Multiple Water Reservoirs in African Continent: Scarcity, Abundance and Distribution

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Abstract The focus of this article is to give an overview of inland water bodies (lakes, dams and lagoons) and surface water bodies (rivers and wetlands), as well as the various groundwater reserves (water tables and aquifers). These natural water reservoirs, its distribution in Africa plays a fundamental role in the constraint of its geological evolution and habitability. The aquifers constitute good underground water reservoirs, from fissured or fractured rocks, allowing a water supply, which are less sensitive to climatic variations. On the other hand, surface waters are more sensitive to pollution and drought. The framework for sustaining and preserving these resources is good environmental management of the various watersheds and coastal zone planning. In addition, the control of groundwater pumping, to avoid a drop in piezometric levels.

Keywords Inland water bodies · Surface water bodies · Rivers · Aquifers · Watersheds · Africa

The original version of this chapter was revised: The affiliation of Driss Belghyti has been updated correctly. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-94191-8_94

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1 Introduction

Water is a very important factor for socio-economic development. Africa has a considerable amount of water resources, but suffers from chronic deficits, due to the uneven distribution of rainfall and runoff in time and space. Groundwater reserves are linked to flows maintained by the water cycle and are therefore, to a large extent, renewable, by recharging the aquifers from rainfall infiltration [33]. A particular type of water reserves is represented by the so-called fossil aquifers, whose exploitation can be compared to that of a mining deposit [3].

The surface water systems of Africa are diverse, the continent has seventeen major rivers and a hundred lakes, however, this resource is poorly distributed between Africa of potential scarcity in the North, Africa of water shortage or Saharan and Sub-Saharan Africa and finally a third Africa, that of excess water, in the equatorial zone [5].

Africa, although it has a significant potential in water resources, it remains confronted with a number of situations, by the increasing pressure of water withdrawals, irrigation, water pollution by untreated wastewater discharges and climate change which constitute the greatest threat to water resources, by the drought that frequently affects many regions, which causes a reduction of wetlands in several African countries and a deficit of water supply.

2 Related Works

In this section, we discuss existing models for modeling water resources, as well as the entire hydrological system whether at the watershed or continental scale. We give two models:

– Water Resources System Model (WRSM): The model serves as a decision support system that evaluates the capacity of existing and proposed water resources systems by simulating physical, water quality, statistical and operational aspects. This required long-term time series of hydrological and climatic inputs for calibration and validation, as well as analysis of hydrogeological data, through the description of the basic state and management of water resources. At the scale of large watersheds, studies can be carried out using GIS tools (Arc Hydro).
– Performance Based Water Resources Engineering: the performance based approach to water resources engineering, including risks such as flooding, drought, and to develop planning, design, and operation procedures in which the consequences of competing risks are properly balanced and investments in damage reduction and recovery can be made appropriately [35]. The computer program of the model is then operated with various input data, the detailed analysis of the output is the last step of the simulation process. Climate models,

simulating global thermal changes on natural and anthropogenic origins on global warming and then their impact on water resources, generally concerning, precipitation, temperature and evapotranspiration.

3 Proposed Method

The Water Budget Methods focuses on the different components of groundwater flow and storage variations, considering only the inputs and outputs of the aquifer. Water budgets are fundamental to the conceptualization of hydrologic systems at all scales. Initial analysis of a water balance can provide insight into the suitability of any recharge estimation technique. Refinement of the water balance and the conceptual model of the system throughout the life of a study can further guide study efforts [17].

The water balance equation for a watershed and the underlying unsaturated and saturated zones can be written:

$$P + Q_{on} = ET + \Delta S + Q_{off} \tag{1}$$

Where: P is Precipitation, Q_{on} is surface and groundwater flow into the watershed, ET is Evapotranspiration, ΔS is stock change, and Q_{off} is surface and groundwater flow out of the watershed.

Water flow in the watershed can be written as the sum of surface water flow (Q_{on}^{sw}) and groundwater flow (Q_{on}^{gw}):

$$Q_{on} = Q_{on}^{sw} + Q_{on}^{gw} \tag{2}$$

Evapotranspiration can be divided according to the source of evaporated water:

$$ET = ET^{sw} + ET^{gw} + ET^{uz} \tag{3}$$

Where ET^{sw} is the evaporation or sublimation of water stored on the soil surface, ET^{uz} is the evaporation from bare soil and plant transpiration of water stored in the unsaturated zone, and ET^{gw} is the evapotranspiration of water stored in the saturated zone.

