Al-Gamal and Hamed, J Geol Geosci 2014, 3:6
DOI: 10.4172/2329-6755.1000181

Journal of Geology & Geosciences

Research Article Open Access

Water Resources of African Circum-Sahara Sub Region (Renewable and Non-renewable Approach)

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Abstract

Circum is a preposition in Latin meaning "around" and Sahara is a preposition in Arabic meaning "Desert" so it is the regions around African desert. Studies related to Circum-Sahara are too little in-depth knowledge and focus on certain basins but, are generally limited by national boundaries, and do not take account of the transboundary portions of the reservoirs. The resulting development plans for these limited resources, thus, are seriously impeded by ignorance of the mutual effects of intensive withdrawal. Circum –Sahara region has the least renewable water resources of all geopolitical regions of the world, after the Middle East where the renewable fresh natural water resources amounts to 520 km^3/year compared to 42,600 km^3/yr worldwide.

Surface water resources: These are represented by nine border crossing river basins of 1. Nile, 2. Niger 3. Senegal, 4. Gambia, 5. Volta, 6. Chari, 7. Guir-Saoura; 8. Mejerdah; 9. Juba-Shebelle. However and as a result of the arid or semi-arid climatic conditions which prevail in most of the region, the renewable surface water resources are not only temporally irregular but also often difficult to store.

Groundwater resources: These are represented by eight border crossing aquifers and can be classified as renewable and non-renewable groundwater resources, these are 1- Nubian Aquifer System (NSAS); 2- North-Western Sahara Aquifer System (NWAS); 3-Senegalo-Mauritanian Aquifer System (SMAS); 4-Taoudeni Aquifer System (TAS); 5-Mourzouk-Djado Aquifer System (MDAS); 6-Irhazer-Iullemeden Aquifer System (IMAS); 7-Chad Aquifer System (CAS); 8- Errachidia Aquifer System (EAS). The yield of natural resources per inhabitant amounts to 1,000 m^3/yr per inhabitant (which corresponds to a population density of 1,000 inhabitants per million m^3/yr of resource) .At the present time, six countries of the Circum-Sahara region have natural water resources below 1,000 m^3/yr per inhabitant (essentially the Maghreb, in addition to Egypt and Kenya). One of these, Libya, has less than 500 m^3/yr. In 2025, another four more countries (Burkina Faso, Ethiopia, Morocco and Somalia) will have resources below 1,000 m^3/yr per inhabitant, making a total of ten countries and 405 million inhabitants (69% of the total of all the Circum-Sahara countries).The future hydrology of this region is not rosy and may lead to political disputes.

Keywords: Circum; Sahara; Renewable; Non-renewable; Per capita; Yield

Introduction

Circum is a preposition in Latin meaning "around" and Sahara is a preposition in Arabic meaning "Desert" so it is the regions around African desert. The arid and semi-arid Sahelian region is marked by a 2-3 month rainy season (mean interannual rainfall between 150 and 600 mm) centred on the month of August, followed by a dry season, marked by the Harmattan winds. The climatic history of sub-Saharan Africa is complicated, but hydrological and rainfall monitoring during the last century pointed to two trends: a "wet" period before 1970 and a "dry" period, ever since. During this "dry" period there has been an overall drop in precipitation of close to 20-30%, with the 200 mm isohyets migrating approximately 100 km southward, and major flow deficit from the watercourses (1984-1985, drying up of the River Niger). Only the essential global figures will be presented here provided that of all the large geopolitical regions in the world, the Circum Sahara region has the least natural water resources, both in absolute terms and in relation to its population. Climate change and natural variability in the distribution and occurrence of water further complicate the sustainable development of these water resources.

Materials and Methods

Review of previous literatures

The only systematic study was conducted in 1970s and led to the publication of a book entitled "World Water Resources and their Future" [1]. To a lesser extent, another studies were carried out in 1970s [2]. More recently, the Russian Institute of Hydrology has been updating the information on water resources at continental level in the works of Korzum Shiklomanov. A more recent works were carried out by La Barbe and Tapsoba [3] and were also important sources of information. Water access and water resource management are highly variable across the continent [4,5]. African countries located in Cirum –Sahara regions are also characterized by water stress brought about by climate variability and wider governance issues [4]. 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 [5]. According to one of the most up-to –date studies carried out by [6], the results of the analysis suggested that threats to water security are already the primary cause of some of the most intractable conflict in Africa.

