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Water Resources Management in Darfur

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Abstract: The Darfur region is suffering from severe water shortage especially in the main urban centers with large concentration of internally displaced people (IDP) and areas of contact between pastoralists and farmers. That is why it has been widely circulated that the Darfur conflict was initiated by competition over stressed natural resources especially water. The Darfur Joint Assessment Mission (D-JAM, 2004) has specially pointed out to the importance of water as a determinant factor for sustainable recovery, development and peace in the region. Any plans for re-settlement require detailed assessment of water resources including water demand for various uses and provision of water supply from reliable sources taking into consideration strategies that ensure sustainability and rational management.

This paper summarizes the results of assessment of surface (Wadis) and groundwater resources and rainwater harvesting potential in Darfur together with assessment of current and future needs for various water uses. Directions for strategic planning and management of water resources are also proposed through pilot projects at targeted areas. These projects include water harvesting, groundwater development, management of aquifer recharge in alluvial and fractured aquifers, conjunctive use of surface and groundwater and integrated watershed management in Wadi systems. The paper also outlines the urgent need for capacity development, research and development, monitoring networks and water information system. Water governance is an important issue which is also tackled in the paper by reviewing the current governance set-up and proposed directions for improvement. The results indicate that though there is a great stress on the readily available water resources in Darfur leading to the current conflict, it is found that there are enough water resources to meet current and future needs. However, harnessing these resources requires significant external and national funding, but this would be only a marginal portion of the cost paid by the UN for its peace keeping force and would certainly lead to peace in a faster and more sustainable way.

Keywords: Darfur; Water harvesting; Ground water management; Conjunctive Use; Monitoring; Capacity Development; Water Governance.

1. INTRODUCTION

The Darfur conflict is strongly linked to increasing pressures on the readily available natural resources, particularly lack of adequate water supply to meet the immediate demand of population. It has been estimated in this study that current water supply in Darfur region represents only about 14% of the required domestic and livestock demand. Available records on conflict in Darfur indicate that out of 49 recorded conflicts that took place during the past six decades, more than 75% of them were triggered due to high competition over water and pasture especially during low rainfall seasons [1,2]. Therefore, any plans to achieve peace and stability in the region, would require an integrated water management strategy that ensures the provision of sustainable water supply to meet livelihood needs of the people of Darfur. Failure to adopt the integrated approach could lead to more water supply problems, which may lead to more conflicts in the future.

This paper summarizes the results of a study on Darfur Water Resources Assessment and Management executed by the Department of the Civil Engineering, University of Khartoum, with funding from the Flemish Community provided within the context of the Flanders-UNESCO Science Trust Fund (FUST) for the support of UNESCO's activities in the field of sciences [3]. The main objective of this study was to conduct a preliminary assessment of the water resources of Darfur and suggest directions for strategic water resources management. While addressing this issue, there were many key problems and bottlenecks pertaining to Darfur water resources that were important to look at, in order to ensure the sustainability of the recommended management strategy. Examples of these problems are absence of monitoring and water resources information base, lack of comprehensive guiding policy document and water strategy linked to a plan of action, poor governance and legislative framework, inadequate capacity development, lack of coordination among water sub- sectors, and inadequate stakeholders participation.

2. THE MAIN WATER RESOURCES POTENTIAL

2.1 Rain Fall

The climate in Darfur varies from extremely arid in the north to semi-tropic climate in the southern part. Accordingly, rainfall varies from less that 50 mm in the northern part of the region to more than 1000 mm in the higher altitude savannah regions of South and West Darfur. Typical to arid zone characteristics, rainfall data analysis in Darfur shows that it is highly seasonal and highly variable in space and time with annual coefficient of variation ranging from 30% in central Darfur to more than 40% in the northern desert. Analysis also shows annual rainfall decreasing trend and a marked shift in rainfall isohyets towards the south [4]. Furthermore, North Darfur rainfall records show increased frequency of droughts over the past 40 years. Sixteen out of 20 driest years on record in North Darfur have occurred since 1972. It appears from the above features that the climate in Darfur is influenced by global climate change. This matter, however, needs further research to determine the effect of global climate dynamics on Darfur climate and suggests action plans to overcome the related challenges. Fig.1 indicates the rainfall variation in the Sahel region for the period (1898 - 2002) which demonstrates the decreasing trend of rainfall in the region as well as the extended Sahel drought of the last few decades [6]. This decreasing trend is supported by Fig. 2 which illustrates a considerable shift in desert boundary between 1958 and 1975 [7] and Fig. 3 which indicates a decreasing trend in the annual rainfall of Genaina for the period (1943 – 2006). In spite of these trends, Table1 clearly illustrates the high potential of the larger Darfur for water harvesting if compared to other larger regions in Northern Sudan.

