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Water Resources in Sudan, Innovations for Conservation, Development, Proper Use and Management

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Abstract

This paper discusses how innovative research efforts, novel approaches and genuine cooperation to utilize appropriate technologies, may enable those of concern in the Sudan to rehabilitate deteriorating eco-systems, enrich degraded soils and increase water resources coupled with efficient use. The result is to alleviate the hazards of drought and possibly reverse desertification and make desert-affected lands of the Sudan to become amenable for sustainable agricultural utilization.

Introduction

Water and soil, which constitute the basic factors in crop production, are facing serious problems all over the world, especially in the arid and semi-arid regions; since millions of hectares are degrading and declining in productivity as a result of erosion, moisture deficit and loss of fertility.

Most of the Sudan is under aridity condition, which is characterized by evident mismatches between water demand and

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supply. Thus, causing occasional droughts, which result in negative impacts on water resources and thereby devastating effect on crop production and may lead to food crises.

The northern third of the Sudan is mainly covered with mobile and fixed dunes, while the north western part is considered as an extension of the eastern outskirts of the Great Desert (FAO 1997).

The cultivated land is not more than 7% of the estimated 105 mill. ha cultivable area of the old area of Sudan. Only about 3% consists of permanent crops and the remaining area consists of annual crops.

About 80% of the population is involved in agriculture. The climate varies from hyper-arid in the northern parts through savannah in the centre to equatorial in the most southern parts of Southern Sudan (before separation). Rainfall varies from 20 mm/year in the north to some 1600 mm/year in the far south, within an average of 436 mm (Adam and Abdalla 2008).

Water Resources

Water used in Sudan is derived exclusively from rainfall, surface water resources (mainly River Nile and tributaries) and underground. Exploitation

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of underground water for agricultural purposes is increasingly getting attention but still in some areas has been hampered by cost as the water table is very deep. Internally produced water resources are estimated at 343 Mld m^3/year (Adam and Adeeb 2006). Table (1) exhibits an estimate of the different water resources in Sudan.

Thus, agricultural activity in most of the Sudan is mainly constrained by aridity; and it is rather unfortunate that very little can be done to change this situation. However, man's activities can be controlled, which may have a direct positive effect on the hydrological cycle by economizing water needs to avoid undesirable side effects such as desertification. It is however, fortunate that water is the most manageable of the natural resources as it can easily be stored, transported, diverted and recycled mainly for agricultural activities, which account for over 80% of the water consumption. Therefore water is the main limiting factor for agricultural production in Sudan.

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Table 1. Estimates of water resources in Sudan

No.	Water Resource	Milliard m^3/year	Constraints
1	Share from R. Nile (measured in Sudan)	20.5	Seasonality of rivers, limited storage facilities
2	Non – nilotic resources (wadis& khors)	2.8	Erratic, intermittent flows, difficulty of monitoring & storage – some are shared with other countries
3	Renewable ground water	4.9	Deep water table, weak infra-structure, requirement of cheap (economical) energy for extraction
4	Development projects (Jonglei, Sudd, water harvesting ...)	6.1	Requirement for source of funding, require assurance against negative impacts (environmentally, socially …)
	Total	**34.3**	

Source: Adam and Adeeb (2006).

It is quite evident that irrigated agriculture can at least be two-fold that of the rain fed agriculture, production wise, provided that appropriate technological packages are strictly applied. On the other hand, if rainfall is supplemented by small amounts of water from any source, particularly during occasional dry spells within crops growing seasons, will increase considerably the efficiency of utilizing water coupled with crops yields (Arar 1984; A/Latif 1995; Bloum 2003; Farah *et al*. 2003 and Mohamed *et al*. 2011).

Appropriate Technologies:

About forty years ago NAS (1974), (the National Academy of Sciences) of

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the United States published an excellent booklet "More Water for Arid lands", which describes a number of promising technologies for enhancing the supply and efficiently using and conserving scarce water supplies in arid areas. They also include innovative irrigation methods, selecting and managing crops to use water more efficiently, and reducing evaporation and seepage losses.