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Received September 26, 2014; **Accepted** October 24, 2014; **Published** November 04, 2014

Citation: Al-Gamal SA, Hamed Y (2014) Water Resources of African Circum-Sahara Sub Region (Renewable and Non-renewable Approach). J Geol Geosci 3: 181. doi:10.4172/2329-6755.1000181

Physiographic setting

The present study has divided Circum-Sahara region into three zones based on climatic, geomorphologic and hydrologic characteristics prevailed as follows:

Northern african zone: This zone has included Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, and Tunisia; (Figure 1) Northern African zone has limited water resources, with less than 10 mm/year on average and it is in a situation of very severe water scarcity, with values per inhabitant varying between 200 and 700 m^3/year [7,8] (Table 1). In terms of internal water resources, it is the poorest sub region in Africa [9,10] with only 1.2% of the continent's total internal water resources and it is the sub region with the highest percentage of external water resources (63%) due to the Nile River (Figure 1). However, the Sahara has very important fossil groundwater reserves of major sedimentary aquifers such as the Continental Sahara, Murzuk, and the Nubian Basin, [11] (Figure 1). These resources are common to various countries [12].

Sudano-Sahelian zone: This zone has included Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger and Senegal [13]. The zone is marked by a climate zoning from north to south, from arid to tropical climates [14]. The hydrographic system is not dense but structured around major transboundary river basins such as the Nile and the Niger, flowing across sub regions. The sub region is also characterized by important endorsees, structural as in the case of Lake Chad, or functional as in the case of the large inner deltas of the Niger and Nile rivers, resulting in important evaporation and reduction in runoff [15] (Figure 1). The groundwater flows are important and there are significant exchanges between surface water and groundwater. The runoff regimes are irregular.

East-African (IGAD) zone: This zone has included Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda. This zone has a population of 140 million of people in an area of 5 million km^2 or 16.5% of Africa and encompasses the following IGAD member states of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda with its Head Quarters in Djibouti, the Republic of Djibouti [16]. Yet four IGAD countries namely Eritrea, Somalia, Djibouti and Kenya are in the category of that experiencing water scarcity i.e. with less than 1000 m^3 per capita. None of the IGAD member states has water per capita necessary for industrial development (2400 m^3/day) countries have .Rainfall ranges between 282 to 1180 mm and averages of 565.7 mm (Figure 1). The equivalent of 304 billion of m^3. The water resources, however are limited (6.5 percent of the continent's internal resources)