2.2 Wadi Water Resources

The hydrological system in Darfur depends mostly on rainfall on Jabal Marra and the surrounding hills of central Darfur draining radially through nine large Wadi systems (Fig. 4). Due to lack of monitoring, Wadi flow data in Darfur is generally poor, except for very few Wadis such as Wadi Nyala. For the purpose of this study, techniques for flow estimation in ungauged catchments have been employed, with catchment characteristics for different Wadis; being derived from satellite data and average rainfall over a gauged catchment. The total average Wadi flow has been estimated as 1159 MCM/y distributed among the three Darfur states as 100 MCM/y, 159 MCM/y and 900 MCM/y for North Darfur, South Darfur and West Darfur respectively. Though this resource is of reasonable magnitude, it is concentrated during the rainy season from June to October and therefore it requires careful management including recharging potentials within the underlying formation.

Table 1. Rainfall in various regions of Sudan

Region	Total Rainfall BCM/y	5% Harvested BCM/y
Northern State	19	0.95
Kordofan	10	5.50
Darfur	175	8.70
Eastern Sudan	63	3.10
Central Sudan	76	3.80
South Sudan	618	31.00

Source: Ref. [8].

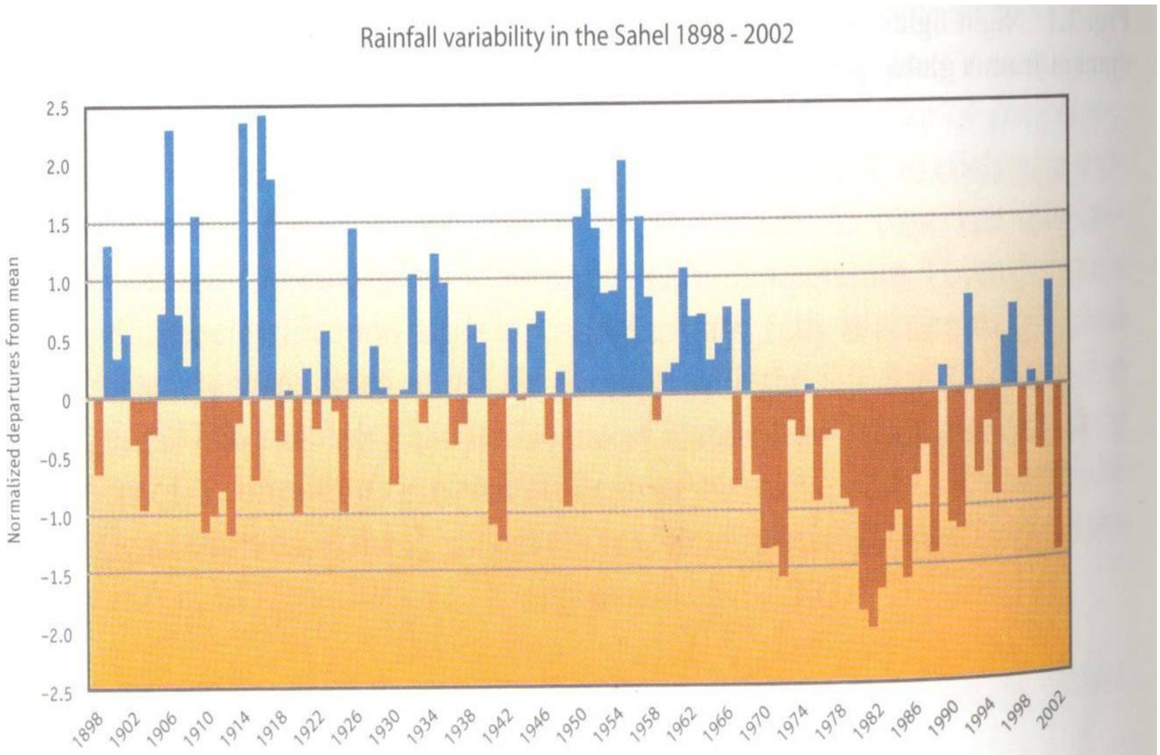

Fig. 1. A century of rainfall variability in the Sahel expressed as normalized departures from long– term mean (Nicholson, [5])

