Simulation for Groundwater Demand and Consumption in Khartoum State

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***Abstract*—This paper is based on simulation for groundwater demand and consumption system which needs heavy investigation efforts and takes long time by using traditional methods to analyze the rates of water demand and consumption. The main purpose of this paper is to estimate the water demand on the basis of population growth in Khartoum state for the coming years so as to fulfill the population needs for water. Information about water consumption and population increase has been covered, with emphasis on the problems of caused by lack of water. All methods in respect to simulation has been taken into consideration, illustrating various models with related definitions and taxonomy as well as various techniques of estimating future consumption of water and prediction for future population. Finally, the study reveals that the existing groundwater with the recharge from the Nile which was estimated to be about 100 million cubic meters per year can not suffice the population demand for water for the coming years in Khartoum state if they depend only on the groundwater. After 35 years from the simulation study year, the population demand will exceed the existing groundwater.**

***Index Terms*—VIN, the water left over in the groundwater basin at the end of the last year, VOL, the total volume, DEM, demand, diff, difference, VNET, the total volume net.**

I. Introduction

Water demand in many countries has already exceeded or will soon exceed available supply due to the rapid increase of population and the increase of economic activities. Therefore it is essential to maintain a proper balance between water demand and water supply. Furthermore, available water sources often are not sufficient quality to meet required uses. [1] The groundwater is one of the resources that require careful planning and management, and it is a vital natural resource for the reliable and economic provision of potable water supply in both the urban and rural environment.

It thus plays a fundamental (but often little appreciated) role in human well-being, as well as that of some aquatic and terrestrial ecosystems. For municipal water supply, high and stable raw-water quality is a prerequisite, and one best met by protected groundwater sources. Recourse to treatment processes (beyond precautionary disinfections) in the achievement of this end should be a last resort, because of their technical complexity and financial cost, and the operational burden they impose. So groundwater can continue to sustain human socio-economic development and the various ecosystems that depend on it.

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The research problem is how to build a simulation model that studies the influence of water demand and water consumption on the groundwater domain in Khartoum state for the coming years, according to the population growth rate. The research organized as follows: in section I, introduced a brief statement about the research problem, and the research objective. Section II presents a literature review of studies that have researched in water demand domain to provide efficient tools in controlling water consumption. Abroad review of water demand models found in this literature. Section III discuss and present the simulation study modeling and the results obtained from the simulation study.

A. Research Problem Statement

The research is attempt to build a simulation model that study and predicts the effectiveness of water demand and consumption on the groundwater in Khartoum state according to population growth rate.

B. Research Objectives

The main purpose of the research is to:

1) Estimate the water demand due to the population growth in Khartoum state for the coming years in order to plane how to fulfill the population needs for water.
2) Provide accurate and reliable information about groundwater and water demand that assist to maintain a proper balance between groundwater quantity and its exploitation.
3) Present options for water management and protection strategies in an integrated approach

II. Literature Review

With the increase in worldwide of water demand over the last few decades, water utilities faced problems of supplying the quantity of demanded water. Many studies have researched in water demand domain to provide efficient tools in controlling water consumption. [2] Most of the studies are regression models based on data collected during various surveys, in region where water demand increased. In a large number of water demand studies, there are different approaches. There is no consensus on the correct method to predict the demand for water. This is in part influenced by the fact that every region has its own characteristics regarding water use and socio-economic influences. [3]Water demand studies started in the 1960 and 70s mainly in USA. In the 1980s the number of studies increased significantly, mostly encountering regression models based on various data sets in

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water scarce areas of the US. In 1990s, conservation methods and water efficient technologies received more attention. Also, a number of studies were done in Europeans and other countries. In additional, some new methods were investigated in order to predict the water demand. This literature review presents specification of the models used in this field as follow.