In the forty years since NAS booklet was published, the need to increase both the supply of usable water and reduce its demand has significantly increased. Hence there has been a significant increase in water resources and irrigation research.

In this paper, some promising initiatives are presented. The salient findings and innovations are of practical significance for water resources in desert and desertification – affected lands with a view to fostering the efficient use, protection, appropriate management and development of these water resources mainly for agricultural activities.

1. Rainfall:

Rainfall is the main source of water in both Northern and Southern Sudan (over 1000 Mld m^3/year). However, in drought prone areas the risk of dependence on it is very

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great. Crop production and yield from rainfed agriculture in such areas is always precarious and unpredictable. Drought spells have been known since the days of Prophet-Joseph. Such spells are cyclic and most probably affected by some non-torrential activities. Desert or desertification on the other hand, occurs when the drought becomes permanent. This happens mostly due to torrential causes such as over consumption or degradation of the elements and ingredients which help the ecosystem to “take off” again after the end of the cyclic non-torrential activity. Many plans are being made and several techniques are being developed by individuals and institutions of concern to rehabilitate such ecosystems (UNEP 1977).

It has been recognized that forests have their effects in creating the appropriate local climate, which encourages precipitation from production clouds when they are in the vicinity. This phenomenon is expressed by the following formula as stated by Elagib (1986):

$$D = \frac{R}{LP}$$

Where: D = Dryness ratio; R = Net radiation; L = Latent heat; P = Precipitation. This shows

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that forests help to reduce "R" and consequently decrease "D".

In addition to this, forests have also another role of providing effective canopy which intercepts the rain drops from falling onto the ground and lost by deep seepage. It is estimated that a forest tree holds between 40 to 100% of 10 mm rain and 10 to 40% of more than 10 mm rain. The water evaporates into and travels farther, as clouds, to the hinterlands. However, the canopy effect may be lost through overcutting of trees and forests clearing. Thus, depriving the hinterlands of its effective deployment role.

Based on this concept of the deploying role played by forests, it is evident that reafforestation projects are equally important, or even more, than the conventional plans of having forestry belts. A great deal can be achieved at negligible cost through mobilized voluntary work in areas lying in the critical zone where the canopy is receding. It must be mentioned that farming is no substitute for forests because field crops do not have the same canopy effect.

Rain water harvesting:

This can be defined as the process of collecting water from down slope areas to increase runoff and

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snow melt. Water harvesting is an ancient practice which was used almost over 4000 years ago during the Bronze Age when agricultural civilization first developed in regions with an annual average rainfall of about 100 mm which is inadequate for conventional agriculture (NAS 1974). Besides utilization in agriculture, the technique is also used for erosion control, human and animal consumption, range improvement, forestation and ground water recharge. Collection of runoff from rooftops is another historical method of harvesting precipitation. Although, the development of centeral domestic water supply systems caused it to be abandoned and forgotten in many parts of the world.

An amount of 50-80 mm average annual rainfall seems to be the lowest limit for water harvesting. However, incidents of harvesting usable runoff from only 24 mm of average annual rainfall are often reported (Arar 1994). In Sudan water harvesting techniques were reported by A/Latif (1995) to increase grain dura production in western Sudan by more than three-folds and dura stalks weight by about 1.7 times as compared to traditional agriculture. Pasture and tree plantations were also increased within 4-6 times.

However, livestock water management in such arid regions must be an integral part of an overall range management plan which includes control of livestock numbers as indiscriminate water development may lead to increased live stock numbers, overgrazing and desertification typical to what is happening in Sudan.

There are various methods and materials that can be used for harvesting water. These include proper management of vegetation, smoothing and compacting the ground by impervious materials such as asphalt, plastic films or by chemical treatments.

Water harvesting techniques are cheap, easy to adopt, do not intervene with the existing ecosystem; but are unreliable as they are liable to failure in drought years.

