Analysis of Irrigation Water Requirements in Gezira Scheme Using Geographic Information Systems: Case Study Block Number 26 (Dolga)

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ABSTRACT- Water scarcity has a direct impact on food security and a real threat to food production for millions of the population. To avoid the unwise and random consumption of available water resources, it is high time for using efficient system and appropriate policies for management of irrigated farms to control water overuse, starting by the analysis of the existing reality. Block number 26 (Dolga) in Gezira scheme had been chosen as a study area. The total area of the study area is about 24616 Feddans. The study aims to apply GIS in the data editing, manipulation, storage, processing, and presentation for the analysis of irrigation water requirements. GIS had been chosen for its capabilities of data capturing, data processing and efficient spatial analysis. Layers of geo-referenced spatial database including crops' maps, irrigation canals network and its command area, each crop water requirements, irrigation water requirement, rainfall data, area cultivated for each crop and contour map of the study area had been created and used for the spatial analysis in ArcGIS software. Five course rotations are applied for the crops of cotton, wheat, sorghum, and groundnut. Each crop covers 20% of the total area and the remaining 20% are fallow and layer for each crop had been created. Crops' water requirements had been calculated applying Penman-Monteith method and saved in the attributes Table of crops layer. It had been found that the seasonal crop water requirements per Feddan for each crop is 3,871.56 m^3, 2,983.26 m^3, 1,847.16 m^3 and 2,007.6 m^3 respectively, calculated using Penman-Monteith method. The total crops water requirements are 50,254,962.66m^3(absorbed by plants), water allotment of the study area according to the ratio of the area is 67, 195,230.327 m^3, irrigation water requirement is 64,537,716.5 m^3 (including the water losses), where the actual water supply is 63,817,600 m^3 which had been calculated applying ArcGIS tools and saved in the attribute Table of the crops and rotation layer. The study had concluded that cotton consumes the largest amount of water supply, rainfall water is in irrigation has the used only in the complementary irrigation of sorghum crop and the implementation of GIS capabilities enables efficient analysis and scheduling of irrigation water.

Keywords: *GIS, Gezira Scheme, Irrigation management, Crop Water Requirement.*

المستلخص- لنقص المياه تأثير مباشر على الأمن الغذائي ومهدد حقيقي لإنتاج الغذاء لملايين البشر. لتفادي الإستهلاك غير المرشد والعشوائي لموارد المياه المتوفرة. حان الوقت لاستخدام نظام ذو كفاءة وسياسات مناسبة لإدارة المياه في المزارع المروية لمنع هدر المياه بداية بتحليل الواقع الحالي. تم إختيار مربع 26 دلقا بمشروع الجزيرة كمنطقة للدراسة. المساحة الكلية لمنطقة الدراسة 24616 فدان. تهدف الدراسة لاستخدام نظم المعلومات الجغرافية في تحرير وإعداد وتخزين ومعالجة وعرض البيانات لتحليل إحتياجات مياه الري. تم إختيار نظم المعلومات الجغرافية لقدراتها في إدخال البيانات ومعالجتها وكفاءة تحليلها مكانياً. تم إنشاء طبقات مسندة جغرافياً شاملة قاعدة البيانات المكانية لخرائط المحاصيل وشبكة قنوات الري والمساحات المقرر ريها واحتياجات كل محصول من المياه واحتياجات المياه للري وبيانات الأمطار والمساحة المخصصة لزراعة كل محصول و خريطة كنتورية لمنطقة الدراسة وتم إستخدامها في التحليل المكاني في برنامج ArcGIS. يتم تطبيق الدورة الخماسية لمحاصيل القطن والقمح والذرة والفول السوداني. كل محصول يغطي 20% من المساحة و20% المتبقية أرض بور وقد تم إنشاء طبقة لكل محصول. تم حساب إحتياجات المحاصيل للمياه بتطبيق طريقة بيتمان مونتيث ووجدت إحتياجات المياه الموسمية لكل محصول بالفدان على الترتيب: 3,871.56 م3 , 2,983.26 م3 , 1,847.16م3, 2,007.6 م3. إحتياجات المياه للمحاصيل الكلي الذي تمتصه النباتات فعلياً 50,254,962.66 م3 ونصيب منطقة الدراسة من المياه حسب نسبة المساحة 67, 195,230.327 م3 وإحتياجات المياه للري 64,537,716.5 م3 شاملاً فاقد المياه بينما الامداد الفعلي 63,817,600 م3 محسوبة بأدوات برنامج ArcGIS ومخزنة في جدول الخصائص لطبقة المحاصيل والدورة. الدراسة خلصت إلى أن القطن يستهلك أكبر كمية من المياه وأن