A. California Water Demand Model

Peter H. Gleick, Heather Cooley and David Groves (2005) from Pacific Institute developed high efficiency scenario that generate three future demand scenarios. The model estimates urban, agriculture, and environmental water used for each California's ten hydrologic regions. Urban water demand includes the demand by households, the commercial and industrial sectors, and public institutions. Agricultural water demand includes irrigation use, delivery and conveyance losses, and other uses. Environmental water demand reflects the amount of water that the water management system would allocate to environmental purposes.

B. Water Resources Simulation and Optimization System

Dr. Kurt Fedra1 and Prof. Dr. Nilgun Harmancioglu from Eylul University, Turkey (2004) study the water resource management in the Eastern and Southern Mediterranean countries. A simulation based water resources planning and optimization system is being developed and applied in case studies in Cyprus, Turkey, Lebanon, Jordan, Palestine and Israel, Tunisia and Morocco. The model system addresses quantity and quality, water demand and supply, surface and ground water, water technologies and efficiency of use, allocation strategies, costs and benefits. A web based client-server implementation supports distributed use and easy access, and a participatory approach involving local stake holders for multi-criteria optimization and decision support.

C. Residential Water Demand Model in Tunis

Mohamed Ayadi (2003) studies the residential water demand in presence of Non linear progressive tariffs. Any optimal policy to change consumer behavior with respect to water demand in an environment characterized by scarce resources requires an appropriate specification and estimation of a suitable model. Incorporating several innovations in a classical consumer demand model has allowed us to obtain satisfactory results for Tunisia.

D. Water Supply/Demand Modeling and Management in Abu Dhabi Emirate, UAE

Mohamed A. Dawoud and Robin Farbridge from Environmental Research and Wildlife Development Agency of Abu Dhabi in (2002) study the water resource management regime development. The first stage of the program of development of a water resources management plan includes the compilation of all data and information pertaining to water resources in an ArcGIS – SQL Server database containing supply and demand data and resource monitoring information for all sectors of water use. Demand data relates to water use for domestic, industrial, agricultural, forestry, and amenity purposes. Water sources comprise groundwater, desalinated water, treated wastewater, and water imported to the Emirate. A supply-demand balance model has been developed, linking demand centers to supply sources in order to predict future water shortfalls and surpluses. In this paper the development of the GIS/Database and the supply-demand model, and their use as an important tool for future assessment, monitoring, and management of water resources is described. The developed model was used to predict the future gaps between water demand and supply for any eastern and central regions of Abu Dhabi Emirate up to the year 2020. The results indicated an increase of about 100%, 132%, 136% and 269% in water demand due to future development in, agriculture, forestry, amenity and domestic sectors respectively.

E. Demand Management Program for an Arid Zone

Turner, S. Campbell and S. White University of Technology, Sydney, 2004 use a simulation model to study the demand of water in Arid Zone. The outdoor demand in arid climates generally represents a significant proportion of total demand and is often extremely seasonal in nature and difficult to characterize, leading to problems when building an end use model and determining which options will provide the highest water savings at the lowest cost. In the investigations undertaken for Alice Springs, a wide variety of low cost methods for gathering data were used to disaggregate water demand, build an end use model and assist in the development of the demand management (DM) program. These included: analysis of bulk water and customer metered demand; review of available data and documents on water issues; the use of a low cost residential water usage survey which was linked to customer metered demand; interviews with suppliers/maintenance specialists (e.g. pools, air conditioners and garden irrigation); and an experiment in relation to evaporative air conditioning systems.

III. The Simulation Study

This study attempts to build a simulation model for the groundwater consumption in Khartoum state, which requires more effort and time to be studied by the traditional methods. The research estimates the demand of Khartoum population for water according to the population growth. To build this simulation model we require data about the population number, the population growth rate, the population consumption rate, the available quantity of groundwater and the water recharge from the river Nile. The data collected as explained below:-

A. The Data

1) Water demand estimation

The population number is the essential factor for the increasing of water consumption quantity. [4] The demand quantity can be calculated by several methods. The method depends on the population number only for estimating water demand was called single coefficient all one in this method the other factors affected water demand neglected. Where the multi coefficient method consider more than one factor e.g., water price and house type. The multiple coefficient used when there is a require for more details and accuracy in the estimation of future water consumption, and when the estimation of future water consumption is for afar range the single coefficient used. Therefore in this research we used the single coefficient method because we want to forecast water for afar range. [5] The water use in Khartoum state was divided into two types area according to the mode of living, urban area, and rural area as follow below.