Supplementary irrigation (conjunctive use of water resources):

The conjunctive use of water resources means supplementing rainfall by artificial irrigation water. This was found to increase considerably the efficiency of utilizing water resources as a whole for the production of food and fibres. It has been found that a linear relationship exists between cereal yields and the amount of rainfall during the growing season

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(Arar 1994). This relationship is represented by the following regression equation:

$$Y = C\ (R\text{-}R_o)$$

Where, Y = Yield of grain (t/ha); C = Coefficient of measuring crop water use efficiency (0.014-0.016); R = Total water (rain or irrigation) up to 600 mm; R_o = Minimum amount of water required to produce cereal vegetative growth with no grains (varying from 100-150 mm).

It becomes evident that from this equation that the first 100 to 150 mm of water (R) will produce no grains, and every(mm) above that (whether from rain or supplementary irrigation) will produce about 14 to 16 kg of grain/ha. Hence the efficiency of the conjunctive use of the supplementary irrigation with rainfall becomes evident. This irrigation water could be from surface, ground, treated sewage, harvested water or any other source. This is confirmed by the findings of Arar (1984) in the Near East Region where supplementary irrigation resulted in an increase of the cereal crops particularly wheat. A minimum yield of more than 3.5 t/ha of wheat was guaranteed in growing areas of 350 mm rainfall and above for which supplementary irrigation within the range of 50 – 200

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mm was given. The increase in yield was 100% as the normal average yield was within the range of 1.5 t/ha. This was also confirmed by the findings of A/Latif (1995) Abdalla and Mustafa (2005), Abdalla and Mustafa (2010)and Mohamed *et al*. (2011) in Sudan.

Rainfall augmentation (cloud seeding):

Adding substances such as ice, frozen CO_2, AgCl, promote condensation (nucleation) of super cooled water vapor in the atmosphere and produces rain. For artificial formation cloud seeding one must have the right meteorological conditions. The results of cloud seeding are difficult to predict. This is because of the still imperfect knowledge of the physical processes causing precipitation and because of the engineering difficulties in getting the added substances (seeds) into clouds in the optimum amounts and at the right time and place. However, research in this respect is still considered at its very early stage.

Iceberg utilization:

About 85% of the World fresh water is trapped as ice in the Polar Regions, but it is generally considered as unavailable. Engineers, glaciologists and physicists are still speculating on whether it can be profitably recovered

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by towing to water short regions. According to some views, "the idea appears both technically feasible and economically attractive and merits serious consideration" (Arar 1994). Data on size and distribution of icebergs indicate that the supply is more than adequate. Satellites imageries (i.e. collective images) can be used to select suitable icebergs. Problems encountered include, the appropriate towing process, the expenses incurred and internationally accepted legals and rights plus other political questions. In the Sudan however this approach is not relevant at the time being.

Dew and fog harvesting:

The possibility of condensing water from the atmosphere by some simple procedure has intrigued several investigators. Fog harvest is a technique, which may well be an important source of water for some coastal and mountainous areas. The technique has been developed in Chile since 1987 and it is that about 5 to 10 liters of fresh water can be collected from a square meter per day with an overall estimated cost of about $ 1.1/ m^3 (NAS 1974). In the Sudan this may be a target in the far future in mountainous areas such as Jebal Mara in the Western Region of Dafur.

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2. Surface water:

There are two sources of the surface water:

i- Nilotic water:

The Nile system includes the Blue and the White Niles and their tributaries. About 44% of the Nile Basin lies in Sudan, while 80% of Sudan lies in the Nile Basin (FAO 1997). The Nile system annual discharge is estimated as about 84 Mld m^3. According to the 1959 Nile Water Agreement between Egypt and Sudan, the Sudan's share is 18.5 Mld m^3 and Egypt's share is 55.5 Mld m^3 as measured in Aswan, while 10 Mld m^3 are regarded as evaporation losses (Table 1).

ii- Non-Nilotic water:

In Sudan, the watersheds, which can be recognized include: Nuba Mountains (south west); the Red Sea hills (east); Angasana Hills (south east); Jebel Marra (west); Elbotana Hills (central) and the Ethiopian Plateau (east). The major streams are the Gash and Baraka in the east of the country. Both streams are characterized by large variations in annual flow and heavy loads of silt.

Each of these watersheds is comprised of many wadis and khors of various sizes ranging from very big ones of annual discharge up to 100 million cubic meters to small ones of annual discharge of less than one million cubic meters (Abdelgadir *et al.* 2003).