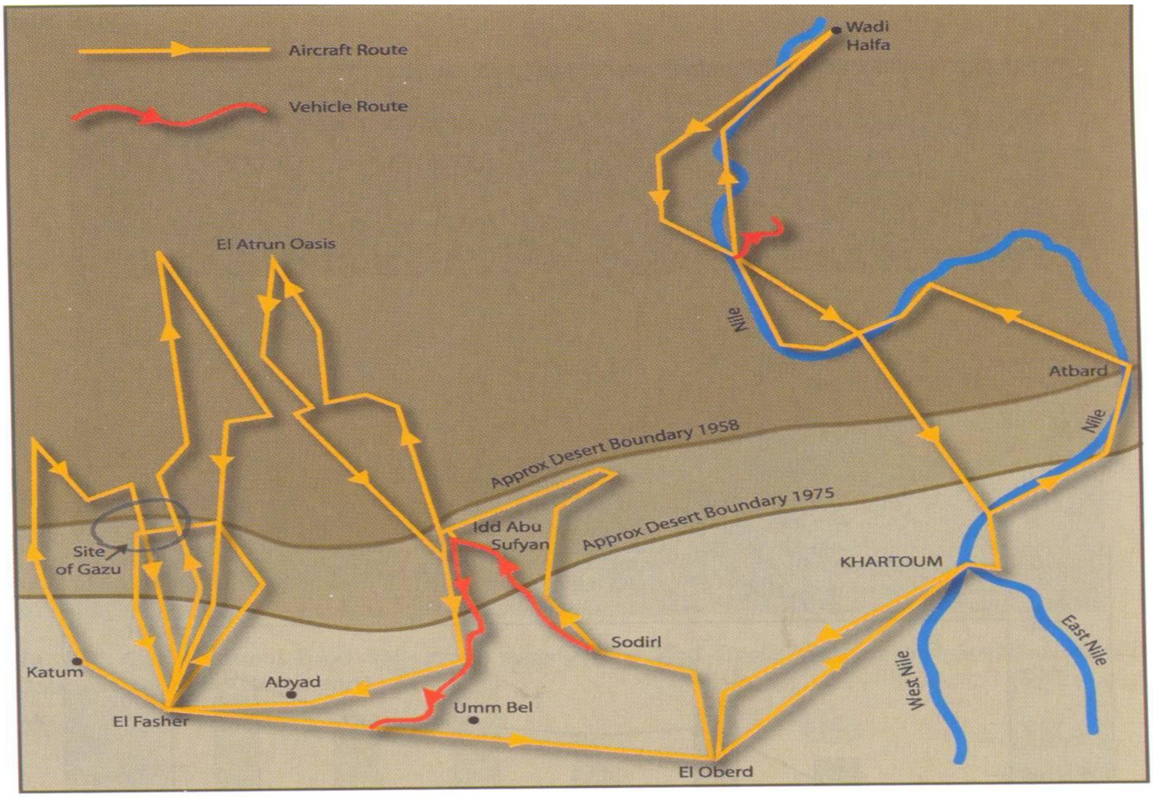

Fig. 2. Shift in Desert Line from 1958 and 1975 (Lamprey, [7])

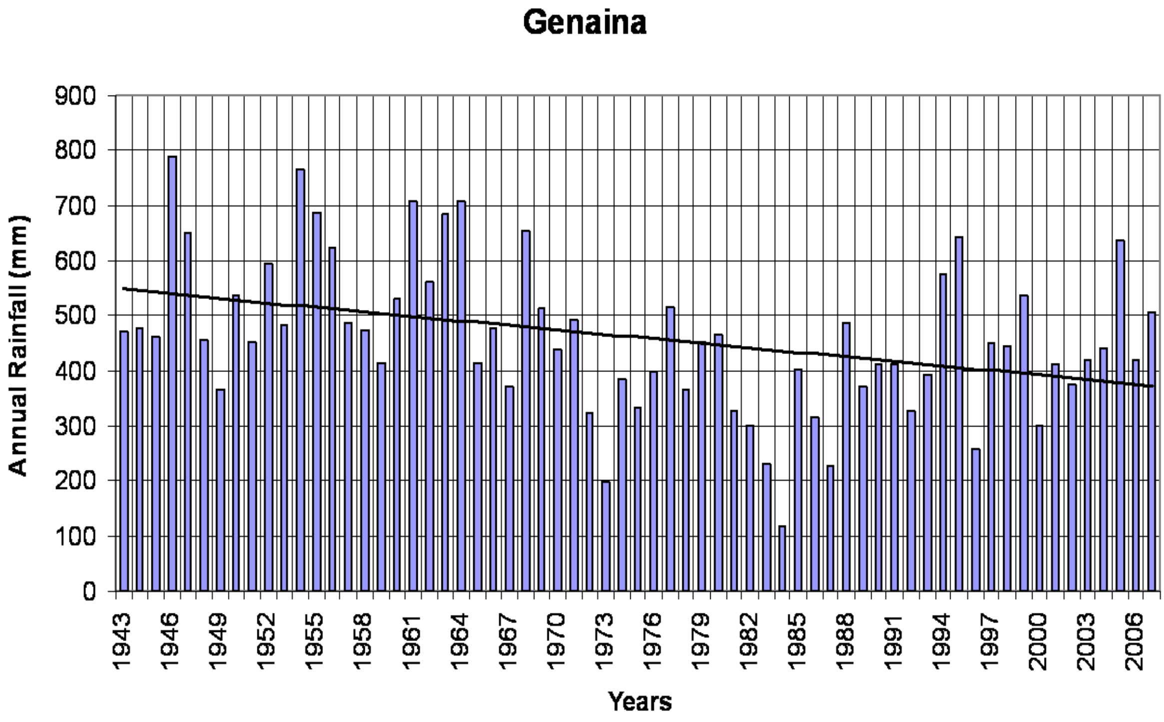

Fig. 3. The rainfall of Genaina for the period (1943 – 2006)