B. Water Uses for Khartoum Urban Areas

1) Domestic uses *Rate of uses*

a) Drinking +food cooking 10 liter person / day
b) Toilet 20 " / " / "
c) Ablution 10 " / " / "
d) House cleaning 10 " / " / "
e) Bathing 35 " / " / "
f) Car washing and 7 " / " / "
g) garden irrigation 8 " / " / "
h) Cloths washing 20 " / " / "
Total 120 " / " / "

2) Other uses

a) Network losing 30 / liter / person/ day
b) Industries 10 / " / " / "
c) Work-shops 10 / " / " / "
d) Commercial 10 / " / " / "
e) Public institutions 14 / " / " / "
f) Entertainment 6 / " / " / "
g) Total 80 / " / " / "

The total demand for a person in urban areas is 200 liter per a day from which 120 liter for

Domestic uses which equal 60% from the total consumption and 80 liter for other uses.

C. Water Uses for Khartoum Rural Areas

1) Domestic uses

Rate of uses Entity: An object that passes through the system, such as cars in an intersection or orders in a factory. Often an event (e.g., arrival) is associated with an entity (e.g., customer). Queue: A queue is not only a physical queue of people, it can also be a task list, a buffer of finished goods waiting for transportation or any place where entities are waiting for something to happen for any reason.

a) Drinking +food cooking 10 liter/a person/day
b)Toilet 10 " / " / "
c) Ablution 10 " / " / "
d) House cleaning 10 " / " / "
e) Bathing 10 " / " / "
f) Animals 20 " / " / "
g)Cloths washing 10 " / " / "
Total 80 " / " / "

2) Other uses

a- Network losing 20 liter / person /day
Trees irrigation in houses 15 " / " / "
Public institutions 5 " / " / "
Total 40 " / " / "

The total demand for a person in rural areas is 120 liter per a day from which 80 liter for domestic uses and 40 liter for other uses [6].

D. Population Size

The water demand in a community is often assumed to be function of the population. Hence, it usually necessary to estimate or to count the population to be used as a basis for an estimation of expected water demand. [7] Here below the population size in Khartoum state for the previous nine years:

TABLE I: POPULATION SIZE IN KHARTOUM STATE BY MODE OF LIVING:

Years	Total Pop (000)	Urban Pop (000)	Rural Pop (000)
1997	3715	3087	628
1998	4372	3633	739
1999	4563	3901	662
2000	4740	4092	648
2001	4936	4299	657
2002	5139	4445	694
2003	5352	4650	702
2004	5553	4842	711
2005	5761	5043	718

E. Groundwater Storage Capacity

The groundwater storage capacity is defined as the volume of water that can be drained by gravity or by pumped from materials underlying a designated groundwater unit. Groundwater in the study area is distributed in tow units or formations namely:

1) The Nubian sandstone formation

The Nubian sandstone formation covers about 75% of the total surface area in Khartoum state.