Irrigation with saline and brackish waters:

Saline waters are waters which have only dissolved salts and of which NaCl is distinctly predominant. They are characterized by (TDS>3000ppm, EC>5 ds/m). Brackish waters may be contaminated with acids, bases, salts or organic matter, viz.: contaminated ground waters.

Beneath many of the World deserts are reserves of saline and brackish water. Also a lot of surface water, estuaries, coastal lagoons, land-locked lakes and irrigation return flow (drainage) contains large amounts of salts.

If saline water and brackish water can be used for irrigation, more desert land will be cultivated; consequently non-saline water will be released for human consumption and other domestic uses.

Today, new appreciation of plant physiology and soil science and modern irrigation techniques are showing that with careful management, saline water can be used to grow a variety of crops (ICBA 2008).

Increasing water use efficiency:

This means increasing yield per unit volume of water (water productivity) which includes amount of water and intervals plus

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inputs e.g. fertilizers, control of pests and diseases and crop management.

Reducing evaporation from water surfaces:

Reservoirs and canals in arid areas are subject to heavy evaporation losses but because evaporating water is invisible, these losses are often not recognized. With large surface areas open to air (compared to the volume of water stored) evaporation losses often exceed the amount of water used productively.

A good example for this is the estimated evaporation losses from Lake Nasir, which amount to about 10 Mld m^3/year (about 12% of the annual average River Nile discharge). Hence, this aspect of water conservation in arid and semiarid areas is very important and must have serious attention. Many methods have been investigated to control evaporation from free water surface. They are categorized by energy-reducing treatments, like changing the water colour, using wind barriers, shading the water surface and floating reflective covers such as continuous paraffin wax, polystyrene rafts and foamed rubber. Using such processes a reduction of about 85-95% is envisaged to be achieved.(NAS 1974).

The selection of any of these methods will depend mainly on economic

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consideration and local conditions. Wind damage to the floating cover can be a disadvantage.

Reducing seepage losses:

These losses are substantial under light soil conditions both from irrigation networks and reservoirs. Seepage can also cause serious problems of water logging, salinization and soil erosion in neighboring lands. Seepage can be reduced by making the soil water-tight as by lining conveyance systems, soil compaction, chemical treatments, soil cover by butyl rubber, plastic sheets, asphalt reinforced with plastic or fiberglass reinforced plastics. However, economic viability must be taken into consideration.

In the Sudan some intermittent trials have been made on reducing seepage losses from irrigation networks However, the most recent and serious trial was conducted by El Gamri (1998). Various locally available building materials were studied under light soils conditions. Based on technical merits and economic feasibility, Khafgi, ferrocement and concrete made form locally available aggregates were recommended. Kenaf-sheets (cement- sand-mortar-sheets reinforced with long and chopped kenaf-fibers) were excluded

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due to their limited durability.

Reducing transpiration:

About 1% of the water absorbed by roots is incorporated into plant tissues as 99% goes through the process of transpiration as water vapor. One hectare of growing vegetation can transpire as much as 100 m^3 of water per day. If a practical way of reducing transpiration could be found without affecting the crop yield, a substantial reduction in water demand could be achieved, especially under aridity condition.

Typical methods include: destruction of unwanted plants, breeding programms, enclosing crops, reducing air movement over crops as by windbreaks, removal of unproductive leaves, physically or chemically by defoliants or using chemical anti-transparent to cause stomata closure.

It is claimed that with developed crops with high water use efficiency, it is possible to produce one man food for a day with only 200 liters of water (NAS 1974).

Controlled environment agriculture:

Encapsulating crops within especially developed enclosure, water lost by seepage, evaporation and transpiration can be reduced and the atmosphere around the plants can be manipulated to maximize productivity. Green houses (plastic houses) can be evaporatively cooled and humidified during the summer with raw seawater or brackish ground water to reduce irrigation requirements. At present this is not practical in Sudan but may be an aim for the long future. Off-season high value crops can also be produced with small amounts of water in very inhospitable regions. However, sometime the cost is prohibitive.

