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A REVIEW OF SUSTAINABLE WATER MANAGEMENT STRATEGIES IN SEMI-ARID AND ARID REGIONS

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ABSTRACT

The earth's hydrosphere has about 1.36 billion km^3 water containing 97 % salt and 3% fresh water. Only 1 % of the fresh water is available for human consumption. Rapid increase in population improvements in living standards industrialization and climate change is currently putting a great demand on clean supply of water, Surface sources of water are subject to extreme temporal and spatial variations, especially in semi-arid and arid regions. Therefore there is need for efficient management of water resources that requires a coordinated overall strategy by an authority with the power to prevent abuses. This Paper emphasizes the challenge to develop ground water resource, as it represents about 98 percent of world's supply of usable freshwater. Besides, this source is not severely affected by climatic extremes in the way that surface sources are, and its development scheme is not so capital intensive as that of a large reservoir project. The focus here is in the planning, development and management of groundwater resources that encompasses siting of well for maximum yield; taking advantage of the different characteristics of surface and groundwater in order to optimize the yield of the total water resource; it will employ a simple regression model as a case, example of groundwater modeling techniques. These aspects, among others, are considered and examined to ensure sustainable water management so as to prevent over-abstraction of water in arid and semi-arid regions.

Keywords: Arid, Management Strategies, Region, Review, Semi-Arid, Sustainable Water

1.0 Introduction

Throughout history people have devised systems for getting water into their communities and households. From the Neolithic to Ancient Age, Classic and today's Modern Age, water has been a primary logistical challenge. Where water resources are insufficient for the population, people fall prey to diseases, dehydration and in extreme cases death. Water is a vital resource for the survival of all living things. Without water, life on planet earth would not exist (Abrashnky, 2004). Development of human societies is heavily dependent upon availability of water of suitable quality and in adequate quantities for a variety of uses ranging from domestic, commercial, industrial, etc (Sundaradive and Vigneswaran, 2004).

The earth's hydrosphere has about 1.36 billion km^3 water and 75 % of the earth's surface is covered with water containing 97 % salt and 3% fresh water. Only 1 % of the fresh water is available for human consumption (Ali *et al*, 2012). Therefore, there is need to use water in a sustainable way and this present a big challenge (FAO 2006). It is certain that societies have to confront, among other things, demographic transitions, geographical shift in population, technological advancement, growing globalization, degradation of the environment and emergence of water scarcity. (Shaban and Sharna, 2007). The increase in demand for water as a result of increase in popuation and changes in life style and economic activities has put pressure on water supply systems which is considered as leading to shortages.It is not any kind of water we need, of course, but fresh water. Sea water is of only limited use to us, and out of reach for people living deep inside continent; and drinking it is harmful. For the most part, therefore, we humans must obtain all the water we need from rivers, lakes and underground aquifers (Alia by, 1996). In the world as a whole there was a projected estimate that presently we should be using about 4350 km" (4.35 x 10^{15} litres) of water a year. Of this, almost 60 per cent is currently used for crop irrigation, 30 per cent for industrial processes and cooling, and 10 per cent for domestic use (Raven *et al., 1993).*

Furthermore, the amount available to us, including that in lakes and inland seas, according to Allaby (1996), is in the region of 15 x 10^{18} litres. Given this figure the total world water looks adequate, but it is unevenly distributed, both geographically and in time. Freshwater scarcity on a global level is a reality already today, with the countries of the arid and semi-arid zones already suffering critical water scarcity. For sustainable water management strategy, if building reservoirs to even out variation in surface runoff is expensive, then there is the need of falling back on groundwater abstraction-especially as groundwater represents about 98 per cent of world's usable fresh water. Additionally, this source is relatively pure and is not easily affected by climatic extremes in the way that surface sources are subject to extreme temporal and spatial variations (Hamill and Bell, 1986).

Therefore, the alternative is to develop the ground water resource, especially as its development is not so capital intensive as that of a large reservoir. Besides, a groundwater scheme can be introduced gradually to keep pace with demand and a degree of flexibility is possible. Management of groundwater resources is a comprehensive term that encompasses both the routine day-to-day aspects of well field operations, and the long - term consideration relating to future water demand, potential sources of supply, economics and other related matters. Some of the routine aspects of groundwater management considered and examined are the workings of the recharge/discharge mechanisms of groundwater; proper and effective siting of wells for maximum yield; monitoring of groundwater; adoption of conjunctive use approach in very demanding areas, so as to appropriate the differing characteristics of surface and groundwater in order to optimize the yield of the total water resource; and employing of groundwater modeling technique by using a simple regression mathematical model.

It is because of the importance of groundwater that this Paper on Review "Sustainable Water Management strategies in Semi -Arid and Arid Regions" reviews the planning, development and management of groundwater resource as a veritable and potent source of water supply.

2.0 Characteristics of Arid and Semi- Arid Region

Arid and semi- arid regions are distinguished on the basis of their annual precipitations sums and vegetation include:

1. Deserts with an annual precipitation sum < 50mm/year arid devoid of vegetation.
2. Arid regions with 50 - 250mm/ year precipitation and sparse vegetation, and
3. Semi- arid regions with a precipitation sum of 250 to 500mm per annum and a steppe savannah praire/ pampa vegetation.

Most deserts and (semi-) arid regions occur between 10° and 35° latitude (e.g. Sahara desert, Kalahari desert) in the interior parts of continents (e.g. Australia, Gobi desert) and in rain shadow areas in fold belts (e.g. Peru, Nepal). Large parts of the arctic tundra receive less than 250mm precipitation per annum and qualify as "arid region" too.

Important geomorphic processes in the dry regions of the world differ from those on more humid environments:

1. Streams are intermittent or ephemeral (and have very irregular discharges),
2. Mass - wasting processes (associated with strongly accidental terrain, e.g. where tectonic up lift has created mountains and in areas with steep fault scarps or incised valleys- often produces erosion landforms, such as residual hills or mountains that remain as isolated features in low - relief plain) and unconfined sheet floods are prominent,
3. Many rivers do not debauch into the sea but end in inland depressions without outlet, e.g. River Okavango in the deserts of Botswana just disappears - gets absorbed,
4. Salt lakes are common landscape features,
5. Aeolian processes play an important role, particularly in area below the *150 mml* year isohyet , and
6. Physical weathering processes are prominent whereas hydrolysis of minerals is subdued (Adeleke and Leong, 1986).

2.1 Shortage of Water

According to the assessment made by the United Nations on world's water resources, the available water resources, globally, are found to be continuously declining as a result of excessive withdrawal of both surface- and groundwater. Also contributed to the decreased water run-off due to reduced precipitation and increased evaporation. Global warming has. Already, in many parts of the world, such as West Asia, the Indo-Gangetic Plain in India, the North China Plain and the High Plains in North America, human water use exceeds the annual average water replenishment. Use of freshwater for agriculture, industry and energy has increased markedly over the last 50 years. (Balasubrian, 2017)

More seriously over 2.8 billion people in 48 countries will face water stress by 2025, based on United Nations medium population projections

There are more than 45 000 large dams in 140 countries. About two-thirds of these dams are in the developing world, with half present in China. These dams, with an estimated potential storage volume of 8 400 km3, impound about 14 per cent of global run-off as estimated (Vörösmarty et al 1997). To enhance international cooperation in addressing the exploitation and degradation of water resources, the United Nations proclaimed 2005–2015 as the International Decade for Action, "Water for Life." A major challenge is focusing attention on action oriented activities and policies directed to sustainable management of the quantity and quality of water resources, in the world.