2) El Gezira formation

[8] El Gezira formation covers the area between the Blue Nile, and the White Nile and on the right banks of the Blue and River Nile. It rests unconformable over the Nubian sandstone formation. The tables below summarized the estimations of groundwater storage capacity for the Nubian sandstone and El Gezira formation aquifers. The storage capacity of the Nubian sandstone aquifer up to the depth of 150 meters is about 77 milliard cubic meters. The storage capacity of El Gezira formation aquifer is about 5.8 milliard cubic meters and the total capacity in the Nubian sandstone and El Gezira formations is about 85 milliard cubic meters. Below the estimation of groundwater storage capacity for the Nubian sandstone aquifers up to the depth of 150 meters calculated from different areas:

TABLE II: GROUNDWATER STORAGE CAPACITY FOR NUBIAN SANDSTONE AQUIFERS TO DEPTH OF 150 M

Sub area no	Surface area km	Storage Capacity m^3
1	500	20×10^8
2	742	71×10^8
3	742	37×10^8
4	742	39×10^8
5	500	18×10^8
6	742	21×10^8

Estimation of groundwater storage capacity of El Gezira formation aquifers calculated from different areas:

TABLE III: GROUNDWATER STORAGE CAPACITY FOR EL-GEZIRA FORMATION

Sub area No	Surface area km	Storage capacity m^3
1	230	1.2×10^8
2	240	4.7×10^8
3	800	2.8×10^8
4	742	5.6×10^8
5	400	1.4×10^8

F. Probability Distribution for Data

As we know the Probability distribution divided to two types' continuous distribution and discrete distribution [9]. To determine to which distribution our data belong to we test the data by using SPSS program. This program used to analysis data, and also used for several purposes like:

1) Test data distribution
2) Calculate the statistical functions e.g. mean, variance

As explain below we use the SPSS program to test the data distribution for the variables "water consumption rate, population size, and storage capacity" via Normal Test.

G. The Distribution of Water Consumption

Due to the statistical test the water consumption for Urban and Rural both belongs to the Normal distribution which is used to Represent quantities [10] as below:

Urban Consumption Distribution:

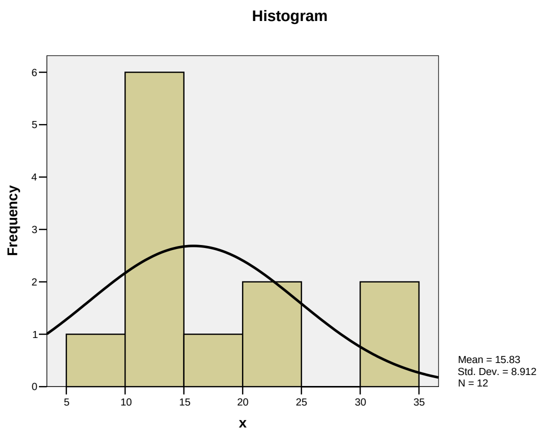

Fig. 1. Urban Consumption Distribution

Rural Consumption Distribution:

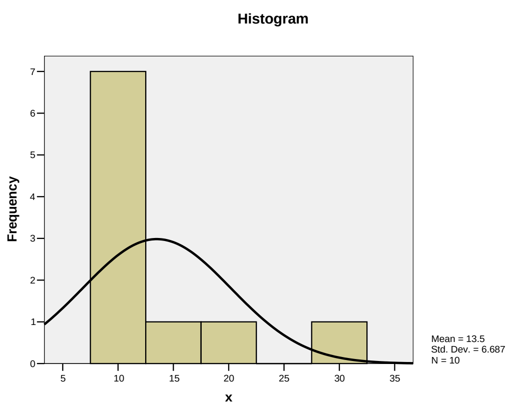

Fig. 2. Rural Consumption Distribution

H. The Population Size Distribution

The population size belongs to the Exponential distribution.