The challenge of water in the watershed, or at the continental scale, involves all components: the physical, climatic, variability of rainfall in time and space, intensity of evaporation and overexploitation of aquifer systems that causes the drying up and decrease in the flow of sources and lowering of the piezometric level, as well as several rivers can become temporary or dry (see Fig. 1).

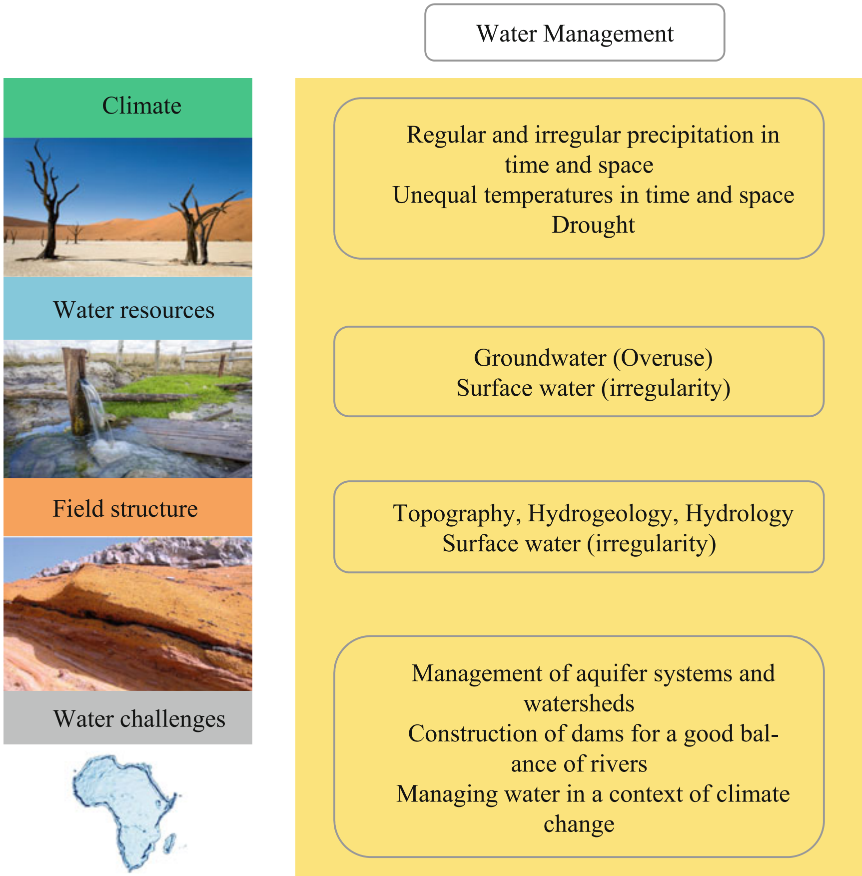

Fig. 1 Work flowchart applied to produce the water resources geodatabase for the Africa

4 Description of Study Area

4.1 Topography and Climate

Africa has many mountains, as all or almost all of the land in Lesotho, Rwanda, and Burundi is at or above 1500 m. Mountains that rise above 4500 m are concentrated in the northwestern, central and eastern regions. By satellite images we can identified several mountains which are mentioned in Table 1:

Table 1 Topographical characteristics of the main mountains of Africa

Mountain	Geographical coordinates		Elevation
	Latitude	Longitude	
Kilimandjaro	−3.06742470	37.35562730	5826
Mount Kenya	−0.15213840	37.30840790	5083
Rwenzori	0.38583300	29.87166700	4965
Mount Karisimbi	−1.50640560	29.45076780	4477
Thabana Ntlenyana	−29.46795800	29.26909090	3465
Mount Heha	−3.60305560	29.49944440	2656