Conservation of water in soils:

Many techniques are used to conserve the soil moisture and that is by the use of covers, mulches (plastic or friable topsoil) or bituminous material.

The use of hydrophilic (water attracting) soil amendments can reduce evaporation and deep percolation losses. Soils with mixed hydrophilic chemicals can absorb water thus keeping it safe from these losses and make moisture easily available to plant roots for an extended period. Promising findings were obtained by Saeed *et al*. (1985,1986) on the use of synthetic polymer products (Culture Plus, Water Grain) as soil moisture retaining agents for stabilizing date-palm offshoots and growing barely.

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New trends and innovations of field irrigation methods:

These are mainly concerned with:

i. Improving conventional surface irrigation methods:

High efficiencies can be achieved by adopting certain technologies such as follows:

Long furrow or border irrigation methods:

When preceded by precision land leveling using laser equipment, better distributions of water are obtained among individual furrows, basins or borders with the size and time of flow selected by the desired irrigation depth, soil characteristics and field slope. In theory, irrigation efficiencies of more than 80% can be obtained with improved surface irrigation methods if design and management are reliable. Improving field distributor systems as by canal lining or alternatively by using a network of piping systems can easily control water. Also, better control and management can be achieved by using techniques such as spiles, gated pipes (hydro flumes) and siphon tubes.

Adoption of the inflow cutback or intermittent water application systems:

These include cablegation, alternate furrows or surge flow systems. Such systems are reported by Walker and Skogerboe (1987) to improve water distribution efficiency within a range of 15-40%, reduce deep percolation losses within 40-80% and increase application efficiency from 55 to 85%. Furthermore, automation may also be incorporated with these systems to give further improvement in the efficiency and reduction in the running cost.

ii. Modern irrigation systems:

They include sprinkler and drip irrigation systems.

Sprinkler irrigation system:

Several sprinkler systems are available:-

- Conventional solid systems sets (portable, permanent and semi-permanent).
- Mobile rainguns that spray large quanties of water over wide areas.
- Spraylines (stationary, oscillating and rotating).
- Mobile lateral systems (center-pivot and side-move systems).
- The floppy irrigation system of South Africa.

Drip irrigation system:

Also, called trickle, localized or micro-irrigation. It is considered as the most important breakthrough in on-farm irrigation technology. Drip irrigation prevents desertification and reduces

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the environmental hazards of surface irrigation, such as soil erosion, runoff and deep percolation of fertilizers and agro-chemicals. It has high application efficiency and can use low quality water such as brackish water. The field under drip irrigation is always easily accessible. Sprinkler and drip irrigation can be automated and chemicals can be mixed directly with the water (chemigation) or fertilizers (fertigation).

New trends in modern irrigation systems:

Application efficiency for a well managed sprinkler system ranges from 70-80%. Research has shown that efficiencies can exceed 95% on some sprinkler systems such as the Low Energy Precision Application (LEPA) (Lyle and Bordovsky 1983). Most of the recent developments and improvements in sprinkler efficiency have been with continuous move systems (centrally pivoted or linearly moving systems). Traveller-Trickler system or Trail-Drip technology is a cross between the high pressure continuous move sprinkler system and the low pressure trickle system. It was to counteract some of the negative aspects of the two systems (mainly the high evaporation losses and distorted distribution associated with sprinklers and the clogging problems associated with the drip system).

The drip lines are trailed behind the continuous moving laterals with either variable tube lengths or hole configurations on the tubes – while matching the application rate with the soil intake rate. However, commercialization of this technology is still under investigation.

Another innovation is a simple approach proposed by Saeed (2003) to conserve water and energy. It consists of a windmill coupled with a simple version of drip system (called bubbler) to irrigate small farming units under arid zones.

Participatory approaches:

These have recently become an accepted mechanism for research management of policy information in the irrigation sector.

Considerable progress has been made towards finding ways in which users can participate jointly with government in the operation and management (O&M) of irrigation systems.

Water Users Associations (WUA's) have now been accepted as a necessary pre-requisite for farmers to be involved in management decisions in collecting fees to cover

O&M costs and in maintenance activities.