It has been found that there are five major drivers demanding a huge expansion of water resources in the 20th century. They are population growth, industrial development, expansion of irrigated agriculture, massive urbanization and rising standards of living. Almost 20% of the world's population or more than 1 billion people lack access to safe drinking water. Their distribution is as follows:

1) 406 million people in East Asia and the Pacific

2) 229 million people in South Asia

3) 314 million people in sub-Saharan Africa

4) 38 million people in the Middle East

5) 49 million people in Latin America and the Caribbean (Balasibranian, 2017)

3.0 Sustainable Water Management in Semi -Arid and Arid Regions

Sustainable development or Sustainability, according to "Brundtland Report" of the WCED (1987), is defined as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs". Accordingly, "Sustainable Water Management in Semi- Arid and Arid Regions" is the ability to manage water resources in a manner that ensures constant and sufficient supply of freshwater to the populace without depleting the reservoirs, especially in areas that recharge of water is slow and insufficient due to little rainfall. In this connection, in the semi -arid and arid region, where the land is very dry and unproductive due to little rain, the usage and management of water resources should be carried out sustainably so that there be conservation and fair distribution. According to WeED (1987), this fact is expected to entrench environmental considerations; commitment to equity; ability for the water resources to last or continue to exist so as to ensure sustained water supply; and achievement of high quality of environment, life, states, of people's health, and quality of work.

3.1 Global sustainability problems in the water sector

In order to identify the big and potentially existential problems of whole regions we have to look for globally spread negative trends. In this sense the most important non-sustainable development trends are:

i. the overexploitation of groundwater basins
ii. the reduction of low flows of rivers,
iii. the destruction of wetlands,
iv. the salinizaiton of soils and
v. the pollution of aquifers with persistent pollutants

Worldwide about 800 km^3/a of fresh water are abstracted from aquifers. About a quarter of this abstraction is not sustainable in the sense that it is not replaced again by recharge. That means it is covered by emptying the storage. On the Arabian Peninsula, in North Africa, Northern China, or the dry west of the United States large quantities of water have been abstracted for large scale irrigation. They cannot be recharged again under present climatic conditions in the foreseeable future. (Kiezalbac et al, 2017)

Due to the consumptive use of water (i.e. use during which water is evaporated) in irrigation of the upstream regions of catchments, the remaining flows in the downstream are considerably reduced. Even big rivers such as the Yellow River in China become ephemeral. In recent years the Yellow river did not flow for more than 100 days on a stretch of several hundred kilometers. The most extreme example is probably the Amu Darya, which has so little water left that the Aral Sea is drying up. The shift of availability of water from the downstream to the upstream contains considerable conflict potential in international catchments.

A related problem is the drying up of wetlands. The global wetland area has been halved between the year 1900 and today. This has a dramatic impact on biodiversity. The tendency is a direct consequence of the competitive allocation of land and water resources to nature and agriculture, which continues undiminished.

Of the worldwide 260 million ha of irrigated agricultural land about 80 million ha are more or less affected by soil salinization. Salinization is a common phenomenon in hot and dry climates. It occurs if evapotranspiration deposits more salt than can be carried away by drainage. The most common mechanism responsible for salinization is based on the groundwater table rise associated with the seepage of irrigation water. If the groundwater table comes within a distance of less than 2 m from the surface capillary rise leads to direct evaporation of water from the groundwater table and consequently deposition of salts dissolved in it at the top soil level.

Finally the pollution of groundwater by persistent pollutants has to be mentioned. One might think of chlorinated hydrocarbon solvents, which is probably still true for the industrialized countries. Worldwide, however, salt is the most important pollutant, especially in arid regions and in coastal areas where salt water intrusion occurs.

In principle all these violations of the principle of sustainability are reversible, however on time scales of several generations. Therefore they are for all practical purposes irreversible (Kinzalbach et al, 2007).

3.2 Global Water Management Concepts

Pressure on global water resources is increasing in an unprecedented manner, and therefore, sustainable groundwater management practices gain importance more than ever before. Although there are many procedures, formulations, and algorithms for sustainable aquifer management (AM), still there is a great need for effective, practical, and applied methodologies. A large number of different approaches including numerical models and their software are available for ready uses, but sustainable water management needs special attention for successful local applications. It is practically impossible to provide a general definition and solution to cover different management strategy, because each AM requires solutions under special, local, and environmental conditions, which may not be exactly valid for other regions. Sen (2015). While many theoretical groundwater management models consider a single aquifer serving a specific group of consumers, a groundwater utility or other resource manager must typically decide how to simultaneously manage multiple aquifers in real world situations. (Roumasset and Wada 2013).

The report on the findings of Phase One of the UNESCO-WWAP Water Scenarios Project to 2050, shows the importance of global water management options. It has been concluded that global water management has to address two fundamental categories of uncertainty.

The first one is related to water supply, which is dependent on the geophysical parameters that dictate water availability (precipitation, runoff, infiltration, etc.) as well as on the impacts of human activities that affect the natural flow of water (e.g. how land use affects storm water runoff) and water quality.

Conventional analysis of historical data coupled with stochastic analysis until now has provided a fairly good basis for examining extremes and sensitivities, robustness, resilience and reliability under past climate variability. For water managers, this is the

starting point for any realistic analysis, and these kinds of analyses are being done routinely in most managed systems.
The second category of uncertainties relates to variability and the rate of growth in water demands. The number and intricacy of choices seem to be growing beyond leaders' abilities to analyze and make decisions. For example, unforeseeable trends in the rising demand for all goods and services, including energy, affect water in some way through production, transport or disposal. This creates new uncertainties and associated risks for water managers.

4.0 Overview of Water Need and Management

A brief exposure to a water shortage at home or a short stay in an area where supply is In short supply is a stern reminder of our dependence on water for survival and for the enjoyment of a high standard of living. For instance, according to Ehrlich *et* al (1972), a United State suburbanite experiencing water shortage first sacrifice the sparkling appearance of the car, then the lawn and shrubs, then a high level of bodily and domestic cleanliness. Those of us living in water -scarce area or water - scarce seasons have not reached the point where such sacrifices can be made. First, we must fit our food growing to our water supply, then water for animal feeding, then whatever can be spared for bodily and domestic cleanliness. What cannot be spared is shared. In semi-arid and arid zones where water supply is very scarce, maximum beneficial use is made of the resource. The quality requirement is that the quantity requirement is met by whatever is there. These are acceptances of compelling necessities, rather than a lack of joy for clean and abundant water. It therefore calls for the improvement of the management of water resource of all communities.
Effective water management becomes much more apparent since water is so unevenly distributed both geographically and in time- although the total world water looks adequate. Apart from the inconvenient geographical distribution of runoff there is also an uneven distribution in time. This brings about age-old problems with water supply -floods and drought. That is, much of the total flow being concentrated in a few month of wet seasons leaving the rest of the year in dry spell. There is therefore the need to even out the flow by catching floodwater during the wet season and releasing then during dry periods, again, this has brought the necessity of rational management to meet rising usage of water in domestic, industrial, agricultural, public services, and recreational areas become more evident. Across the world one-third of the land area is well watered, and two -thirds are arid to semi-arid, (Ehrlich *et et.*, 1972). This is a challenge to water managers in the latter group and calls for dedicated, effective and efficient management of the resource - water.

4.1 The Hydrosphere

The term 'hydrosphere' refers to the sphere of water on earth. It refers to the water on or surrounding the surface of the globe. It is the segment that includes all forms of water distributed over atmosphere, lithosphere, and biosphere. Indeed water makes up to 70% of the earth's surface. Water is not only present is seas and oceans, but also as ice caps glaciers, rivers, lakes, reservoirs, soil water, ground water and atmospheric water vapour. Similar to the variation of pressure and temperature with reference to altitude in atmosphere, there is a remarkable variation in the physic-chemical properties with reference to the depth of water masses. The average annual rainfall over land amounts to 119 000 km3. Out of this, some 74 000 km3 of water gets evaporated back into the atmosphere. The remaining 45 000 km3 of water flows into lakes, reservoirs and streams or infiltrate into the ground to replenish the subsurface formations. This represents what is traditionally known as the "water resources of the world". Not all of these 45 000 km3 are accessible for human use. This is due to the reason that part of the water flows into rivers and during seasonal floods. An estimated 9 000 - 14 000 km3 of water alone may be economically available for human use and consumption. The actual annual withdrawals of water for human use amounts to about 3 600 km3.