- Thabana Ntlenyana, is a black mountain located in Lesotho at 3465 m altitude
- Mount Karisimbi is a volcano located on the border separating Rwanda from the Democratic Republic of Congo, with an altitude of 4477 m
- Mount Heha, located in the province of Bujumbura rural at 2656 m altitude
- Kilimanjaro, located in northeastern Tanzania, consisting of three volcanoes: the Shira, the Mawenzi and the Kibo, with an altitude of 5826 m at Uhuru Peak in Kibo volcano
- Mount Kenya is the highest point of Kenya and the second highest peak in Africa, behind Kilimanjaro at 5083 m altitude
- Rewenzori, is a small mountain range in Central Africa, located on the border between Uganda and the Democratic Republic of Congo, culminating at 4965 m at Mount Stanley Peak

Topographic elevations and proximity to the equator cause seasonal variations. These characteristics create climatic variability that is sometimes aggravated by cycles of flooding and drought. (see Fig. 2).

Topographic features and temperature differences between the sea and land surface influence the climatic differences between the eastern and western parts of the continent. Groundwater distribution is based on topography as shallow aquifers are found near natural ponds or in the hollows of mountains [37]. In areas with extremely flat topography and especially near marine areas, the aquifers are particularly sensitive to saltwater intrusion [7].

The climate in Africa is characterized by random rainfall [34]. There are two levels of rainfall extremes, ranging from almost zero in dry regions such as the Sahara Desert, to very high rainfall in the Congo-Guinean rainforests [14, 37].

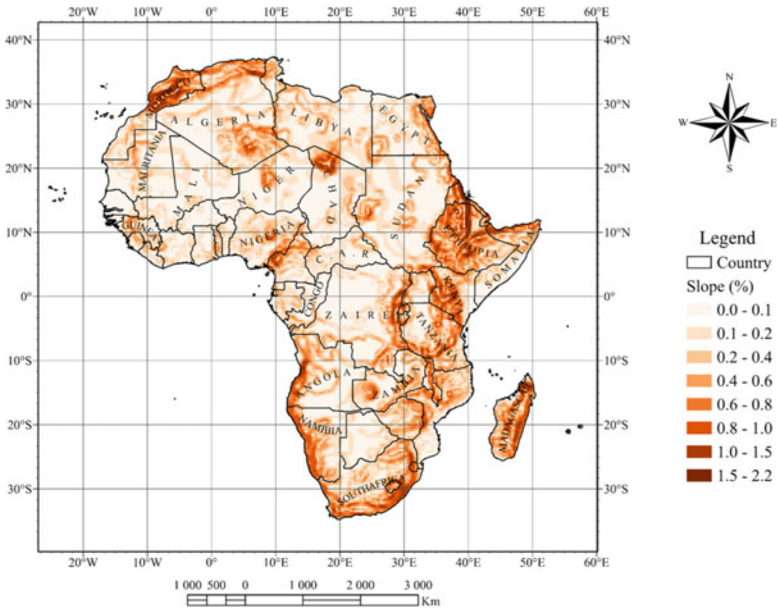

Fig. 2 Map of the slopes of Africa

4.2 Hydrogeology

The different geological reservoirs of Africa are located in a wide range of climatic zones: desert to semi-desert, arid, humid tropical, equatorial.

The variability of aquifer recharge depends on climatic variability, as well as on geological formations, since a reservoir with matrix porosity is more productive than a fractured or fissured reservoir or an ancient consolidated sedimentary terrain [9, 21].

The origin of groundwater varies according to the climatic, geomorphological context and sedimentary processes, may originate from rainwater that is infiltrated and stored in pores or fissured of saturated rocks, or marine by a connection between aquifer water and sea water [12, 28] (See Fig. 3).