Participatory research is also becoming more widely used as a mode of collaborative field research in which research institutions work jointly with irrigation management agencies to bring about simultaneous changes in the agency and in the process of managing irrigation systems (Lenton 1995).

3. Groundwater:

It constitutes the main water supply source for drinking and domestic use for more than 80% of the human population and their livestock in the country. It is found under about 50% of the area of the country (Kheiralla 1989). The groundwater basins are found in simple or complex forms according to their geological formations. These can be classified as follows:

a) The Nubian basin, which includes; Sahara, Nile Basin, Wadi El Magadam, Wadi El Qa'ab, El Khowi and Wadi El Selaim

b) Sahara Nubian Basin: This covers the northern part and northern Darfur State.

c) Nuhud Basin: It covers parts of the central part of northern Kordofan State.

d) Other basins include: Sag El Na'am, River Atbara, Umm Rawaba, Sudd, Eastern

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Kordofan, Blue Nile, Nubian Basalt, Shagara and the Alluvial Basins.

Hence if ground water from deep wells has to be used for irrigation purposes advanced agricultural technology and high value crops have to be introduced so as to make the enterprise economically viable. This is so unless special circumstances of social and food security are taken into consideration to justify its use.

Ground water recharge

Artificial recharge of the ground water provides ready made storage reservoirs free from evaporation and protection from pollution. In arid areas rain usually comes in sudden storms and flows down the wadis, which normally have impermeable layer beneath their beds.

It has been estimated that about 80% of runoff in a typical storm is lost to man's use because of high evaporation. The critical operation is to divert as much as possible of the available water to the groundwater aquifer or wells.

The origin of ground water may be from fossil ages or more recently from replenishing rains. Recently, the Deep Hole Technology is revealing the probability that water is being made from its basic elements in geothermal reactions. This is a new source which is available to arid zones, especially where ground water is thought to be depletable.

Modern technology made it possible to develop underground water works similar to those made for surface water. Underground dams may be built to control or to redirect ground water. Grouting with synthetic materials is used to seal cracks or permeable rock and to isolate saline acquifers. Underground reservoirs may be used to preserve water from evaporation from flowing away into the sea. Zigzagged terraces can be made to decelerate water and lengthen its passages so that it can seep down and recharge such reservoirs. Sometimes boreholes can be drilled for feeding the reservoirs.

Isotope techniques may be used to label ground water and hence map subterranean flow. Radioisotope dating techniques also enable researchers to know whether the water origin is only fossil or replenishable, hence proper planning can be made.

Although, underground reservoirs have the advantage of less evaporation, they are of course prone to losing water through seepage. However, energy is needed to pump groundwater. In more remote areas this presents a

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major problem. Alternative energies have to be used, e.g. solar and wind energies. A breakthrough is still needed in the technologies of these energies before they are competitive with conventional energies or within the purchase ability of users in arid zones (Elagib 1986).

Concluding remarks:

It is evident that there is a growing scarcity and misuse of the available water resources particularly under aridity conditions. This urged great concern from decision-makers. Various means and ways have been devised with a view to conserving, developing and properly using and managing water to satisfy essential requirements. Many non-conventional technologies are developed and others are still subject to further investigation.

Weather Satellites and Remote Sensing (RS) techniques are giving new dimensions to the sciences of meteorology and climatology. Isotope Hydrology and Deep Hole Technology are widening the knowledge about ground water. Genetic engineering, tissue culture and new breeding techniques are already helping man to breed drought resistant flora and funa. Biotechnology is helping man to enrich the

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soil biota through nitrogen bacteria fixation. Both intensive energy and alternative energy technologies are multiplying human abilities. New techniques have also been developed to increase water uses by improving and/or modernizing conventional irrigation methods. Also, through water development, conservation, protection and management practices.

The context of this paper addresses itself to the impact of such technologies on the development of water resources of Sudan, particularly, in the desert and desertification-affected lands. However, it worth mentioning that such technologies and innovations should be looked into as supplements to, and not substitutes for standard and reasonably accepted conventional methods. Furthermore, when intending to adopt them, consideration must be given to the unique locality conditions. These conditions affect success with respect to technical merits, potential application, viability on the economical, environmental, social and institutional aspects.

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