4.1.1 Distribution of water on Earth

The earth has about 1.386 billion cubic kilometers of water. In this, about 97% lies in the form of seas and oceans, containing salt water. More than 2% exists as ice caps and glaciers, and about 1% is spread in the form of rivers, lakes, ground water and water vapour. Almost 97% of the water existing in the hydrosphere is distributed as seas and oceans. These are all saline water masses. They are not suitable for direct consumption like drinking, cooking and for industries and irrigational purposes. Only 3% of the water available on earth is fresh water if we look at the further distribution of freshwater alone, almost 66.7% is locked up in the form of ice caps and glaciers. About 30.1% is existing below the surface as groundwater. The surface water, which is directly available on the land surface, is only 0.3% the rest 0.9% exist as water vapour and soil water. The surface water available as 0.3% is shared by lakes, swamps and running water as rivers. In this, a very small proportion exists as biological water.

Table 1: Inventory of World's Water

Reservoir	Volume (million Km3)	Percent of Total	Reproduction Rate Cu.Km/ year
Oceans & Seas	1370	96.5	452
Ice caps & Glaciers	24	1.74	3
Ground water	60	1.74	12
Rivers, Lakes & Swamp	0.2812	0.0132	39
Soil moisture	0.083	0.001	83
Water vapour	0.014	0.001	525
Biosphere	0.0011	0.0001	39
Total	**1454.3793**	**99.9953**	

Source: Balasubramania, 2015

If we look at the inventory of world's water distribution, the

a) Oceans and seas contain about 1370 M.Cu.Km.

b) Ice caps and glaciers contain about 24 M.Cu. km.

c) Groundwater constitutes almost 60.0 M.Cu.Km.

d) Rivers, streams lakes and swamps contain about 0.2812 M.Cu.km.

e) Soil moisture constitutes about 0.083M Cu Km.

f) Water vapour contains about 0.014 M Cu Km and

g) the biosphere contain about 0.0011 M Cu Km. of water.

All of these water masses are called as water reservoirs of the earth. On average water is renewed in rivers every 16 days. Water in the atmosphere is completely replaced once in every 8 days. The replacement is show in lake lakes, glaciers and in groundwater systems. The reproduction rate also varies from one reservoir to the other. It is highest for the water present in the atmosphere and lowest in the ice caps and glaciers Table 1.

4.1.2 Residence time of water in major reservoirs

The residence time of a water reservoir within the hydrologic cycle is the average time a water molecule will spend within that reservoir. It is a measure of the average age of the water in that reservoir. Residence time can be estimated in two ways. The more common method relies on the principle of conservation of mass and assumes that the amount of water in a given reservoir is roughly constant. In this method, the residence times are estimated by dividing the volume of the reservoir by the rate by which water either enters or exits the reservoir. Dating the age of water using isotopic techniques is the second popular method. The following table shows the approximate residence time of water in major reservoirs.

Table 2: Residence time of water in major reservoirs

Major Reservoirs	Approximate Residence Time
Oceans and seas	>100000 years
Glaciers	40 years
Seasonal Snow Cover	0.4
Soil moisture	0.2
Shallow Groundwater	200
Deep Groundwater	10000
Lakes	100 years
Rivers	0.4 years

Source: Balasubramania, 2015

The residence time of water in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation. Deep groundwater may stay over 10,000 years beneath Earth's surface. The Ice from the Antarctica has been estimated to of the age of 800,000 years before present. If the 0.6 per cent of total water that is available as fresh water. About half is celow a depth of snom and so is not practically available on the surface. This means that the stock of the Earth's fresh water that is obtainable one way or another for man's use is about 4 x 10^6 km^3 and is mainly in the ground. Spread over the Earth's land surface it would be about 30m deep, (Wilson: 1990). Accordingly, the data of the four processes of precipitation, evaporation and transpiration surface runoff or stream flow and groundwater flows are needed to predict the most likely quantities involved in the extreme cases of flood and drought Table 3.

5.0 The Hydrological Cycle

According to Harvey and Hallett (1977), the bulk of the water resource of the Earth -roughly

97 per cent in fact -is in the oceans, so our freshwater needs must be met from the remaining 3 percent. Allaby (1996) continues to state that water can exist as either gas or liquid at temperatures commonly encountered near the surface and consequently it is constantly evaporating and condensing again. At any instant there is movement of water between oceans, air and land through a sequence of events known as the hydrological cycle. Since it is a circle, we can break into it at any point. Starting with the obviously exposed water surface of the oceans, lakes and rivers we can envisage the sun's energy falling on them and evaporates some of the water at the surface.

This warm vapour rises and forms clouds, as explained by Harvey and +allett (1977). Some condenses again to form large enough droplets to fall as 'ain on the ocean and sea but other clouds are carried away by the wind over and where they fall as rain. Taking an overall picture both on a global scale and smoothing out seasonal variations we find that quite a large part of the water which falls on the land stays sufficiently near the surface long enough for evaporation to take place and new clouds to form. Some of the water is used by green plants for growth, some seep underground but most run off in streams and rivers to return to the sea. More rain falls on the land than is evaporated from it in any given period and the balance is maintained by a supply of windborne clouds from sea and by runoff water in rivers. The energy supplied by the sun keeps the cycle flowing Table 3 shows the annual fluxes in the global hydrological cycle indicating the various processes.

At present, man tend to meet his needs by drawing on those surface water’s which he can store in artificial reservoirs or by drawing directly from rivers.

Table 3: Fluxes in the Global Hydrological Cycle

SN	ANNUAL FLUX	VALUES (Km^3 x 10^3)
1.	Evaporation	496.0
2.	Ocean	425.0
3.	Land	71.0
4.	Precipitation	496.0
5.	Ocean	385.0
6.	Land	111.0
7.	Runoff to Oceans	41.5
8.	Rivers	27.0
9.	Ground water	12.0
10.	Glacial melt water	2.5

Sources: Nelson (1992)

5.1 Factors controlling Hydrologic Cycle

Several factors control the circulation of water on the earth. The following are the major factors, controlling the hydrologic cycle:

1. Nature and application of energy that promotes circulation.
2. Inherent properties of the water, air and other masses
3. Structure of the natural reservoirs and their conduits (channels) promoting movement

4. The earth's gravitational attraction, which is responsible to activate the flow.

The hydrologic cycle has a direct link with the monsoon cycle of a region. Any drastic climatic variation or climatic changes that are occurring on the globe will have a direct consequence on the circulation pattern of water on the earth. The weather, configuration of the land (topography), and human activities greatly alter the hydrological cycle. For instance, rainfall is influenced by wind: on and topography. Storms of lesser intensity but longer duration may produce a large volume of precipitation (Ayuba, 2005). According to UNEP-GEM (1992), rapid population growth and expanding economic activities are already putting enormous pressure on global water resources. The large water requirements of household, industries, and farms increasingly exceed local supplies. Industrial wastes and the intensive use of fertilizers often overload water supplies with dangerous chemicals, while poor irrigation practices raise soil salinity and evaporation rates, putting a great pressure on water resources.

Meanwhile, the need for neighboring nation to share water resources raises the spectra of political conflict. As there is reduced precipitation due to sparse rainfall, freshwater storage serves, primarily in the form of groundwater, steadily shrinks. Also, large variations in precipitation from year to year or an increase in extreme events such as drought and floods undermine the reliability of many critical sources. In river basins, worsening droughts combined with the over-exploitation of water sources causes' salt to leach from the soil, again, raising the salinity of the unsaturated zone (the layer between the ground and the underlying water table). These various effects have extremely negative consequences for river. Balasubramanian (2017).

6.0 Water Resource Conservation and Management

According to Allaby (1996), water is a so-called "renewable" resource. After it has been used it returns to the hydrological cycle and in time it will be used again. It is also abundant globally and the oceans are so vast that their capacity for absorbing, diluting, and detoxifying pollutants is immense. Despite this, the provision of wholesome freshwater and the hygienic disposal of liquid waste in the impoverished semi-arid regions of the world are woefully inadequate. It is there treating fetching water for ordinary domestic use involves arduous hours of walking and carrying, mainly by women and children, and where debilitating water-borne diseases are common.

