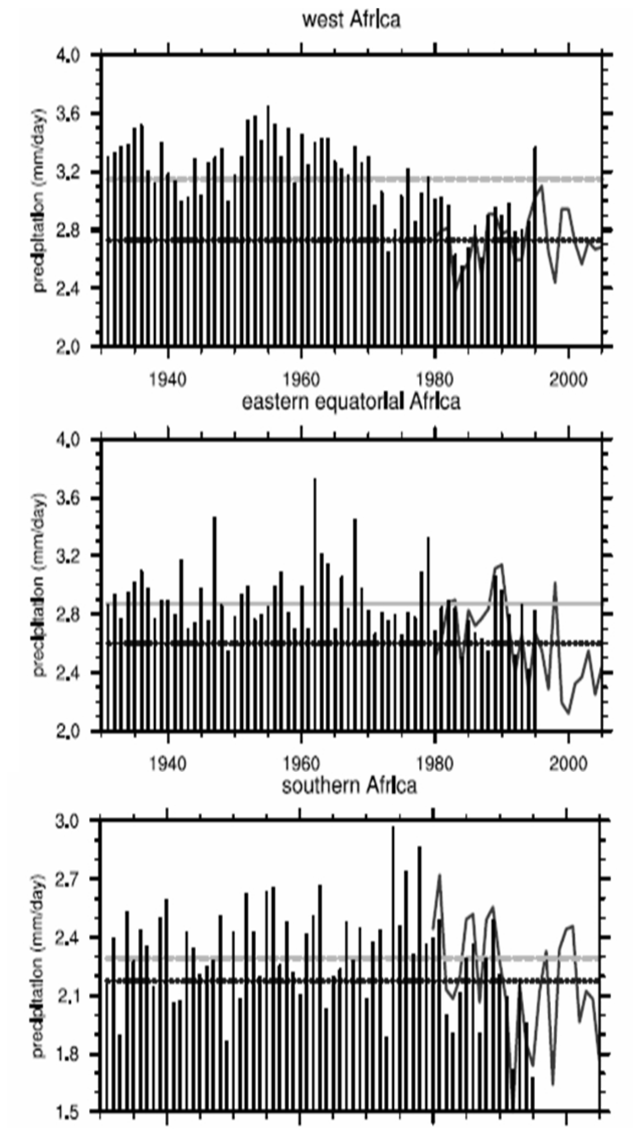

Figure 10. Regional averages of annual mean (July-June) precipitation over 1930-2005;the three regions are western (0_N to 20_N, 20_W to 20_E), eastern equatorial (10_S to 10_N, 20_E to 50_E), and southern Africa (25_S to 10_S, 20_E to 40_E). (Giannini et al., 2007).

In West Africa, shallow aquifers in the nearby locations to Niger River (in Mali) have shown a very strong correlation with both the reduction in precipitation as well as the reduction in the flow of Niger river as a direct consequence to climatic change in West Africa

In Africa, the El-Nino-Southern Oscillation (ENSO) as well as Surface Sea Temperature (SST) in the Indian Ocean are the dominant sources of climate variability over eastern Africa

Rainfall trends over South Africa have an shown annual average of rainfall (1922-1999) that illustrates the frequent persistence of a series of wet or dry years.

In conclusion, and based on the magnitudes and frequencies of rainfall and its variability in Africa, three different patterns of rainfall variability have been recognized; 1) the northern/ southern extremities of Africa, with a Mediterranean climate, and subject to future drying, (2) the margins of monsoons, such as the Sahel, but also possibly a similar region in southern Africa, and (3) the wetter equatorial regions.

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