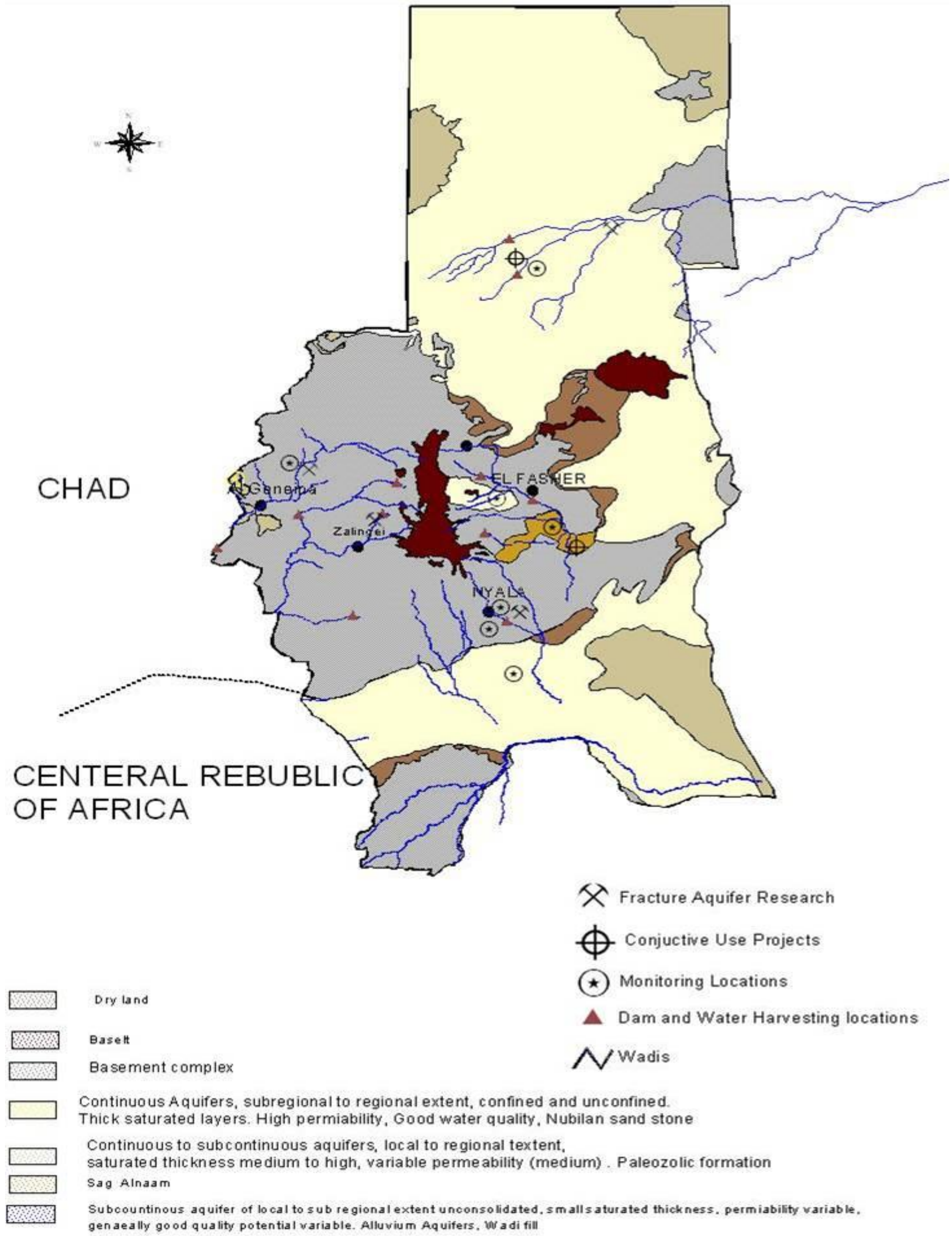

Fig. 4. The hydrological system in Darfur

2.3 Groundwater Resources

Darfur has three basic hydrogeological units, the deep sedimentary basins of the Nubian Sandstone and Um Ruwaba aquifers**,** the Wadi Alluvial aquifers and the fractured aquifers of the Basement Complex (Fig. 5). Detailed information on the vertical extents, saturated thicknesses, the hydrogeological characteristics, recharge sources and recharge mechanisms, water balance components and exchange of flow between surface and groundwater or between aquifers themselves in the different basins are not available. Considerable work is needed to fill in these information gaps. However, for the purpose of this study, a rapid assessment has been carried out using the available limited data and the results are presented in Table 2 which shows the Darfur groundwater storage potential, annual recharge and current abstraction rates. As can be seen, the current groundwater abstraction represents less than 2% of the annual recharge. Therefore, there is still large renewable and storage potential for groundwater development in all Darfur States. It should be emphasized that groundwater monitoring systems should be put in place before embarking on large scale development. In addition, it must be emphasized that large areas in Darfur are underlain by huge non-renewable groundwater formations, which represent considerable future potential for all uses.