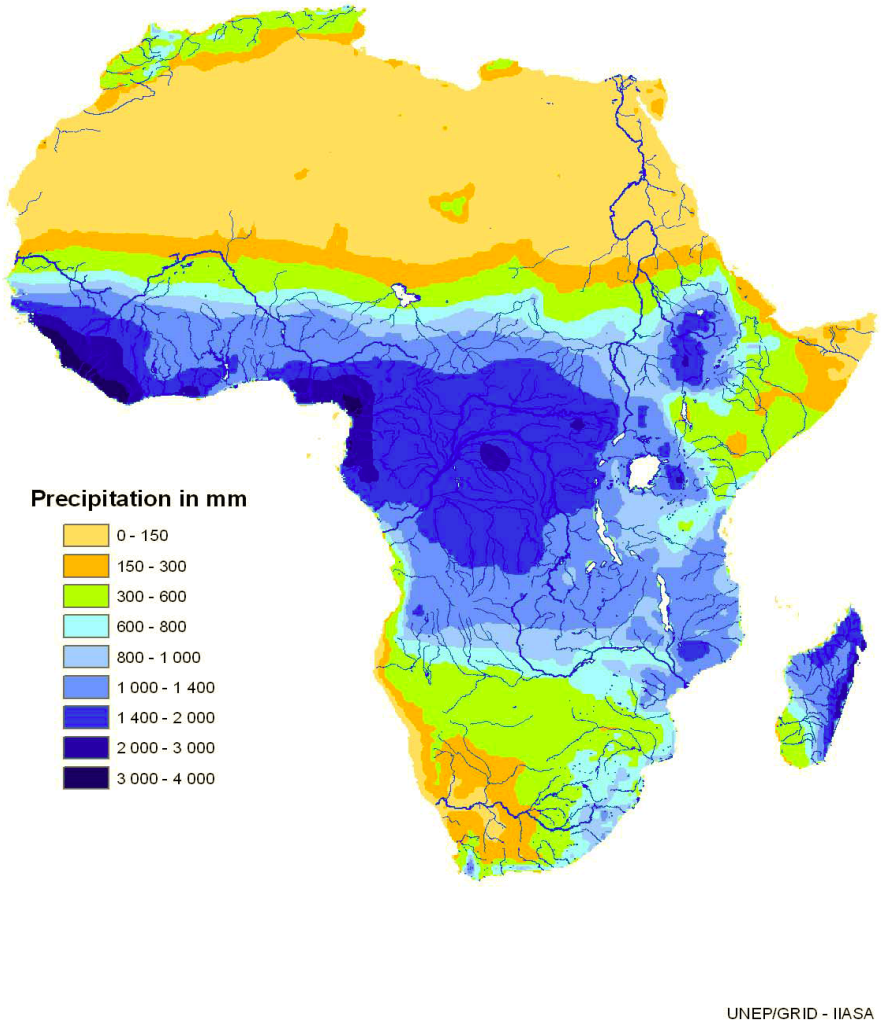

Figure 1: Mean annual precipitation in Circum-Sahara region.

Sub region and country	Groundwater) component (km^3/year)	Natural (km^3/year)	Actual (km^3/year)	External (km^3/year)	Groundwater Flow (km^3/year)	Av.water resources/ capita in the year 2000 (m^3/year)	Water resources per capita in the year 2025 based on avg. population by the UN (2000) (m^3/year)	Rate of independence (internal flow/ total flow) %
Maghreb	49.75	0		49.75	9.6	663	466	100
Algeria	16	0.2		16.2	2.7	515	348	99
Libya	0.6	0		0.6	0.4	107	69	100
Morocco	29	0		29	5	1,023	750	100
Tunisia	4.15	0.42		4.57	1.5	477	356	91
Sahel	142.1	94.2		236.3	~50	4,171	2,223	60
Burkina Faso	17.5	0		17.5	5	1,46	75	100
Cape Verde	0.3	0		0.3	0.1	698	448	100
Gambia	3	5		8	1	6,107	3,721	37.5
Guinea-Bissau	16	15.4		31.4	9	25,950	16,103	51
Mali	60	~40	?	~100	13	8,905	4,695	60
Mauritania	0.4	11	?	11.4	1.5	4,270	2,390	3.5
Niger	3.5	29	?	32.5	5	3,029	1,512	10.8
Senegal	26.4	13		39.4	7	4,156	2,354	67
Chad	15	~28		~43	8	5,621	3,091	35
The Nile Basin and Northeast Africa	215.1	19.2		234.3	~144	1,032	629	92
Djibouti	0.3	2		2.3	0.2	3,594	2,233	13
Egypt	1.8	85	56.5	58.3	55.8	851	610	2
Eritrea	2.8	6		8.8	~1	2,286	1,317	32
Ethiopia	110	0		110	30	1,758	953	100
Kenya	20.2	~10		»30	~5	997	718	67
Uganda	39	27		66	~30	3,030	1,485	59
Somalia	6	7.5		13.5	~2	1,537	636	44
Sudan	35	119	34.5	69.5	~20	2,357	1,502	50
Rounded total	407	113		520	204	1,450	887	78

Table 1: Renewable water resources in the Circum-Sahara region (Compiled from different sources).

and the sub region does not receive much water from outside [17]. Groundwater resources are important and there is a high overlap with surface runoff. This sub region provides water to the Sudano-Sahelian sub region through the Nile River.

Results and Discussion

Water resources in Circum-Sahara countries

The Circum-Sahara sub region embraces almost all the countries in Africa's Sahara and Sahel ring, from the hyper-arid, arid and semi-arid regions to the sub-humid regions (Figure 1). The arid and semi-arid Sahelian region is marked by a 2-3 month rainy season (mean inter annual rainfall between 150 and 600 mm) centred on the month of August, followed by a dry season, marked by the Harmattan winds [10,18]. The climatic history of sub-Saharan Africa is complicated, but hydrological and rainfall monitoring during the last century pointed to two trends: a "wet" period before 1970 and a "dry" period, ever since. During this "dry" period there has been an overall drop in precipitation of close to 20-30%, with the 200 mm isohyets migrating approximately 100 km southward, (Figure 1) and major flow deficit from the watercourses (1984-1985), drying up of the River Niger [12].