The resource is renewable, but distributed unevenly, and its efficient management requires an elaborate infrastructure of reservoirs, treatment plant, declines, and sewerage, coordinated within an overall strategy by an authority the power to prevent abuses. For people in those regions (arid), improvements a living standard depend crucially on the establishment of such strategies for later management, and once living standards begin to raise it are inevitable that *the* demand for water will increase substantially. As rising demand encounters. It's in the supply available; conflicts may ensue, as they have already between Syria and Jordan over abstraction from the river Jordan. This is one of the most challenges facing us (Allaby, 1996).

In addition long term droughts do have serious consequences on available water resources. This could advisedly affect the level of upper ground water and earn flows, as well as the underground water. They also affect the level of large lakes, thereby affecting riparian access as in Lake Chad, which has receded beyond the borders of Nigeria (FGN, 2000). It is therefore toward promoting sustainable utilization of water resources in the dry-lands that Nigeria Established River Basin Development Authorities (RBRDAs) under the supervision of the Federal Ministry of Water Resources. These are actively involved in development of water resources (surface and underground) for multipurpose use with particular emphasis on the provision of irrigation infrastructure and the control of floods and erosions and for watershed management. The RBRDAs are also involved in the construction, operation and maintenance of dams, dykes, wells, boreholes, irrigation and drainage systems. Also, the Federal Government of Nigeria, with World Bank has distance, as also implemented a programme tagged National Fadama Development Project for the purpose of optimally utilizing the water resources of the wetlands of Nigeria for small scale irrigation (FGN, 2000). Consequent upon the above, there is the need to manage and conserve freshwater in a sustainable manner. This has to be carried out in effectively harnessing the various processes of surface water, groundwater and precipitation.

6.1 Surface Water and Groundwater Management

Pressure on global water resources is increasing in an unprecedented manner, and therefore, sustainable groundwater management practices gain importance more than ever before. Groundwater management deals with the complex interaction between human societal activities and the physical environment, which pose an extremely complex and difficult problem to solve for the benefit of all parties involved. Those using aquifer are little motivated to preserve it; any preservation may simply be exploited in future by other individuals. Although there are many procedures, formulations, and algorithms for sustainable aquifer management (AM), still there is a great need for effective, practical, and applied methodologies. A large number of different approaches including numerical models and their software are available for ready uses, but sustainable water management needs special attention for successful local applications. It is practically impossible to provide a general definition and solution to cover different management strategy, because each AM requires solutions under special, local, and environmental conditions, which may not be exactly valid for other regions.

There are difficulties caused by the generally predictable annual cycle of runoff, where in much of the total flow is concentrated in a few months of wet season, and by unpredictable year-to year variation in the exact timing of this pattern and in the total annual flow. To even out the flow by catching floodwater and releasing them during dry spells, dams are built along most of world major rivers. However, increases in available flow achieved by means of reservoirs are bought at the expense of increased loss by evaporation, because of the large surface area of the reservoirs (Ehrlich *et al., 1972).*

In this connection, hydrology should be employed as an application in engineering. For instance, to the practicing engineer concerned with the planning and building of hydraulic structures, hydrology becomes an indispensable tool. Suppose, for example, that a city wishes to increase or improve its water supply. The engineer first looks for sources of supply; having perhaps found a clear uninhabited mountain catchments area, he must make an estimate of its capacity of supplying water. How much rain will fall on it? How long will dry period be and what amount of storage will be necessary to even out the flow? How much of the runoff will be lost as evaporation and transpiration? Would a surface storage scheme be better than abstraction of the groundwater flow from wells nearer the city? The questions do not stop there. If a dam is to be built, what capacity must the spillway have? What diameter should the supply pipelines be? Would afforestation of the catchment area be beneficial to the scheme or not? These are planning and development strategies of managing water put in questions form by Wilson (1990).

If it is considered that building reservoirs to even out variation of surface runoff is expensive, then there is the need of falling back on groundwater abstraction. According to Ehrlich *et al.* (1972), in this connection, reservoirs of groundwater (aquifers) are recharged naturally by seepage from the surface and underground flows at rates that depend on the permeability of surrounding rock and soil. When the rate of withdrawal of groundwater from aquifer exceeds the rate of recharge over a period of time, the water table falls. When this happen too far below the surface, extracting the water become altogether uneconomical. In practical terms, water in such cases is a non-renewable resource that has been mined out. Such declines do not only represent the long term loss of the accessible groundwater resource, but they also can lead to the reduction of surface stream flow, the drying - up of ecologically important ponds and bogs, the Intrusion of saltwater into freshwater aquifers and subsidence.

Goudie (1986) supports that lowering the water table considerably causes ground subsidence due to the reduction in volume of the material comprising the saturated layer as this dries. Between 1865 and 1931, groundwater abstraction in London caused the ground to subside at 0.91-1.21mm per year, producing a total subsidence 0.06-0.08m. In Tokyo, the ground subsided 4m between 1892 and 1972, at a rate of 500mm per year, and Mexico City is sinking at 250-300 mm per year for the same reason. In the views of Wilson (1990), civilization is primarily depended on water supply. As the trend towards larger cities and increasing industrialization continues, so will be an increased need in water supply to meet the demand of anger populations for drinking, sanitation, irrigation, and industry and power generation. If water supply has to be extended to siting of industry and agriculture, for instance, the type and extent to be practiced have to be known the size of population that can be supported, and then a broader scheme has to be envisaged. In such a scheme, development of water resources over a whole river basin or geographical region may be considered.

Perhaps, as the last resort, water transfer scheme should be employed to augment water resource management, as in the case of transferring water from River Gurara to Lower Usuma in Abuja, and the Lake Chad Basin Commission plan to resuscitate Lake Chad by transferring water to it from central African basin. Accordingly, Minklin (1994) contends that whereas it is wrong to reject giant engineering project to solve water problems in arid regions outright (e.g., long-distance importation of water from other drainage basins to the Aral Sea watershed), because of huge cost, potential major environmental problems, lengthy implementation periods, inflexibility of design to adjust to changing conditions and political difficulties, such schemes should be avoided and contemplated only as last resorts.

6.1.1 Development and Management of Groundwater Resource.

In the wake of the declaration in 1980 by the World Health Organization of the International Decade of Drinking Water and Sanitation, Hamill and Bell (1986) stressed that the importance to mankind of a continuous clean supply of water could not have been demonstrated more effectively. Unfortunately, many surface sources of water are subject to extreme temporal and spatial variations, hence the limitation in this source of water to meet the objective of the aforementioned declaration. On the other hand, groundwater represents about 98 per cent of the world's supply of usable fresh water. This source is usually relatively pure and is not allowed by climatic extremes in the way that surface sources are. The challenge is to develop the groundwater resource. Furthermore a ground water development scheme is not so capital intensive as that of a large reservoir project. Another advantage is that a groundwater scheme can be introduced gradually to keep pace with demand and a degree of flexibility is possible. Because of the importance of groundwater supplies there is the need for groundwater specialists whose sole function is to plan, develop and manage groundwater resources. This should be an interdisciplinary undertaking involving geologist, civil engineers, environmental scientists, mathematians, chemists and water well contractors, for example.

6.1.2 Groundwater Resources:

Groundwater is one of the important reservoirs of water on earth. It is the water stored in the pore spaces of subsurface geological formations. The subsurface/vertical distribution of groundwater is divided into two zones as, zones of aeration and saturation. The zone of aeration consists of interstitial openings that are occupied partially by water and partially by air. In the zone of saturation, all the interstitial spaces are filled with water, under hydrostatic pressure. It is also a fact that on most parts of the land masses of the earth, a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface. The depth of the aquifer also goes into several hundred meters below the surface. The occurrence, distribution and movement of groundwater depend on the hydrological properties of the geological formations. The hydraulic properties of soils and rocks depend on the sizes and shapes of the void spaces. These may vary over very short distances. The water bearing geological formations are called as aquifers. Groundwater gets replenished through natural recharge from rainfall. This system supplies water for a major portion of population all over the world. This resource gets depleted due to over exploitation. Springs are seepages coming out of where groundwater touches the surface.