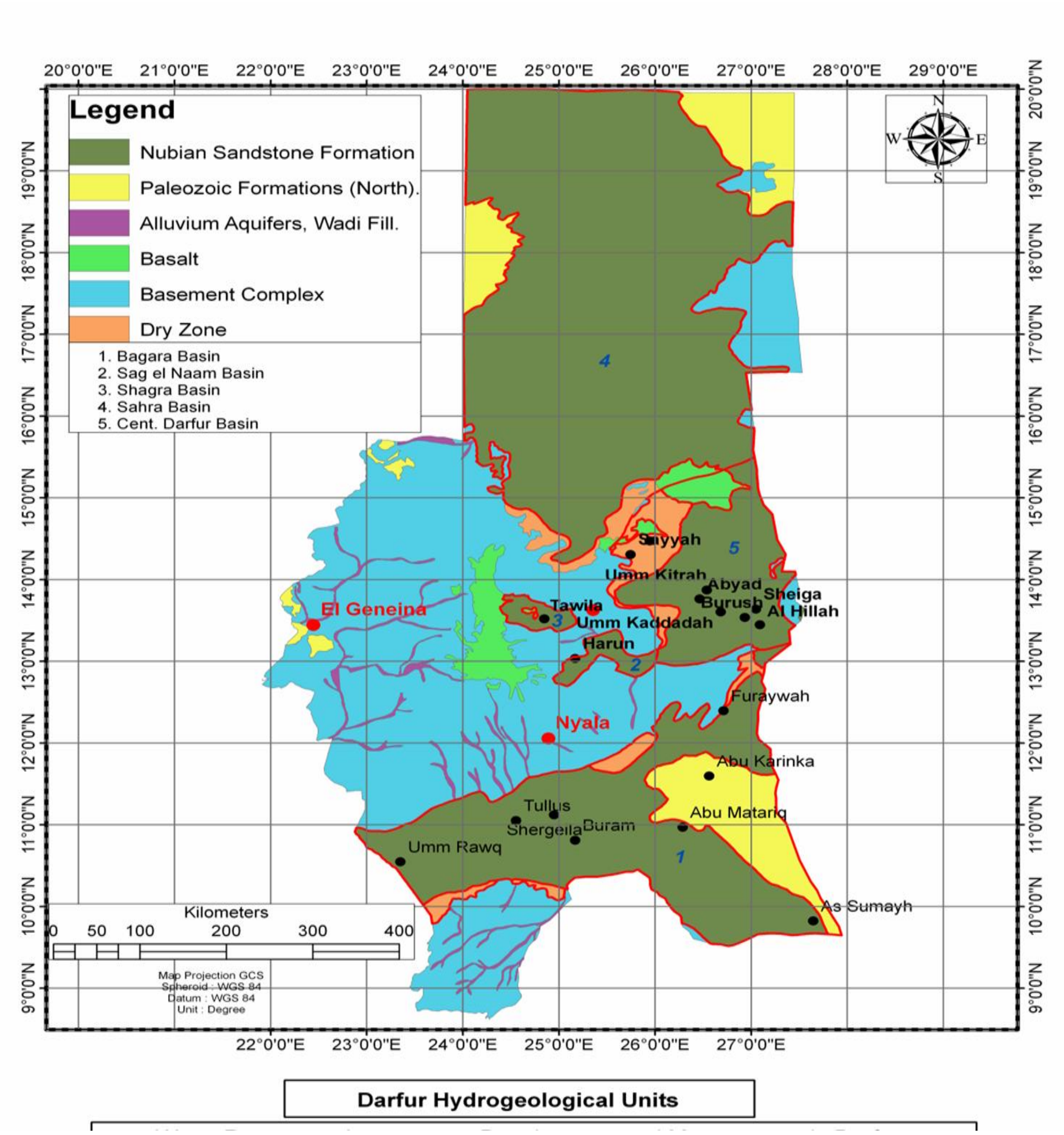

Fig. 5. Groundwater resources in Darfur

Table 2. Summary of groundwater potential in Darfur states

Basin	Location	Area (km^2)	Depth to Static water level (m)	Total storage (MCM)	Recharge (MCM/y)	Abstraction (MCM/y)
Baggara Basin	South Darfur	60,000	20-100	300,000	250	7
Sahara Basin	North of North Darfur	200,000	3- 45	4,000,000	50	>1.0
Um Kaddada Basin	East of North Darfur	5,500	20-50	30,000	21	2
Sag El Naam	SE of North Darfur	2,250	60-95	100,000	20	0.5
Shagera	ELFashr	1,250	40-70	20,000	15	5
Dasia	El Geneina	1,750	30-60	20,000	10	0.4
Alluvium Basins	Along the Wadis	2,000	1-30	5	2,000	20
Basement	49% of Darfur	65,333	30-60	1.5	3	2.2