The main types of water resources considered in this work are discussed under two main categories: Renewable and non-renewable water resources.

Renewable water resources: It represents the long-term average annual flow of rivers (surface water) and groundwater bodies that receive a considerable recharge [5] (Table 1). It distinguishes between the natural situation (natural renewable resources), which corresponds to a situation without human influence, and the current or actual situation.

Circum –Sahara region has the least renewable water resources of all geopolitical regions of the world, after the Middle East where, the renewable fresh natural water resources amounts to 520 km^3/year compared to 42,600 km^3/yr worldwide [19].

Surface water resources: These are represented by nine border crossing river basins (Figure 2) of:

1. Nile
2. Niger
3. Senegal
4. Gambia
5. Volta
6. Chari
7. Guir-Saoura;
8. Mejerdah;
9. Juba-Shebelle [20] (Figure 2).

However and as a result of the arid or semi-arid climatic conditions which prevail in most of the region, the renewable surface water resources are not only temporally irregular but also often difficult to store [19]. Surface water resources in the Circum-Sahara countries were seriously affected by climate variations during the second half of the 20th century which resulted in major changes in the outflow regimes of

the major watercourses as shown by the annual discharge of rivers in the Circum-Sahara sub region of Figure 3 [21]. This can be concluded from the reduction in flow rates (between 1950 and the present, flow rates in the Niger River dropped by 23% in Mali and 36% in Niger and variations in periods of peak rainfall and flooding [22]. Internal surface waters contribute substantially to the people's drinking water supply, livestock production, agriculture, mining, shipping and fisheries. These resources play a decisive role in countries with insufficient hydraulic infrastructure and little groundwater withdrawal, especially with regard to the provision of drinking water and water for irrigated agriculture in places where the irrigation practices by tradition are well adapted to the watercourse regimes e.g. the large rivers in the region [23].

Groundwater resources: These are represented by eight border crossing aquifers (Figure 4) and can be classified as renewable and non-renewable groundwater resources, these are [24]:

1 - Nubian Sandstones Aquifer System (NSAS); 2 - North Western Sahara Aquifer System (NWSAS); 3 - Senegalo-Mauritanian Aquifer System (SMAS); 4 - Taoudeni Aquifer System (TAS); 5 - Mourzouk-Djado Aquifer System(MAS); 6 - Irhazer-Iullemeden Aquifer System (IIAS); 7 - Chad Aquifer System(CAS); 8 - Errachidia Aquifer System (EAS). The yield of natural resources per inhabitant amounts to 1,000 m^3/yr per inhabitant (which corresponds to a population density of 1,000 inhabitants per million m^3/yr of resource [25]. At the present time, six countries of the Circum-Sahara region have natural water resources below 1,000 m^3/yr per inhabitant (essentially the Maghreb, in addition to Egypt and Kenya). One of these, Libya, has less than 500 m^3/yr (Figures 4-6). In 2025, Burkina Faso, Ethiopia, Morocco and Somalia will have resources below 1,000 m^3/yr per inhabitant, making a total of ten countries and 405 million inhabitants (69% of the total of all the Circum-Sahara countries) [20]. Table 1 presents with some details the different components that constitute the total renewable water resources in Circum-Sahara region.

The further inspection of Table 1 [19] reveals the following facts:

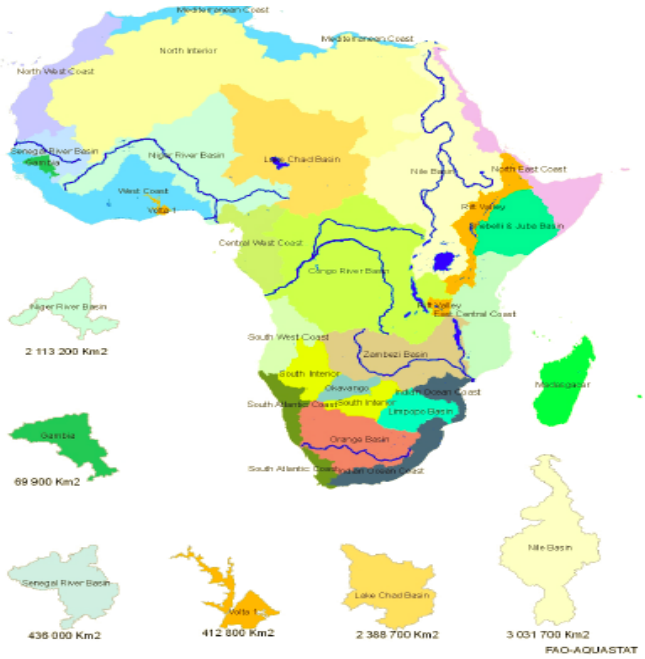

Figure 2: Major river basins in Circum-Sahara region.