Groundwater has its own residence time. The residence time of groundwater depends on several factors including seasonal inputs from rainfall and output as base flow. The base flow consists of water that infiltrates into the ground during and after a rain storm. It also relates to the sustaining stream flow during dry periods and between storm flows. The source of base flow is the groundwater that flows through unsaturated and saturated soils and cracks or layers in bedrock or other impermeable layers adjacent to the stream. Table 1 shows the estimated amount of water available if it could all be released from storage. Only 0.6 per cent of the total water resources of the world are in the form of groundwater. According to Huisman, 1972) and Wilson (1990) not all this is available for exploitation since about half is below soon and therefore is too deep for economic utilization. However, the capacity of the underground resource should not be underestimated; about 98 per cent of the usable freshwater of the Earth is stored underground. By any standard 8250 x 10^{12} m^3 is a lot of water.

Since groundwater is so invaluable to mankind, the processes for its sustenance and recharging must be of importance. According to Hamill and Bel, 1986), the proportion of rain water that manages to gravitate to the water table may be referred to as natural groundwater recharge, as it is a natural part of the hydrological cycle. This is totally different from artificial groundwater recharge. In which water is pumped down wells or spread on the ground surface so as to reduce infiltration, and increase the amount of water that enter aquifers (Taylor 1963). Artificial recharge may be undertaken, according to Hamill and Bell (1986)

1. Supplement the amount of natural recharge to aquifer.
2. Store water underground for retrieval some time later.
3. Optimize water use in an area which suffers seasonal water shortages.
4. Prevent large reductions in groundwater level as a result of over-abstract-o and thus reduce the possibility of ground subsidence and saline intrusion.
5. Improve the standard of water in a poor quality aquifer.

Most groundwater is derived from precipitation, so infiltration and percolation are the means by which water reaches the water table (Dunin. 1976). However, not all the precipitation that falls to a land surface becomes infiltrated. Some is intercepted by the vegetation cover and never reaches the ground. While some proportion is lost as evapotranspiration. According to Hamill and Bell, (1986), increased precipitation does not necessarily translate into increased water table level as there is water balance mechanism. The water balance techniques provide a useful insight into both groundwater recharge and aquifer characteristics. For instance, the wet season surplus and dry season deficit means that fluctuations in groundwater level usually follow an annual pattern, with the maximum elevation of the water table being recorded during wet season and the minimum value during the dry season. However, groundwater recharge which caused an appreciable rise in water level may discharge or spill into the river system instead, so that the subsequent rise in the water table is small. During periods of low groundwater levels the river may recharge the aquifer, thus preventing any further decline.

It should be stated that generally, and under natural conditions, most aquifers discharge either directly or indirectly to rivers and seas by way of seepage and springs. This is distinct from artificial discharge which takes place as a result of man's intervention in the natural cycle of groundwater movement. The groundwater discharge which becomes the base flow of a river is the outflow from unconfined or artesian aquifers bordering the rivers, which go on charging more and more slowly with time as the differential head falls. The linkage go a bit further as details pertaining to groundwater quality may throw some light on such factors as the interconnection between surface water and aquifers, groundwater movement and storage (Hamill and Bell, 1986).

6.1.3 Maximum Yield Wells:

There are many considerations that influence ~he siting of a well in an aquifer. Some may be concerned with politics, economics, access, or water distribution. However, from the hydrological point of view, the long-term yield of a well depends upon the following factors, according .o Hamill and Bell (1986)

1) The annual rate of groundwater recharge: This determines the rate of

flow in the aquifer and thus the amount of water available for abstraction.

2) The location of the well in the aquifer: There may be some advantage in siting the well near to a recharge area, so that a surface water resource is diverted underground to augment aquifer flow by induced infiltration. This could increase well yields.
3) The permeability of the aquifer in the area surrounding the well the higher the permeability the easier it is for water to flow to the well during period of abstraction.
4) The thickness of the aquifer at the well site: The well should be located where the saturated thickness is greatest.
5) The location and orientation of any faults or notable discontinuities: These may act as preferred flow channels and greatly increase the flow to a well.
6) The location of wells with respect to any features that may jeopardize the quality and quantity of the discharge, or the groundwater resource as a whole: It is important that a well should be able to operate at its design discharge and drawdown without the quantity and quality of the abstracted water being adversely affected, and without the abstraction having an adverse effect upon ecological or environmental features or resulting in the derogation of existing groundwater sources.

6.1.4 Groundwater Monitoring:

The routine monitoring of groundwater level and water quality is a fundamental part of aquifer management (Tester and Harker, 1981; Tester and Harker, 1982). Not only does this provide an early warning system for pollution incidents and phenomena such as over- abstraction, induced infiltration and saline intrusion, it also provides essential background data that may be required for compression purposes as well as information that is vital to the effective management of the aquifer. Todd *et at.* (1976) outlined a method of groundwater quality monitoring which consisted of a number of steps taken in a given order. The method has been described subsequently in much more detail by Everett (1981). Because groundwater recharge and the subsequent flow of water through the aquifer is a slow and imprecise process, it is not always possible to calculate the perennial yield accurately. However, a detailed analysis of the chemicals present in the groundwater and the changes that occur over a period of many years, may give a valuable insight into aquifer recharge-discharge mechanisms. This may also indicate whether or not the aquifer has reached a fully developed state and if any alterations to the long-term management objectives are necessary (Edmunds and Walton, 1983).

In almost all situations where groundwater monitoring is undertaken, it is important that adequate background samples are obtained before the groundwater abstraction scheme, waste disposal operation, or whatever, is inaugurated. Without this background data it will be impossible to assess the effects of the new development. Thus routine all-year-round monitoring is essential. It should also be remembered that groundwater can undergo cyclic changes in quality, so any apparent changes must be interpreted with caution (Pettyjohn, 1982). Pfannkuch (1982) considered unanticipated contamination and pointed out that the first important step in designing an efficient groundwater monitoring system is the proper understanding of the mechanics and dynamics of contaminant propagation (e.g.

soluble flow), the nature of the controlling flow mechanism (e.g. saturated flow) and the aquifer characteristics (e.g. permeability, porosity).

6.2 Conjunctive Use:

The increasing acuteness of water scarcity problems, worldwide, requires the adoption of a double approach of water supply management and water demand management. Conjunctive Water Management is intended as the efficient utilization of all freshwater resources existing in a specific basin – surface waters, groundwater shallow and deep, but also rainfall, treated wastewaters and other non-conventional sources – according to an overall strategy aimed at improving water availability and reliability. It is crucial for integrated water resources management and helpful to reduce vulnerabilities of water supply systems and mitigate the water supply stress in responding to climate change. Conjunctive management means using resources in harmony to maximize and stabilize long-term supplies. It does not mean maximizing the use of two separate but interrelated resources for unsustainable short-term gains. Conjunctive management includes two main practices: (i) integrating surface water diversions and groundwater withdrawals to maximize efficiency and minimize impacts on other resource users and ecological processes; (ii) capturing surplus or unused surface water and injecting or infiltrating that water into groundwater aquifers in order to increase recharge rates. Surface water and groundwater are inextricably linked; understanding of their interactions is essential for developing effective conjunctive water resources management strategies, especially for adaptation to growing climate variability and change that can result in significant impacts on regional and global surface water and groundwater resources. Using groundwater as a complementary source of water has provided an effective means to satisfy the ever-increasing water demands and deal with surface water shortages problems due to the robust capability of groundwater in responding to climate change (Zekâi, 2015).