Source: Ref. [9]

3. WATER SUPPLY AND DEMAND

There are an estimated 426 boreholes, 174 hafirs and small dams, 4287 hand pumps and large diameter dug wells that supply a total of about 30 MCM/y of water in Darfur [10], 2008). Table (3) shows the renewable water resources in the three Darfur States, the volume of the current supply and the estimated present and future human and livestock water demand up to year 2020. Present human and livestock population and their projection up to year 2020 have been obtained from [11]. Water demand calculation was based on 80 l/p/d for urban areas and 40l/p/d for rural areas. For livestock demand, an average value of 10l/head/d was assumed. The table shows that, in general, current renewable water supply in Darfur represents only about 14% of the required demand. This demonstrates the very critical water supply situation in Darfur. It is also evident that the current demand represents less than 7% of the renewable water resources. Therefore, water availability is not a problem in Darfur but it needs additional technical and financial resources and enhanced management capacity to harness these resources. Irrigation water demand has not been included in the table. The agricultural sector in Darfur depends basically on traditional rain fed cultivation. The cultivated area varies from year to year depending on the rainy season but on average it is about 1.68 million hectares (4 million feddans). Also there is a large number of gardens for fruits and vegetables production in Darfur with a total area of about 13,000 hectares (30,000 feddans). The garden water requirement is estimated as 125 MCM, 50 MCM and 100 MCM for West, North and South Darfur, respectively, and it is met from Wadi floods during the rainy season supplemented by groundwater from alluvial aquifers [12]. However, it must be emphasized that through an IWRM approach and rational exploitation of renewable and non-renewable water resources (Rainfall, Wadi flow, groundwater and water re-use), considerable food production opportunities and re-settlement of pastoralists could be materialized.

4. WATER GOVERNANCE AND CAPACITY DEVELOPMENT IN DARFUR

In Darfur there are several institutions and water sectors at different levels that govern water resources development and management. At State level, the key institution is the State Water Corporation (SWC) which functions under the auspices of the Ministry of Planning and Public Utilities. At federal level, the key ministries are the Ministry of Irrigation and Water Resources, the Ministry of Health, the Ministry of Agriculture and the Ministry of Environment. Under the Ministry of Irrigation and Water Resources are the Public Water Corporation (PWC) and the Groundwater and Wadi Directorate (GWWD).Similarly, there are various acts and strategies under different institutions and sectors. Important relevant acts are the Water Resources Act of 1995, the State Water Corporations Acts of 1998, and the Public Water Corporation Act of 2008. As indicated above, authority in the water sector in Darfur is mostly fragmented and responsibilities are distributed among various institutions without effective and institutionalized mechanism of coordination and clear demarcation lines of authority. This often leads to conflicting actions and lower impacts of projects that could have given a much better return. There is no an effective guiding policy document at the country Federal level and consequently there is no comprehensive water policy at the level of Darfur States. Also, there is a great gap in capacity development including institutional and human resources which are essential requirements for assessing, planning, designing, operating and managing of water resources in Darfur in a holistic way.

5. DIRECTIONS FOR STRATEGIC WATER RESOURCES MANAGEMENT

Due to the above mentioned shortcomings, it was not possible to develop within the framework of this study a comprehensive water management strategy for Darfur States. However, the study proposes the following directions that could serve the anticipated strategy and could be implemented as separate or one package.

5.1 Establishment of a Water Resources Monitoring and Information System

The presence of an adequate water monitoring and information system is a pre-requisite for any successful assessment, planning, design, operation and management of water resources systems. As has been discussed before, monitoring and water information system in Darfur had been very minimal and suffered huge degeneration as a result of economic and political instability. In its strict sense provide adequate information for the various purposes mentioned above. However, monitoring in its broad sense requires

Table 3. Water Resources, Current Supply, Present and Future Water Demand in Darfur

State	Estimated Average Water Resources MCM/y		Present Water Supply MCM/y	Present Demand MCM/y			Future Demand (2020) MCM/y		
	Surface	Ground-water Renewable		Human	Livestock	Total	Human	Livestock	Total
South Darfur	159	1250	12.4	61.1	39.3	100.4	92.4	47.8	140.2
North Darfur	103	106	11.6	31.7	28.1	59.8	48	34.2	82.2
West Darfur	900	1010	6.36	25.3	41.8	67.1	49.5	50.8	100.3
	1,159	2,266	30.35	118.1	109.2	227.3	189.9	132.8	322.7
Total	3,425								

regular observation and collection of information on other areas very important for the assessment, planning, operation and management of the region's water resources such as water use data, socioeconomic data, supporting remote sensing data, knowledge base, capacity development issues and linkages to other relevant databases. The monitored information needs to be collected and checked for consistency and harmony by qualified staff at the office before analysis and processing and finally entered to the database for storage and dissemination to the stakeholders and end users. This may look as the ideal and dream situation, but for Darfur, one would be realistic to suggest progress in phases linked to specific research and development projects. Examples of the recommended research projects are groundwater management in fractured aquifers in Darfur, conjunctive use of surface and groundwater in Sag El Naam basin, North Darfur, groundwater development in the Sahara basin using renewable energy and integrated management of Wadi Nyala