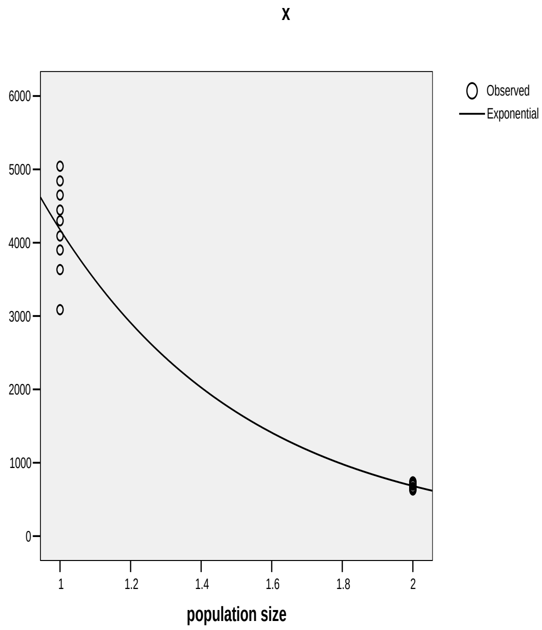

Fig. 3. Population Size Distribution

I. The Storage Capacity Distribution:

The storage capacity data belong to the Normal distribution

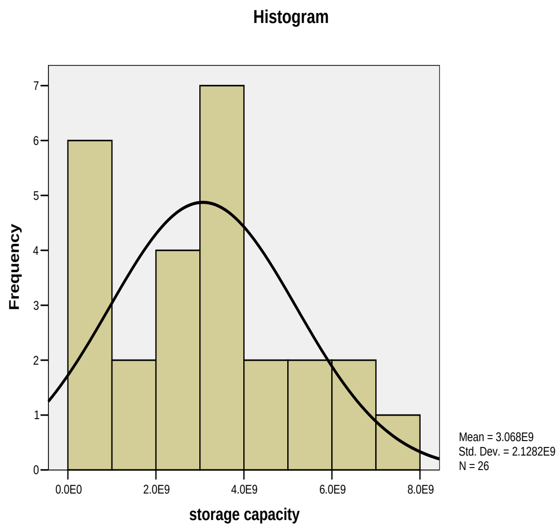

Fig. 4. Storage Capacity Distribution

J. The Simulation Algorithm

At the beginning of the simulation we consider the water which left over in the groundwater basin as the gross volume water of the last year which will be known as the available quantity. Also we consider the total amount of the river recharge as an input called VIN, so the simulation algorithm is as follows:-

1. Start
2. Add the input volume VIN to the water left over in the groundwater basin at the end of the last year VOL(y-1) this give as the total volume

$$\text{Total Vol} = \text{VOL}(y-1) + \text{VIN}$$

3. Compare the Total Volume with the Demand DEM
4. If Total Vol <= 0 then

Total Vol = 0
Short = DEM
Else
If DEM > Total Vol then
The groundwater basin runs dry and the shortage is given by:
Short = DEM – Total Vol
Diff = 0
Else
If DEM < Total Vol then
DIFF = VNET – DEM
Short = 0
Where the difference is the water left over

5. Calculate the average for:

Short in this year
Water left over in this year

6. Print the average for this year
7. Do the simulation year's end

No return to step 2
Yes GO TO step 8

8. End

K. Demand Subroutine Algorithm

We design the following subroutine algorithm to compute the demand of Khartoum state population for water as below:

1. Start
2. If area is urban then

Enter the consumption rate of urban area
Calculate the population number of urban area
Dem = population number * consumption rate
Else
If area is rural then
Enter the consumption rate of rural area
Calculate the population number of rural area
Dem population number * consumption rate

3. Repeat until the current month day's end and then calculate the total demand
4. Does the current year months end

No return to step 2
Yes GoTo step 5

5. Calculate the total demand for this year
6. End

IV. Conclusion

The simulation results showed that the population size in Khartoum state growth rapidly and lead to the increase of water demand. The simulation predicted that the existing water in the groundwater basin with the recharge from the Nile which was estimated to be about 100 million meter cubic yearly can not suffice the population demand for water for the coming years in Khartoum state. Also the results showed that the production of groundwater is greater than 55% of the whole production water by other resources. So the dependences on the groundwater only to face the increase of water demand to fulfill the population needs for water lead to the declining of this resource, also the research found that after 35 years from the simulation start year the population demand for water will exceeded the water exist in the groundwater basin.

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