The water balance equation can be written for a given period (see Eqs. (4) and (5)), according to Law of conservation of mass:

$$Input + Output = Stock\ variation \tag{4}$$

$$P - ET - R = \Delta S \tag{5}$$

Water storage comes in different forms. We can distinguish three main types of reservoirs:

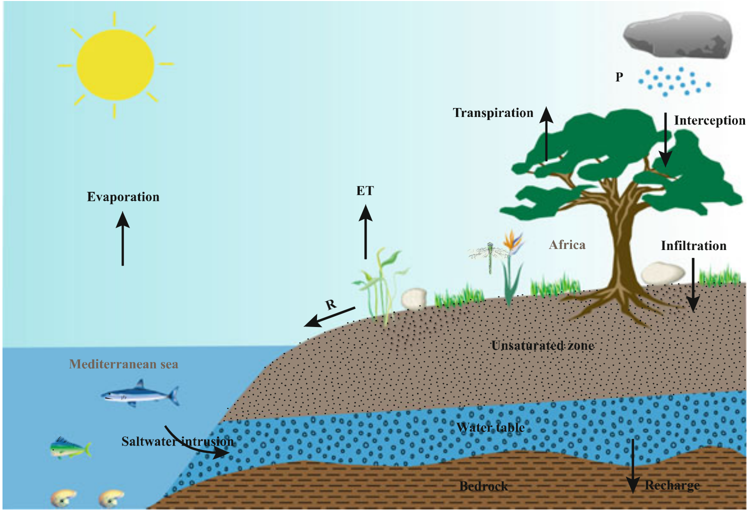

Fig. 3 Water balance. P: the water, due to condensation and aggregation processes inside the clouds, has become too heavy to remain suspended in the atmosphere, R: Runoff, the flow of water on the surface of the earth, especially the surface of the soil, ET: the amount of water transferred to the atmosphere by evaporation from sea, watercourse and from the interception according to which meteoric water is retained by tree leaves and plants, and by transpiration of water from plants

– Surface water stock, such as a natural lake or dams
– Groundwater stock, a reservoir rock whose porosity allows the accumulation of water (water table, aquifer)
– Water stock in solid form by snow and ice covers

The groundwater recharge process depends in particular on highly concentrated rainfall events, accumulation of runoff water in depressions and streams and rapid percolation through fissures and fractures [8, 16].

In Table 2, we have the spatial distribution of the different aquifers, we got, Continuous media aquifers, composed of sedimentary formations of Mesozoic to Quaternary age, occupy 41.7% of the total area, then ancient sedimentary aquifers of Precambrian and Paleozoic ages, often assimilated to basement aquifers in fractured environments, share with the basement aquifers 41.5% of Africa's surface, and at last complex aquifers of 16.8% of the surface, of which volcanic aquifers of 4% [4, 30].

Underground reservoirs have an underlay of geological formations with low storage capacity, are dependent on rainfall for recharge. Since is facilitated by the percolation of precipitation through the unsaturated zone leading to the replenishment of the saturated zone, so there is a significant variation in the African continent [29]. Figure 4 shows the spatial distribution according to the sub-region, as the majority of groundwater is concentrated in central Africa, including the southern Sahara, the eastern West African Shield and the western Great Rift Valley.

Table 2 Hydrogeological entities of Africa [4]

Nature of formation	Type of environment
Quaternary sediment	Continuous media with matrix porosity or double porosity
Paleogene-Neogene sedimentary	
Nubian sandstone formations	
Karoo type formation (Carboniferous to Jurassic)	Complex structure with multiple superimposed reservoirs
Cretaceous carbonate formations	Complex structures locally karstic
Jurassic-Triassic formations	
Detrital/Carbonate to volcano-sedimentary formations (Neoproterozoic to Paleozoic and Precambrian)	Fissured/fractured dominant
Sedimentary to volcano-sedimentary formations and associated volcano-plutonism (Precambrian)	
Plutonic and metamorphic complexes (Precambrian to Paleozoic)	Fissured/fractured
Plutonic massifs (Cambrian to Precambrian)	
Volcanic and volcano-plutonic massifs of the Phanerozoic	Fissured/fractured dominant, but porous materials may be interspersed