5.2 Innovative Directions for Water Utilization in Darfur

Water harvesting, linked whenever possible to artificial recharge to underlying formations and management, is one of the most effective methodologies for water conservation in arid and semi arid areas. There is large potential for water harvesting in Wadi system in the three states of Darfur. As shown in Table 1, if 5% of the available water is harvested it will give close to 9 billion cubic meters of water annually on average. Traditional water harvesting systems have been used in Darfur for a long time. Based on the survey carried out at Darfur states, it has been concluded that many water harvesting projects have collapsed due to technical faults and poor design. New techniques of water harvesting systems that serve multipurpose objectives can be recommended in this study. This new technique can include besides water spreading for irrigating vast areas, the following components;

i- "Hafir" system, and

ii- "Wells: dug upstream the main control structure that is normally constructed in the main stream of the Wadi".

These wells will be recharged by the retarded water at the upstream side of the water harvesting system. Water harvesting systems can also include earth dams that can be constructed across selected Wadis for water storage to be utilized for domestic use and agriculture. The design of these dams is to be based on hydrological studies carried out competently for the considered Wadi catchments.

Management of aquifer recharge (MAR) through artificial recharge methodologies is also one way of enhancing groundwater resources in Darfur. There is a large potential for artificial recharge in Darfur, especially in areas underlain by alluvial and fractured aquifers and intersected by Wadis. As reported by [13], artificial recharge has a large potential in Sudan and can provide a viable option for water resources management in Darfur and other parts of Sudan.

One of the important methods that can be introduced in rain fed agricultural areas is mechanized farming. Currently there is little contribution of mechanized farming in Darfur but its introduction will certainly enhance productivity and hence food security. Deficit or supplementary irrigation using modern irrigation methods could also have a big potential in Darfur. Aqua crop Model [14] that relates between soil characteristics, soil fertility, types of crops, climatic conditions, rainfall intensity, rainfall frequency, runoff and the prevailing field management; can be applied in Darfur cultivated areas to improve irrigation water management and consequently increase crop production.

5.3 Conjunctive Use of Surface and Groundwater

As mentioned before, Darfur has enough water resources that can secure the present and future demands if properly managed. However, the old approach of fragmented development needs to be changed to a more coordinated or integrated approach in which all the available resources are utilized conjunctively in a manner that maximizes the benefits from utilization. In Darfur, surface and groundwater are often available at the same location but surface water availability is highly seasonal and highly variable, typical to the characteristics of arid and semi arid areas. As the pattern of surface water availability in Darfur is considerably different from the pattern of water demand, it could be very useful to exploit groundwater at times of low or no surface water availability and recharge surface water into groundwater at times of high surface water availability using artificial recharge methodologies. Conjunctive use has large potential in Darfur and could be applied to almost all Wadis and their associated alluvial aquifers. Considering Wadi Nyala as an example, though the estimated average flow of the Wadi is about 40 MCM/year, a maximum of only 6 MCM/year is currently utilized mainly through groundwater abstraction from the alluvial aquifer. Using mathematical modeling, Hussein [15] shows that abstraction from the aquifer could be doubled if the pumping pattern is modified and more wells are introduced, and that the aquifer would still be fully recharged from the following year Wadi runoff (enhanced recharge). Another example where conjunctive use could be applied is for enhancing agricultural production in Sag El Naam area which lies 42 kilometer south east of El Fasher town, North Darfur. The area is relatively rich in agricultural land resources as well as surface and groundwater. Previously, an irrigation project was implemented in the area and was supplied from groundwater of Sag El Naam basin. However, the project had failed due to the large imbalance between groundwater abstraction and natural aquifer recharge leading to excessive drawdown and high cost of pumping. Another reason for the failure is the inefficient method of irrigation used. The high cost of pumping could be offset by conjunctive use of groundwater and surface water of Wadi El Ku which runs through the area. Also natural groundwater recharge to Sag El Naam aquifer could be enhanced through artificial recharge of Wadi El Ku flood. It is also important to introduce modern water saving irrigation technologies such as sprinkler irrigation and modern methodologies for determining cropping patterns and crop water requirements as suggested in various FAO publications [14].