According to Hamill and Bell (1986) the use of surface reservoirs to regulate river flow, usually for the benefit of downstream abstraction and water treatment works, is quite common. The idea of using groundwater for the same purpose is not so well known. The combined use of surface and groundwater in this fashion is known as conjunctive use. By adopting a conjunctive use approach the differing characteristics of surface and groundwater can be used to optimize the yield of the total water resource. For instance, surface waters are available seasonally, but usually some uncertainty surrounds the time and amount available. Additionally, surface systems are characterized by floods that cannot be captured by impounding reservoirs or used for water supply. While surface reservoirs can be filled rapidly, they are subject to losses by evaporation and seepage. On the other hand, groundwater is usually available in large aquifers in large quantities, with relatively little variation over time. Groundwater reservoirs tend to react comparatively slowly to changes in inflow or outflow. Thus, less uncertainty is involved in predicting future groundwater availability than in predicting surface stream flow. A conjunctive use approach to water supply aims to manage jointly the surface and groundwater resources of an area to obtain a net gain in yield. As demand levels increase towards the upper limits of available reservoirs, a conjunctive use strategy becomes more and more attractive (Maknoon and Burges, 1978).

A detailed treatment of the concept of the integrated use of surface and groundwater, and of optimizing the resources of a particular area was provided by Downing *et al.* (1974). Some of the considerations involved in the design and operation of a conjunctive use scheme include the following:-

1. Groundwater can be used to augment river flow during the dry part of the year or during drought.
2. The drawdown experienced by the aquifer and thus the time required for groundwater levels to recover, will depend not only upon the properties of the aquifers but also the level of river regulation adopted, for example 60,70,80,90 per cent of mean flow.
3. Some idea regarding the rate at which groundwater levels will recover naturally can be obtained from a consideration of the aquifer response time. This parameter also gives an indication of the seasonal variation in groundwater flow to a river. The response time can be defined as T/SL^2 where T is the coefficient of transmissibly, S the coefficient of storage and L is the distance from the river to the impermeable boundary of the aquifer or to a groundwater divide which is parallel to the line of the river (Oakes and Wilkinson, 1972; Downing *et al., 1974).*
4. Groundwater levels could be increased during periods of surplus river flow -wet season - using artificial recharge techniques if natural recharge is insufficient or too slow.
5. The efficiency of the conjunctive aquifer-river system is expressed as the net gain that is the net increase in river flow taking into account any reduction in river flow that occurs as a result of groundwater abstraction. Thus,

Net gain = Groundwater abstraction rate - Reduction in river flow Groundwater abstraction rate

6. According to Downing *et al* (1974), the best results are obtained when the aquifer has a relatively low permeability and a high storage coefficient (that is a slow response time). Additionally, the wells should be concentrated in restricted areas, to limit the area affected by pumping and hence reduce the length of river over which decreased flow can be expected.

Conjunctive use schemes are quite complex to operate and require a detailed preliminary study to assess their feasibility. Consequently, before deciding to initiate conjunctive use, it should be certain that the advantages of doing so outweigh the disadvantages. The principal merits and demerits conjunctive use are summarized below:

Advantages

1) Optimization of waters use. Employing both surface and underground reservoirs provides a large storage capacity and reduces 'wasted' runoff.
2) Smaller impending reservoirs are needed since ground water storage can satisfy the additional demand during critical drought periods.
3) Greater flood control. Since waters can be transferred from impounding reservoirs to underground storage the level in surface reservoirs can be dropped to allow for increased flood storage.
4) Greater flexibility when responding to an increase in demand, since more than one source as available.

Disadvantages

1) Higher running costs as a result of greater power consumption through increased pumping. This is so because conjunctive use schemes need pumps to recover water from underground, transport it to the river. Monitory costs would also be increased.
2) Decreased pumping efficiency due to large fluctuations in ground water levels. This is most significant when artificial recharge is practiced.
3) Management problems are increased because there is greater variety of options, such as which source to use at any time, when to stop groundwater abstraction and switch to a surface source, when to initiate groundwater recharge and so on. This may mean expensive computer systems are required to operate real time monitoring and to control remotely various pumps, valves and switches
4) Economic assessment of the scheme is more difficult because these are 'lumber of surface and groundwater source that can be used independently or simultaneously.
5) If water is derived from different source at different time the water supplied the consumer may change from soft moorland water to hard groundwater.

As can be appreciated from above, conjunctive use schemes are complex and have some significant disadvantages. Consequently, it may be advisable to not attempt such a scheme unless there is adequate justification, namely a shortage of water that cannot be satisfied by any other reasonable means. If such a scheme is undertaken, than it should be on a small scale initially and models should be developed to help predict future trends select the most appropriate option and generally assist the management process.

6.3 Groundwater Modeling Techniques:

It is possible to assess groundwater recharge and perennial yield of wells and aquifers using modeling techniques (Pinder and Bredehoeft, 1968; Nutbrown, 1976; Connorton and Reed. 1978). Hamill and Bell (1986) defined a groundwater model as any system that can duplicate the response of a groundwater reservoir. The operation of the model and the manipulation of the results are termed simulation. Models are creakingly popular because of the progressive increase in the demand for water which has necessitated more efficient management. When an aquifer is in all early stage of development there may be little or no justification for the use of sophisticated models. As the aquifer becomes fully developed (Le. abstraction -roughly equals the recharge) then the need to optimize the management of the groundwater resource naturally leads to the adoption of models to predict the consequences of different regimes of pumping.

In the view of Hamill and Bell (1986), model is any system that can supplicate the response of a groundwater reservoir, regardless of whether the cases of the model are physical (that is a scaled - down version of the aquifer) or Mathematical. One of the simplest types of mathematical model is the regression or factor mode\. The objective of such a model is to determine the relationship between two or more variables by conducting a regression or least squares analysis on the data. This effectively achieves the same result as plotting the data and drawing the best fit line through the points. Using regression analysis merely puts this process on a more quantitative basis. The resulting regression equation can then be regarded as a simple model describing the relationship between the variables.

6.3.1 Example of a Simple Regression (or Factor) Mathematical Model (Hamill and Bell, 1986)

A factor model is based upon the assumption that variations in a groundwater resource are determined by the influence of a set of factors. The problem is to determine the response function, y, from a set of factors, X1, X2, X3, X_n. This can be achieved by using regression analysis. A standard computer program can be employed to conduct the necessary calculations, although relatively simple linear regressions can be solved with a calculator. A typical analysis could be concerned with the relationship between groundwater level and abstraction rate, or rainfall and groundwater level as in the example below. **Example:** The first three columns of Table 4 show the annual rainfall recorded at a rain gauge located in the recharge area of an aquifer and the corresponding groundwater level at the end of December. The problem is to determine the relationship between groundwater level, y, and the annual rainfall, x, and to decide whether or not the relationship is significant.

Table 4: Linear Regression Data and Analysis

Year`	Groundwater Level, y(mAOD)	Annual Rainfall, x(m)	XY	X^2	Y^2
1967	69.30	0.8344	57.824	0.6962	4802.490
1968	68.20	0.7490	51.082	0.5610	4651.240
1969	68.45	0.7639	52.289	0.5835	4685.403
1970	66.60	0.6252	41.638	0.3909	4435.560
1971	65.90	0.5928	39.066	0.3514	4342.810
1972	66.25	0.5310	35.179	0.2820	4389.063
1973	64.79	0.4873	31.572	0.2375	4197.744
1974	66.08	0.6025	39.813	0.3630	4366.566
1975	65.96	0.5156	34.009	0.2658	4350.722
Sum	**601.53**	**5.7017**	**382.472**	**3.7313**	**40221.598**
Mean	**66.837**	**0.6335**			

Source: Hamil and Bel (1986)

<u>Solution</u>: The data are used to calculate a regression equation using the simple .near model y=a + bx. Table 4 shows the means and the sums of the cross - products and squares, as well as their individual values. These are 9years of data so N=9

$$\frac{\sum xy - \sum x \sum y/N}{\sum x^2 - (\sum x)^{2/N}} = \frac{382.472 - 5.7017\ x\ 601.53/9}{3.7313 - \quad (5.7017)2/9}$$

b = 11.662 -Regression Coefficient

a = ẏ-bẋ = 66.837 – 11.662 x 0.6335

a = 69.450 - Intercept

Then,

y = a + bx

from the regression equation,

y=a + bx

y=dependent variable (response function)

x= independent variable

a= y-intercept (constant)

b=coefficient (constant)

y = 69.450 + 11.662x - Regression Equation

$$Sx^2 = \frac{\sum x^2 - \frac{(\sum x)^2}{N}}{N-1} = \frac{3.7313 - (5.7017)2/9}{8}$$