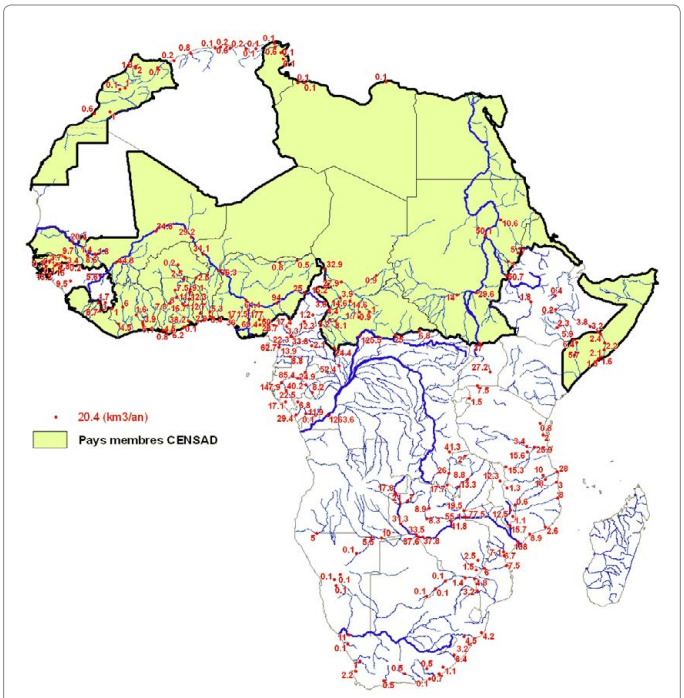

Figure 3: Average annual river discharge in Circum-Sahara sub region.

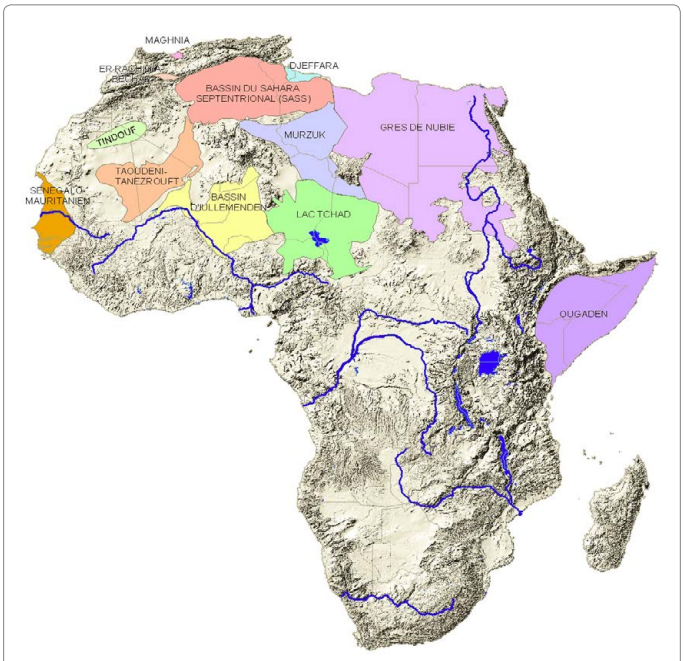

Figure 4: Major aquifers in Circum-Sahara sub region.

1. Groundwater component amounts to 55 km^3/year out of the total renewable water resources.

2. 50% of the average discharge of the Senegal River which amounts to 11 km^3/year in addition to 2 km^3/year of Gambia river constitute part of the total renewable water resources.