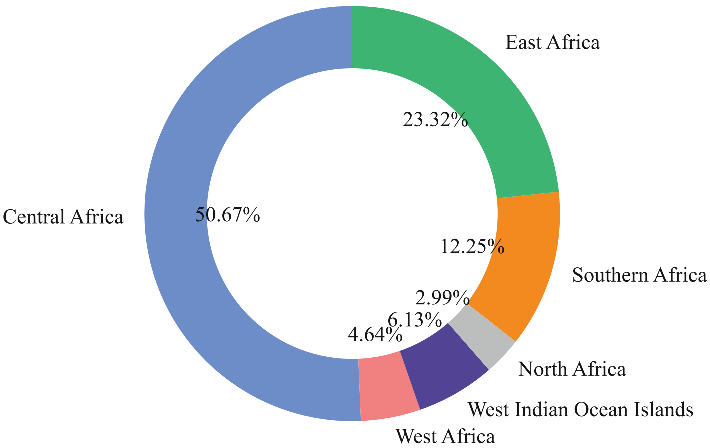

Fig. 4 Groundwater resources in sub-regions of Africa (Data: [15])

5 Water Resources

5.1 Major River Basins

African rivers experience dramatic seasonal variability and interannual variations, which reflect the rainfall patterns in these basins. The Congo Basin is the second

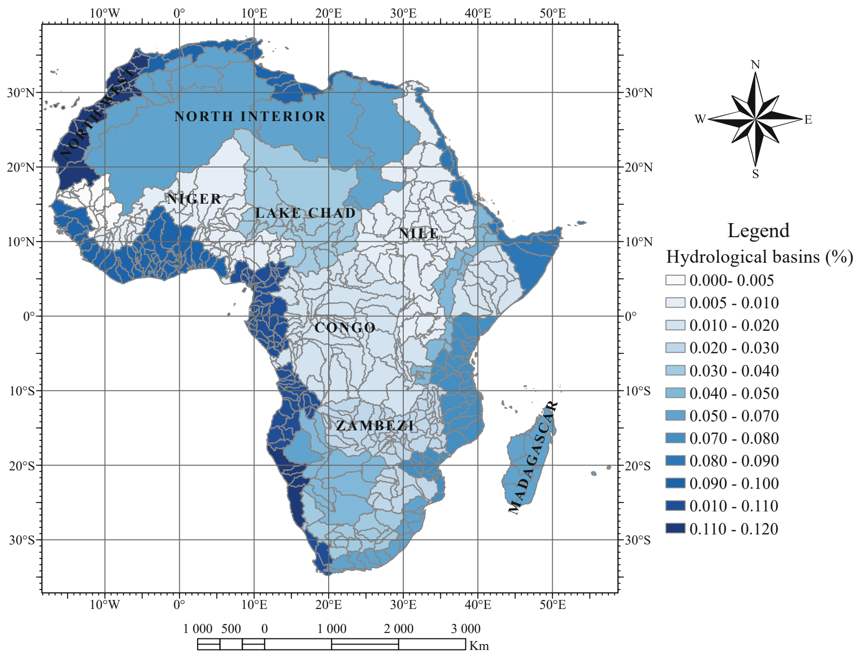

Fig. 5 Major river basins of Africa

largest river basin in the world, after the Amazon (see Fig. 5). This is mainly due to the basin's highly intense rainfall, with an mean flow of 1260×10^9 m^3/s (see Fig. 6), the Congo River accounts for more than one-third of Africa's freshwater resources and offers considerable potential [27, 37].

The Congo Basin covers about 1.2×10^6 km^2 and is one of the largest intracratonic basins in the world. It is underlain by a thick lithosphere (200 ± 30 km) and coincides with a region of pronounced long-wave gravity anomaly [11, 19].

The Nile Basin is the third largest watershed in the world, after the Amazon and the Congo, and the second largest in Africa.

The Nile Basin is the third largest river basin in the world, after the Amazon and Congo, and the second largest in Africa. It has two main tributaries: the Blue Nile, originating from Lake Tana in Ethiopia; and the White Nile, originating from Lake Victoria and the mountains of Burundi, Rwanda, and the Democratic Republic of Congo [38]. Large regional aquifer systems containing substantial amounts of groundwater underlie the Nile region. Some of the aquifers contain fossil water, but others are recharged by rainfall over the basin, or by irrigation areas and the Nile base flow.