$Sx^2 = 0.01489$ - Variable of x

$$Sy^2 = \frac{\sum y^2 - \frac{(\sum y)^2}{N}}{N-1} = \frac{40221.598 - (601.53)/9}{8}$$

$Sy^2 = 2.16724$ – Variable of y

$$R = b\,\frac{Sx}{Sy} = 11.662 \times \frac{0.122}{8}$$

R = 0.97 - Correlation Coefficient

With v= (N-2) or 7 degrees of freedom this relationship is significant at the 5 level. The calculations indicate that the regression equation is;

y= 59.450 +11.662x

While the correlation coefficient is 0.97 Correlation analysis is a statistical method which measures the degree of association between samples of two variables. The correlation coefficient can vary from +1 (indicating complete functional dependence) through zero (independence) to-t (implying complete dependence in opposing directions). If the absolute value of the calculated correlation coefficient exceeds the tabulation value, it can be concluded that the correlation exists and the level of significance represents the probability of having drawn the wrong conclusion. When using the table of correlation coefficients, it should be noted that v, the number of degrees of freedom, is generally taken as 2 less than the number of pairs of data in the sample (Hamill and Bell, 1986).

The result of correlation analysis can be interpreted using the values of the correlation coefficient (r), the coefficient of determination (,-2) as well as the value of the t-test. Using the example above, there is a positive and high correlation between rainfall amount and groundwater level (r=0.97). This relationship indicates that as the value of rainfall amount increases that of groundwater level increases and vice versa. The coefficient of determination (,-2=0.97^2 implies 0.9409=94.09 percent) indicates that rainfall amount is responsible for 94.09 per cent of the contribution in groundwater storage. The remaining 5.91 per cent unaccounted for by rainfall amount can be attributed to other factors other than rainfall, such as soil type, cover condition and groundwater movement.

The result of the analysis is found to be significant at 0.05 confidence limit having a computed t-value of 10.56 greater than the table t-value of only 2.36

7.0 Some case studies

7.1 Overexploitation of the North-West Sahara Aquifer System

The North West Sahara covers an aquifer system which has twice the area of France. It consists of two main aquifers, the deeper Continental Intercalary (CI) and the shallower Terminal Complex (CT) (Figure 1). The water resources of these aquifers are used by three countries: Algeria, Tunisia, and Libya. Today the system has practically no natural recharge anymore. The maximum estimate of recharge is about 30 km^3/a in the outcrops of the aquifers in the Atlas Mountains. It drains to the chotts or terminal salt lakes, which are at the lowest points of the endorrheic basin. There, about 10 m^3/s are evaporated. A small portion of not more than 5 m^3/s goes into the Mediterranean in Libya.

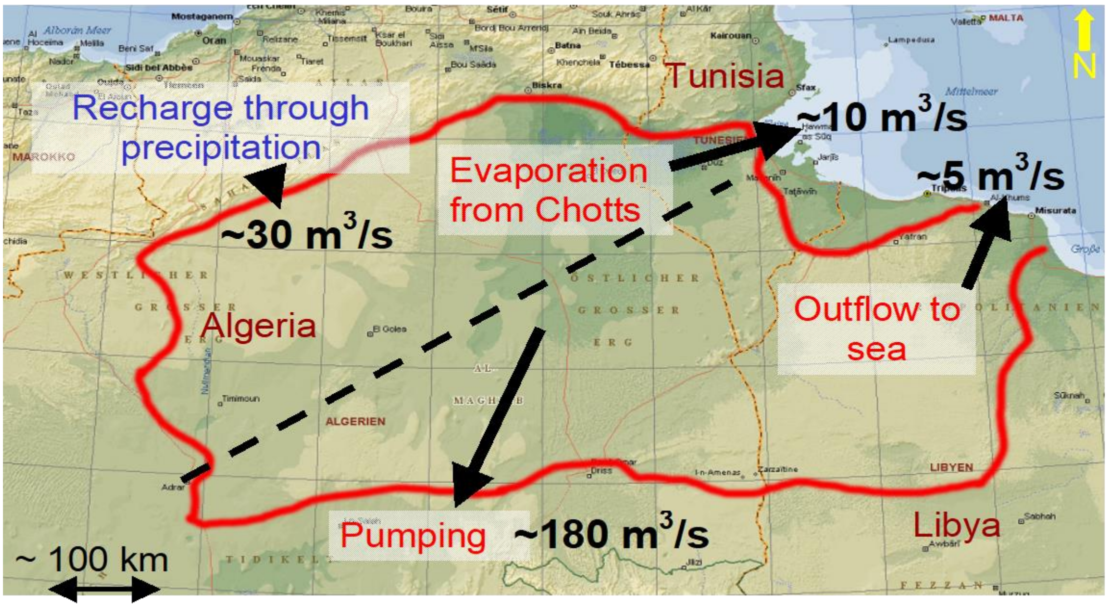

Fig. 1: Overview over the North West Sahara Aquifer System and its water balance (ERESS, 1972)
Sources: Kihzalbach et al, 2007

Till 1959 the water abstraction was small. Since then, however, the population has tripled and the water abstraction for irrigation increased by the same factor. Today, about 180 m^3/s are abstracted.

As a consequence, the large springs close to the Chotts ran dry (Fig. 2) The Artesianism vanished and over large areas where formerly the water flowed out without any energy input now pumping has become necessary.

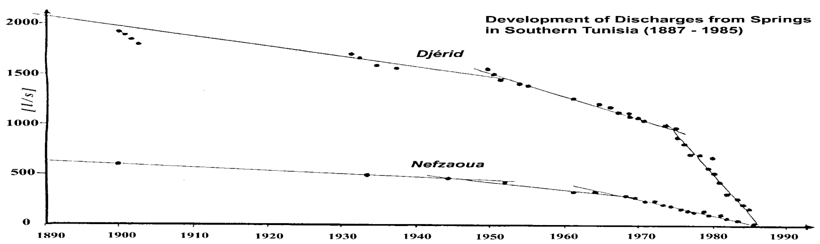

Fig. 2: Development of flow of two springs in Southern Tunisia (1887-1985) (Mamou, 1990)
Sources: Kihzalbach et al, 2007

7.1.1 Water resources management in the Okavango Delta, Botswana

The Okavango originates on the Benguela Plateau in Southern Angola and flows in south-east direction through the Caprivi Strip into Botswana, where an inland delta is formed (Fig. 3). There almost the total flow is consumed by evapotranspiration. The Delta is one of the biggest animal reserves in Africa and an attraction for numerous tourists. The annual floods of the river turn the Delta into a seasonal swamp (Hutchins et al., 1976, Thomas and Shaw, 1991, McCarthy et al., 1993, 2003, Ellery et al., 1993, McCarthy and Ellery, 1994, Gumbricht et al., 2001, 2003)