5.4 Integrated Watershed Management

Integrated Watershed management offers an effective method for conserving the hydrological regime of the Wadi systems in Darfur and maximizing the benefits from its water resources. Many techniques of water conservation have been traditionally developed along hill slopes with the intention of preventing soil erosion, regulating surface runoff, increasing the infiltration in the ground and recharging the underlying aquifers. Traditional terraced agriculture is certainly one of the most common water harvesting methods in arid areas. Where the terraces are well maintained, they effectively control the runoff and improve aquifer recharge but, once allowed to fall into disuse, they progressively lead to gully erosion, collapse of the retaining walls and destruction of the whole system. Also, severe modification of the local hydrological regime could occur. Because of the siltation problems often experienced in many areas, programmes of soil and water conservation as well as forestation should be undertaken. Although the primary objective of the watershed management is to limit the soil erosion and therefore reduce sediment accumulation in the surface reservoirs downstream, the effect of these practices may also become significantly positive on aquifer recharge [16]. The overall approach should aim towards integrated water resources management (IWRM) which consider in additional to technical considerations (Water quantity and quality), socio-economic, environmental, legal and governance considerations.

5.5 Water Governance and Capacity Development

Though it was found from this study that there is enough water resources from renewable and none-renewable sources, it must be emphasized that these resources require sound governance in addition to a great deal of financial and human resources to make them sustainably available for the various uses and the corresponding stakeholders. The old approach of business as usual has led to huge conflict between the various users (particularly the farmers and the animal owners), over abstraction and quality deterioration of the readily available renewable resources. In the new approach more work is needed in tools such as water harvesting, artificial recharge, developing non-renewable water resources and managing demand as well as implementing the practice of conjunctive use of rainfall, wadi flows and groundwater. All these can never be successful without sound governance at all levels (local, state and federal). Sound governance requires transparency, equity, ethical behavior and sense of ownership at all levels. This is particularly important in Darfur where the role of users, mainly farmers, in decision making, is relatively higher but the existing water resources are often threatened by depletion, contamination and competition with the owners of the moving animal resources. The following are some recommendations for improving governance and capacity development in Darfur:

- Reform and enhance existing institutional setup avoiding fragmentation and single sector management, with more stakeholder participation. The role of water users and the civil society in water governance is currently limited, in both rural and urban areas of Darfur. This has to be enhanced significantly to achieve the desired level of ownership.
- Revise national and state level policies and strategies and plans to provide for measures of good governance.
- Correct inappropriate legislative framework (for protecting water quality and eco-systems) and promote enforcement mechanisms.
- Build capacity for different sectors, enhance sharing of experience and knowledge and develop effective mechanisms for flow of information.
- Mobilize financial resources and encourage investment in water resources management. Improve accountability and transparency.

5.6 Bridging the Gap between Research and Policy

As has been mentioned before, there are many gaps and divides that hinder reliable assessment and sustainable development and management of water resources in Darfur. The most important of these are gaps in knowledge base and capacity development, absence of comprehensive water resources policy, lack of coordinated decision making at federal, State and local levels and gaps between decision makers and target groups. All these gaps have been addressed in the study which indicated that there could be enough water resources to meet present and future demands if managed in a sustainable manner considering closure of the above gaps.

It is clear that there is a gap between researchers, decision makers and stakeholders. Bridging this gap is very crucial for sustainable development and management of water resources in Darfur and elsewhere. The following are some recommendations to achieve this purpose:

- Foster dialogue between researchers, decision makers and stakeholders through an institutionalized platform to share their knowledge and work more effectively. This will enhance cooperation between various disciplines and help promoting trust and confidence building between them.
- Encourage multidisciplinary research that addresses the interests and motivations of decisions makers and researchers and fulfill the needs of the community. This encourages cooperation and supports decisions that ensure sustainability of the scarce water resources for the present time and future generation.
- Research results and findings should be communicated and explained to the decision makers and stakeholder with translation of their importance to the decision at hand.
- Research institutes should encourage multidisciplinary water education and training programs for engineers, managers, decision makers and the public. In this way, researchers could communicate their research findings more effectively to influence policy and consequently sustainable actions. Such activities will enhance cooperation among disciplines, promotes capacity development among institutions, decision makers and stakeholders, and hence bridge the gap in understanding between researchers, policy makers and the public at large.

6. CONCLUSIONS

The conflict in Darfur is strongly linked to a fastly growing competition between various users on continually decreasing natural resources, particularly the readily available renewable water resources including rainfall. A recent UNESCO supported study has indicated that there are considerable potentials for obtaining additional resources through better management of the renewable water resources (rainfall, wadi flow, ground water) and the untapped huge quantities of non-renewable groundwater resources. Provided that adequate technical and financial resources are made available, the potential water resources in Darfur could meet the current and future needs of Darfur population for domestic, food production as well as other demands such as mining, industrial, recreation and ecosystem. This should be reached, however, through an integrated water resources management approach (IWRM). The water family of International organizations such as UNESCO could play a role relevant to its mandate to achieve this goal by funding; and few proposals have been prepared awaiting support from funding sources.

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