مياه الأمطار مستخدمة فقط في الري التكاملي لمحصول الذرة وأن إمكانيات تطبيق نظم المعلومات الجغرافية يمكن من فاعلية تحليل وجدولة مياه الري.

INTRODUCTION:

Water scarcity is closely linked to food security; hence a vital question is raised as whether the growth in agricultural production is required to sustain population growth and reduce rural poverty can be met with the dwindling water resources available for irrigation, (FAO, 1996) [1] Water supply is becoming a major constrain to irrigated agriculture in Sudan. An estimate made by FAO (1993) showed that distribution losses constitute 15%, field application losses 25%, other losses 15% and the water effectively used by crops constitutes only about 45% of the total irrigation water [1]. With increasing competition across water using sectors, savings and more efficient water use are highly needed [2]. Efficient management of irrigation is necessary due to inappropriate rainfall, non-uniform rainfall, growing a number of crops during a year, growing perennial crops, growing commercial crops with additional water, and proper control of water supply. Irrigation requirement of crops differs from one area to another due to varying climatic and soil characteristics of different agro-climatic zones. Estimation of an optimal requirement of water (water by irrigation) for a crop is indispensable for getting maximum yield with economical use of water. Management of water is required for getting more crops per drop of water [3]. The remedy of the water deficits during critical growth periods and avoid the waste of water in the meantime, precise supplemental irrigation schedules are recommended in different weather conditions [4]. Irrigated agricultural production under water scarcity conditions necessitates transfer and adaptation of appropriate technologies and innovations [5]. The objective of the study is to apply GIS in the computations and analysis of irrigation water requirements and creation of layers for irrigation network and the cultivated area.

LITERATURE REVIEW

Geographic Information Systems

The U.S Federal Interagency Coordinating Committee (1988) [4] definition stated that a GIS is a system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modularity, and display of spatially referenced data for solving complex planning and management problems. GIS is a geospatial information system composed of hardware, software, data, people and procedures. GIS has the capability to connect spatial entities represented in maps and attributes stored in database Tables, in the form of text as nominal or ordinal or numbers as interval or ratio, by unique identifier. Spatial data such as maps, satellite imageries and aerial photographs, represent or depict features and locations on the surface of the earth, are stored in overlaid layers spatially referenced by common coordinates and coordinate system. Main GIS functionalities are data acquisition, storage and retrieval, processing, spatial analysis, and presentation. Spatial analysis distinguishes GIS from other database systems. Spatial analysis tools can interrogate the overlaid layers of different data types to answer queries and to detect relationships between data applying predefined criteria (criterion). Results of spatial analysis generate new data layers, which can be used for further analysis and modeled for application. GIS model builder can be applied to save the steps of the analysis processing according to the designed sequence and the model can be generated to repeat the steps automatically. Results of the analysis can be presented in the form of maps, photos, Tables, statistical reports or textual reports, to support decision-making. GIS is an efficient spatial decision support system having the basic characteristics of decision support systems.