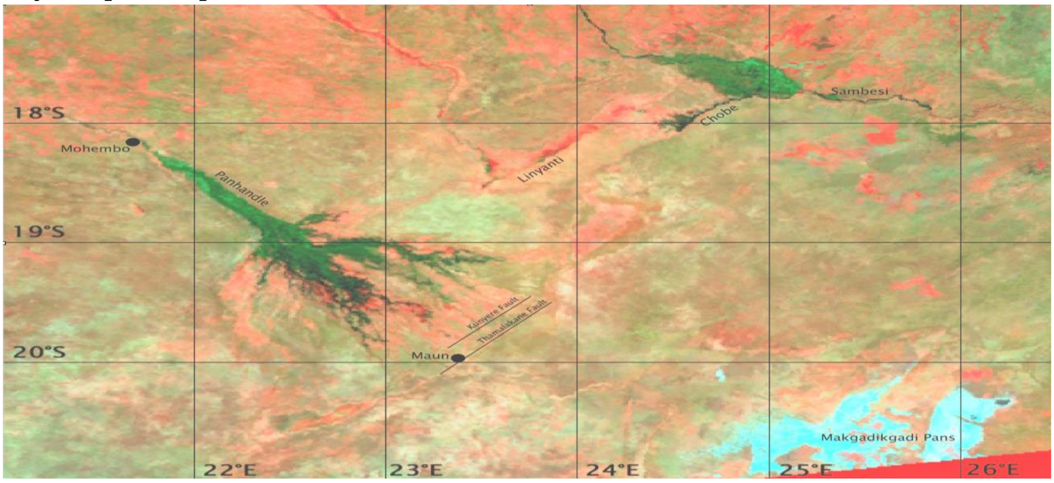

Fig. 3: Satellite image of the Okavango Delta (Length from right to left about 550 km)
Sources: Kihzalbach et al, 2007

As the annual flood wave takes 3 months to proceed from the inflow at Mohembo to the distal part of the Delta at Maun, it is out of phase with the local rainy season. This leads to an essential prolongation of water availability. The countries in the upstream are discussing plans to abstract water from the Okavango or build dams for both power generation and irrigation. In Botswana several sectors of the economy have proposed a more intensive utilization of the Okavango water both for agriculture and mining. All these measures threaten the Delta in its existence. Abstraction in the upstream and acceleration of the flood propagation by canalization lead to a decrease and a redistribution of the seasonally flooded swamp area.

In order to assess the impact of hydraulic measures on the flooded area a numerical model with a 1 km by 1 km raster was constructed (Bauer, 2003, Bauer et al., 2006), which couples surface and groundwater in two layers separated by the topography. In the surface water layer the flow is described by the Darcy-Weissbach law, while in groundwater and dense growths of papyrus Darcy's law is used. The average water level in a cell determines whether the cell is flooded and therefore transports also surface water, or whether there is only groundwater flow. The exchange between the surface and groundwater layers is essential as groundwater is supplying the trees on the islands with water. Satellite data on the time varying size of the flooded areas over 20 years were used in the model calibration. Other data applied were the inflow at Mohembo, precipitation from Meteosat data (according to Herman, et al., 1997), evapotranspiration from the multispectral NOAA AVHRR sensor (with the method from Bastiaanssen et al, 1998a,b) and finally local hydrographs which are measured routinely by the Department of Water Affairs. The model is capable to reproduce the seasonal dynamics both in the average flooded area of the Delta as well as in its temporal variation (Fig. 4). The final sink for all the water is evapotranspiration via the vegetation or evaporation from water surfaces. These processes determine also the distribution of salt in the Delta. Salt crusts in the centers of islands show where the natural storage sites for salt are. Their continued functioning is essential for keeping the rest of the Delta fresh.

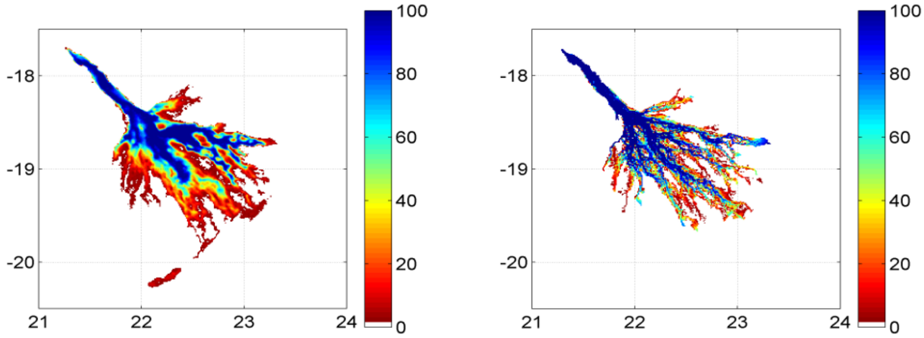

Fig. 4: Observed (left) and modeled (right) flooding frequencies (%)
Sources: Kihzalbach et al, 2007

An example of measures with potentially serious repercussions on the Delta is the abstraction of water in the upstream. Computation runs comparing the evolution of the seasonal swamp area with and without abstractions are shown in Fig. 4. Computations show that an abstraction is magnified as the relative reduction of swamp area is twice as large as the relative reduction of the inflow. Dams in the upstream have both the effect of inflow reduction as well as a temporal redistribution of flood water. Morphological changes by dredging of channels or cutting of the papyrus also have a pronounced effect, not so much on the total area of the Delta as on the redistribution of the flooded area within the Delta.

The local abstractions for private households both from the aquifer and directly from surface water are so small, that their impact is negligible. If one ranks the anthropogenic and natural impacts on the Delta's size by influence and magnitude, the following list in direction of decreasing impact can be given:

- abstraction larger than 20 m^3/s in the upstream, climate change to drier climate,
- large dams in the upstream, morphological change (Canalization, cutting of papyrus, tectonics)

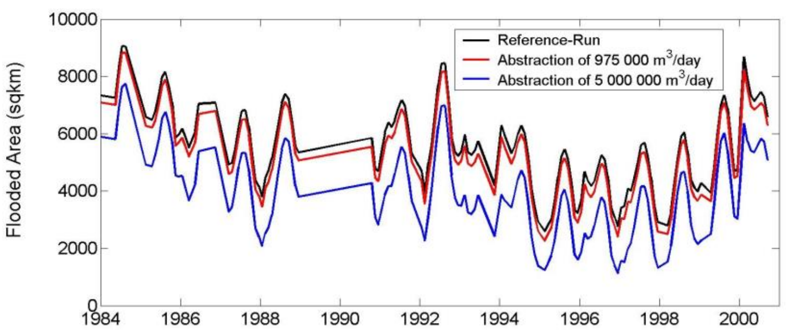

Fig. 5: Flooded area for different abstraction scenarios in comparison to the modeled development over the last 20 years (note that there are no data for 1989-1990)

Sources: Kihzalbach et al, 2007

The model provides a quantitative basis for the political debate between the riparians of the Okavango. The water comes from Angola while the income for tourism is mainly generated in Botswana. It is clear that for the conservation of the Delta part of the income from tourism has to be redirected to the upstream in exchange for a guaranteed inflow at Mohembo. The key parameter for an administrable, negotiated solution is the guaranteed minimal inflow at Mohembo and its temporal variability.

8.0 Summary and Conclusion

This Paper entitled "Sustainable Water Management in Semi -Arid and Arid Regions" attempts to bring into focus the need for a sustainable management of water so as to ensure a continuous clean supply of water to mankind, where rainfall is sparse and surface sources of water are not only few and far between, but are subject to extreme temporal and spatial variations. Because of these variations, "part of management strategy is to catch floodwater during the rainy season, by building dams, and releasing same during dry periods. The need to develop groundwater resource since it represents about 98 of world's supply of usable fresh water. Besides, this source is usually relatively pure and is not subject to by climatic extremes in the way that surface sources are. Consequently, various approaches are examined in the planning, development and management of groundwater; and to take advantage of differing characteristics of surface and groundwater in order to optimize the yield of the total water resource.

Additionally, we need to upgrade our existing infrastructure for water storage. In particular, more facilities are needed for storage of water during the rainy season to help alleviate dry period drought problems. Other important steps would be to sensitize people to the problems of water wastage and to introduce policies or taxes that would cut waste and constrain demand. Also, a survey of the vulnerability and resiliency of water basin is needed to support water use planning; and it is expected that forest hydrology should play a significant role, as forests have effect on the recession characteristics of the catchments. In particular, by revegetating denuded areas water is therefore released more gradually.

Finally, because of uneven distribution of water over time and space and the slow recharge rate of underground water there is insufficient water supply to the target population, water can then be distributed geographically by transferring it in pipelines or canals from one drainage basin to another- only that this should be considered as the last resort.

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