3. A sum of 55.5 km^3/year constitute a part of the regularised Nile flow allocated to Egypt by treaty.

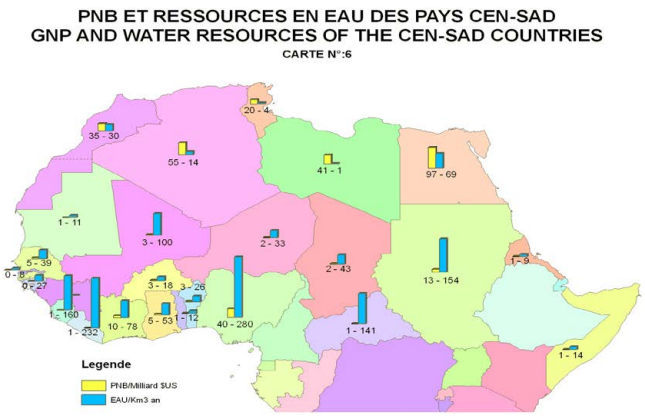

Figure 5: Global National Products (GNP) in billion USD (yellow Histogram) and water resources in cubic kilometres/year (blue histogram) for circum Sahara countries.

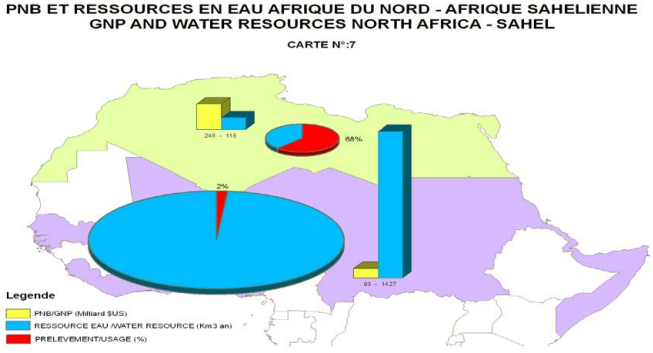

Figure 6: GNP in billion USD (yellow), water resources in cubic kilometres/year (blue) and percentage of usage (red) for North-African Sahelian countries.

4. A total of 117.5 km^3/year in the Nile basin can be segmented into 90.5 coming from Blue Nile and tributaries (Ethiopia); and 27 km^3/year are coming from White Nile (Uganda) [26] (Figures 5 and 6).

Non-renewable water resources: These are groundwater bodies (deep aquifers) that have a negligible rate of recharge on the human time-scale and thus can be considered non-renewable [27]. However and according to [28] who uses water isotopes (^{2}H,^{18}O) and was able to conclude that some of transboundary aquifers such as NWSAS is receiving a considerable modern recharge and can't be considered non-renewable groundwater resources. These barely renewable groundwater are stored in the aquifers of the large sedimentary or crystalline multi-country basins that extend over an area of more than 4 million km^2 and are composed of about ten aquifer systems. Table 2 present the most important non-renewable water resources of which all sedimentary deep aquifers, except those of the Quaternary and Plio-Quaternary are considered non-renewable groundwater resources [13]. The further inspection of Table 2 reveals the following facts:

- As far as the Great-Man-made River in Libya, 1.6 to 2.2 km^3/year [29] was taken into consideration as annual flow and was included.
- The total volume of water that can be withdrawn was estimated based on effective porosities approach for unconfined aquifers of Mali, Niger and Chad [30] with the condition that a maximum drawdown of 10m is allowed for Mali, 10 m of drawdown out of a maximum of 100 m as saturated thickness was proposed for Niger, maximum saturated thickness of 100 m was considered for Senegal and a maximum drawdown from 5 to 10 m was proposed for Chad [23].

A summary of the internal water resources compared to precipitation in regions related to Cirum-Sahara compiled from different resources [3,13,17] is presented in Table 3. The inspection of this table along with Figures 5 and 6 reveals that the table compares the values for internally produced water resources (including surface water and groundwater) and total renewable resources with precipitation and population for the three geographic and climatic regions of Circum -Sahara.

Current rate of exploitation at circum-sahara sub region

The exploitation rates (ratio of total withdrawals from renewable resources/average flow of these resource of some countries of Circum-Sahara range from scarcely 1% to over 100% are shown as Table 4, and Figure 7 [31] Generally, exploitation rate is high in the Maghreb and in the Nile basin and is still low, indeed minimal, in the Sahel, Eastern Africa and Egypt [6] exploitation level is evaluated at 108 billion m^3 per year or 6.9% of the total renewable water resources (surface waters, renewable ground waters) in Africa (1,500 billion per m^3 per year). Yet, the volume of water withdrawn in the Circum-Sahara area is equal to 6.9% of the total annual withdrawal in Africa (total withdrawals estimated at 155 billion m^3 per year). Water is mainly used for irrigated agriculture, which consumes close to 92 billion m^3 per year, or 86% of total extractions (Table 2). Potable water is reckoned at close to 9 billion m^3 per year (8%) and water for industry, at close to 7 billion m^3 per year (6%) (Figure 7).