The Niger Basin is the fourth largest basin in Africa. Its river originates in well-watered regions before crossing the Sahelian zones. The right bank of the Ansongo-Niamey reach comprises three major sub-basins:

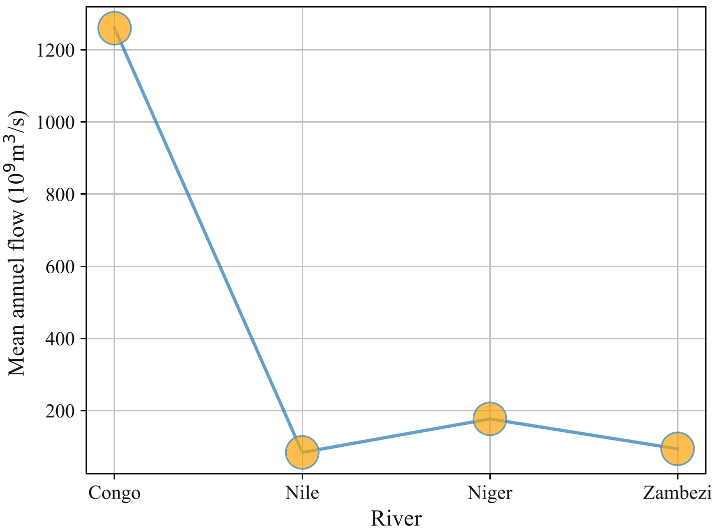

Fig. 6 Annual mean flow of major river systems in Africa (Data: [37])

- The Gorouol, the northern and largest, extends over Mali, Burkina Faso and Niger
- The Dargol, shared between Niger and Burkina Faso
- The Sirba, the southern one shared between Burkina Faso and Niger

The left bank of the Niger River is characterized by smaller, largely endoreic watersheds with a limited contribution to the flow of the Niger. However, since the beginning of the century, outbursts of endoreism have been observed in the small basins of the left bank [13, 23, 25, 26].

The Zambezi is the fourth largest river in Africa and the largest river flowing into the Indian Ocean. It originates in the Kalene Hills. Tributaries flow along both banks, draining portions of eastern and southeastern Angola and northern Zambia into low-lying areas, which form the Barotseland floodplain.

The Zambezi River is characterized by two large hydroelectric dams framing the large Kafue Flats floodplain: the Itezhi-Tezhi Dam upstream and the Upper Kafue Gorge Power Station downstream [40].

5.2 Inland Water Bodies

The amount of water supply depends on the availability and sustainability of the resource. Precipitation, surface runoff and groundwater recharge are intimately linked in the hydrological cycle. Therefore, a good knowledge of temperature and

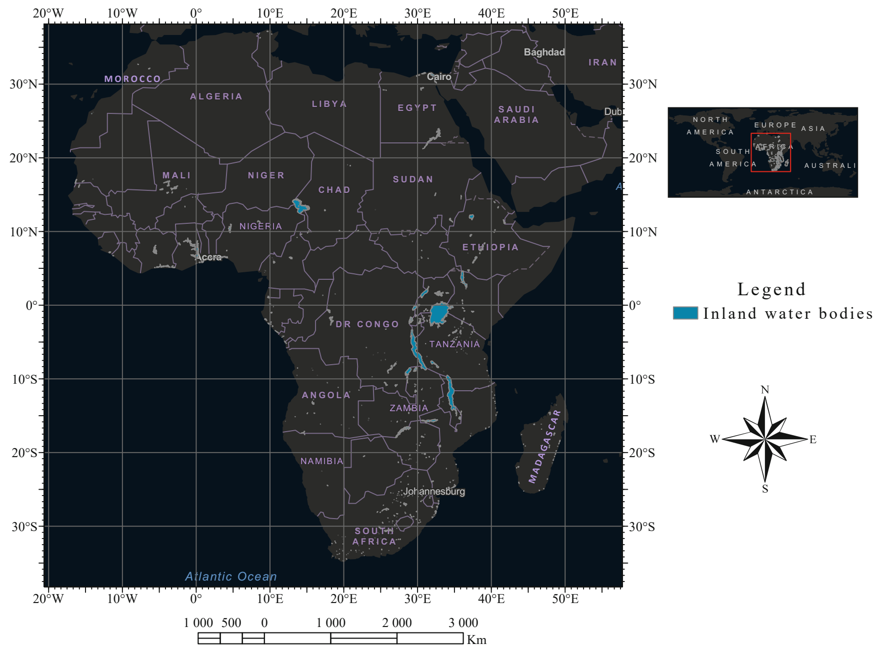

Fig. 7 Inland waters of Africa

precipitation trends is very important for a better management of water resources in a basin, water demand and availability [2, 24].