Country	Estimated exploitable reserves (km^3)	Average annual discharge capacity(km^3/yr)	reference
Algeria	1,500	5	Khourji,1990
Libya	4,000	2.8-3.9	Salem,1992
Morocco	3	?	-
Tunisia	1,700	49	Khourji,1990
Mali	80-190 2000	?	Anonymous,1989
Mauritania	400	?	Khourji,1990
Niger	260-550 2,500	?	Anonymous,1990
Senegal	80-180	?	Sylla,1992
Chad	170-340	?	Terap,1992
Egypt	6,000	?	Khourji,1990
Sudan	40	?	Khourji,1990

Table 2: Non-Renewable water resources for some of the Circum-Sahara regions (Compiled from different sources).

Region	Area (km^2) FAOSTAT, 1999)	Rainfall (km^3/yr) (FAO,1997)	Internal resources (Km^3/yr), (FAO,2003)	External resources: Actual (Km^3/yr)	Total Resources actual (Km^3/yr)	TRWR actual/ inhab. (m^3/yr)
Northern Africa	5 752 890	411	49.5	85	134.5	941.5
Sudano-Sahelian	8 587 030	2 878	160.2	213.9	374.1	3 756.4
Eastern Africa	2 924 970	2 364	260	2.1	262.1	1579.3

Table 3: Water resources compared to rainfall intensities in Circum Sahara regions (compiled from different sources).

Country	Natural %	Mobilizable %
Algeria	25	52
Moroco	47	57.5
Tunisia	57	72

Table 4: Current rate of the exploitation of renewable resources.

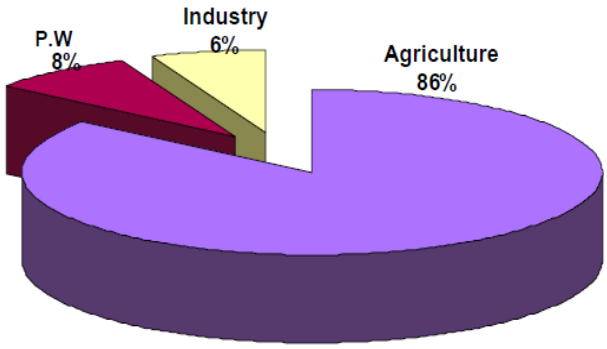

Figure 7: Water extraction in Circum-Sahara region (billion m3/year, compiled from different sources).

The global volume of withdrawals is near to the average discharge of renewable resources in Egypt and in Tunisia, and exceeds it substantially in Libya due to intensive exploitation of non-renewable resources. Over pumping of groundwater from renewable resources in Algeria, Mauritania or Senegal may also increase the apparent exploitation rate [32], as well as the fact that part of the resources may be used several times (remobilized returns of water, notably in Egypt).

Conclusions

Studies related to Circum-Sahara are too little in-depth knowledge and focus on certain basins. The results of the analysis suggested that threats to water security are already the primary cause of some of the most intractable conflict in Africa. Salinization of coastal aquifers due to heavy withdrawals of freshwater, pollution of rivers, lakes, and reduction in hydropower energy as direct consequences to climatic changes, as well as other abuses of water resources, could lead to extremely serious disputes.On the other hand, in the Sahel countries and the 'Horn of Africa' demands on resources are still very low due to the lack of agricultural wells and urban and rural drinking water networks. Exploitation rate is high in the Maghreb countries while is still low, indeed minimal, in the Sahel and Eastern Africa**.** By the year 2025, ten countries constituting 69% of circum Sahara total population (405 million inhabitants) will have resources below 1,000 m^3/yr per Capita.

Lessons learned from the foregoing water conflicts have shown that, although high water interdependency can be opportunities for promoting international cooperation, they can also be causes for aggravated conflict risk**.** Consequently, it is recommended that the impact of climate on water resources be recognized on an ad hoc basis in order to reduce risks of climate-inducing water conflict.

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