Lakes and Dams. In Africa, the Great Lakes region is a system of lakes located in East Africa, bordered by four countries: Burundi, the Democratic Republic of Congo, Uganda and Rwanda (see Fig. 7). It is characterized by its ancient volcanic activity; this part of Africa is also one of the most fertile regions. Its altitude also gives it a rather temperate climate despite its equatorial location.

In Central Africa, the Lake Chad Basin has seen an uninterrupted decline in its water level over the past few decades due to variables such as climate change and overexploitation, as well as some drought periods. Lake Chad is a large shallow lake in Africa with fresh water, which is rare for an endoreic lake. It is bounded by four countries: Chad, Cameroon, Niger and Nigeria [18].

South Africa and Zimbabwe have the largest dams, allowing rainwater harvesting. This is seen as a coping strategy in drought-prone environments [1]. The following dams can be mentioned: Akosombo Dam, Kariba Dam, Cahora Bassa Dam, Aswan High Dam, Al Wahda Dam, Katse Dam, Mohale Dam and the Renaissance Dam under construction.

Lagoons. They are transitional water systems between land and ocean. Their ecosystem is particularly productive, they are shallow aquatic environments that generally present a wide variety of colonization by macrophytes [22].

In Africa, the coastal lagoons have a wide geographical distribution on the Mediterranean coast in the North, so in the West African coast, they are environments, where fresh water and salt water of the Atlantic Ocean mix. But the environments of the coastal zone can also be affected indirectly by human actions located inland [31].

5.3 Surface Water Bodies

Over the past decade, water supply and sanitation conditions have deteriorated in rural Africa and remained at a poor level in urban areas (see Fig. 8).

Total water storage changes in basins that drain into the ocean closely follow the El Niño-Southern Oscillation cycle, and it is likely that some endoreic basins will be similarly affected [32].

Major Rivers. Africa is characterized by a diversified hydrographic network, we can quote the main rivers and we will start with the Congo River which crosses the countries of the Democratic Republic of Congo and the Republic of Congo, with a length of 4700 km, it is the eighth longest river in the world but the second after the Amazon for its mean flow of 41,800 m^3/s at the mouth. The Niger is a West African river, with a flow of 6000 m^3/s. However, a closer look at the time series reveals the presence of abrupt changes in these records, similar to those previously detected in some West African rivers, notably the Senegal and Niger Basins [36, 39].

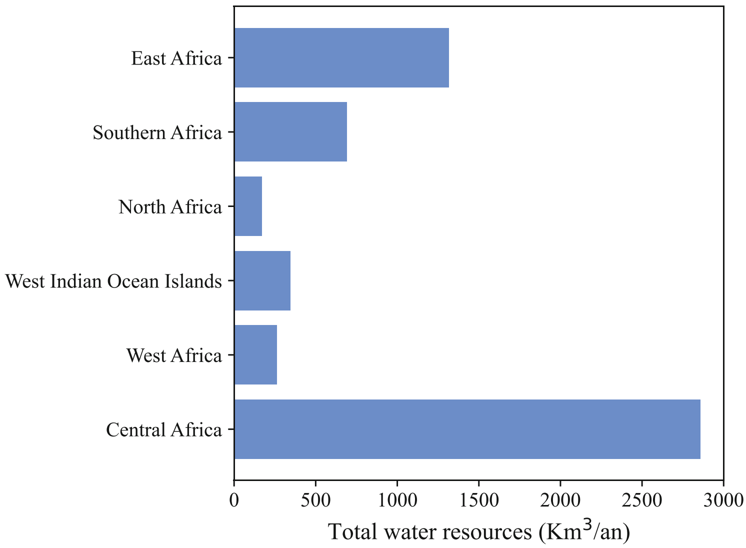

Fig. 8 Total water resources in sub-regions of Africa (Data: [37])

The Nile, with a length of 6650 km, by the origin of his waters, its source is the Blue Nile is located in Ethiopia, while another arm of water, the White Nile, finds its origin in Rwanda. In Egypt, the Nile where most of the water supply comes from the transboundary river flow, in Sudan clearly appears to be highly dependent on upstream flows [10, 41].

The Zambezi is a southern African river, originating in the Black Swamp in northwestern Zambia, because the amplitude of seasonal water level changes is strongly buffered and controlled by the Kariba Dam, the Zambezi downstream does not cause such strong seasonal backwater effects [40].

Wetlands. Wetlands exist in all climate zones, from the polar regions to the tropics. Africa's wetland ecosystems are estimated at over 131 million hectares. They are found where rivers such as the Congo, Zambezi, Nile, Niger, Senegal flow into the ocean (see Fig. 9). They are generally a unique combination of physical characteristics associated with their shape, watershed, connection to the sea and tidal regime [6, 20].

We can cite several wetlands in Africa, we have: Inner Niger Delta, is the largest delta in West Africa, it is a natural region of Mali extending over an area of 40,000 km^2, Okavango Delta, is the second largest inland delta in Africa, with an area of 18,000 km^2, the Hadejia-Nguru wetlands, concern a part of the flood plain of the

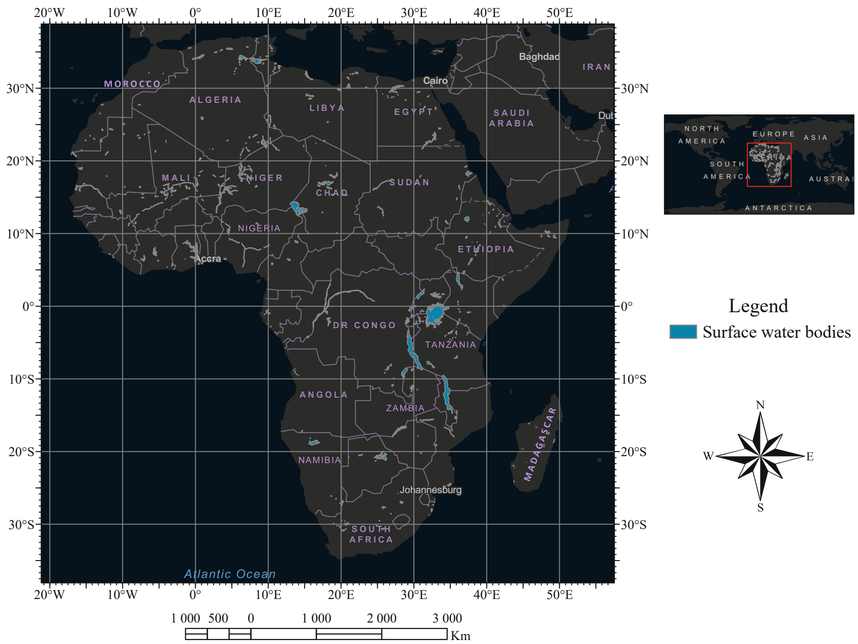

Fig. 9 Surface waters of Africa

Komadougou-Yobe river basin in the Lake Chad basin in the North-East of Nigeria, we can also mention Sidi Boughaba, it is a freshwater swampy wetland of the North-West coast of Morocco.

6 Conclusion

The African water reservoirs, whether underground or surface, constitute a resource to be protected and not wasted. With the exception of arid and semi-arid areas, Africa is very rich in water. The optimal development of this resource must be based on the management of watersheds. The first step is to gain a better understanding of groundwater and surface water resources, by having quantitative and qualitative data on these resources, in order to better use water to support socio-economic development. Indeed, by carrying out projects for drinking water supply, liquid sanitation, irrigation, as well as energy.

The results of this study can inform that water resources must hold groundwater management, especially aquifers and fossil water deposits that have a high risk of overexploitation and consumption and require consideration. For an adequate supply of fresh water for the population, dams are considered an essential tool to supplement dry periods, capturing ephemeral river flows.

Another challenge is to anticipate and preserve water resources and associated ecosystems, and to fight against the quantitative degradation of water resources resulting from various factors, such as changes in the hydrological regime or pollution. The participation of the populations through the establishment of participatory management mechanisms constitutes a better management and sustainability of water and the environment.

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