GIS is very useful in the field of agriculture, particularly in the choice of the best crops, and irrigation management. Data on soil, land, climate, crop, irrigation, topography, and hydrology are the fundamental elements that affect decision making in agriculture. GIS among suitability tools can support to answer (where, when and what is the best crop to grow). Furthermore, it enables efficient management of cultivation operations, starting from land preparation stage up to harvesting, storage, transportation, and marketing stages. In GIS databases records are saved for each field by a unique identifier including data of owner, soil, crop, dates of different cultivation operations, quantities of annual yield, price, customers, cost, annual profit and any other necessary data. Computations and comparisons can be made, and results can be presented in the form of maps, Tables, statistical reports or textual reports. Fields can be monitored periodically applying remote sensing to test the health growth of the plants against predesigned models stored in GIS Model Builder automatically after the input of the new data and parameters (if it exists). Many tools are available for the analysis of the monitored fields such as classification (supervised or unsupervised) and normalized difference vegetation index (NDVI). Appropriate interventions can be applied due to the results of GIS analyses for maintenance such as addition of fertilizers, herbicides, pesticides, irrigation and among others. It saves time and effort in the computations and manipulations of complex data structures needed to take the right decisions. Layers of irrigation network including canals and records of their attributes such as scheduled dates and volumes of filling and discharge water beside the connections between main, minor, sub-minors, up to the smallest canals. Topology tools of GIS can build connectivity between canals by vertices. Layer of irrigation network can be analyzed with the layer of cultivated fields to manage the irrigation operations.

Irrigation management depends on the computation of the algorithm for effective rainfall, Evapo-Transpiration (ET), crop coefficient, percolation application efficiency, water conveyance efficiency, cropping pattern distribution [4]. GIS helps in these computations to determine crops water requirements and final irrigation water requirements and it is useful in the proper scheduling of the available water for irrigation in optimal manner.

Crop Water Requirements

This method depends mainly on the determination of the crop evapotranspiration (ETO), which is affected by two factors: evapotranspiration and crop characteristics. The reference evapotranspiration (ETO) is the rate of evapotranspiration from an extended surface of a green cover, completely shading the ground, and not shortage of water [6]. The crop coefficient (Kc) is the factor that represents different ET levels for different types of crops under identical environmental conditions [7]. This coefficient is a function of crop height, roughness, reflection, ground cover, rooting characteristics, and resistance to transpiration. The CWR had been calculated as shown in Equation (1):

CWR = (ETO Kc) – Reff (1)

Where:

CWR is Crop Water Requirement (mm/day)

Kc is Crop coefficient

ETO is Reference Evapotranspiration (mm/day)

Reff is Effective rainfall (mm/day)

For the evaluation process, the data for CWR calculation had been taken from the Nile Basin Initiative Tool-Kit climatic data (7). Table 1 shows the average climatic data (from 1970 to 2015) and Kc values for Gezira scheme main crops. The seasonal CWR for the Gezira scheme was determined by considering annual variations in the cultivated area for each crop.

Irrigation Network and Water Management

The layout of the water canalization system of a typical block of 90 Feddans called (Nimra (block or Number)). From the minor canal, water is supplied to sub minor (Abu Eshreen) which has an average carrying capacity of 116 m3/ sec and serves one "Number. The "Number" is divided into 22.5 fields (Hawashat) of 4 Feddans and each (Hawasha) is served by an (Abu Sitta) (50 m3/sec capacity). Each (Hawasha) is divided into seven divisions called (Angaya) having an area of 0.57 Feddans for each. Irrigation water to every (Angaya) is delivered through a small field chanal called "Gadwall" (7 m3/sec capacity). A small field divider called (Tagnet) divides the (Angaya) into two equal halves. The (Abu Sitta) runs perpendicular to (Abu Ashreen) and parallel to the "Minor" and both (Gadwal) and (Tangent) run parallel to the (Abu Ashreen) [12] Figure 3).

Crops and Rotation

The main crops usually grown in the scheme are cotton, wheat, sorghum and groundnuts. VegeTables are sometime grown, and permanent gardens are also grown in some locations, but comprise a small area compared to the main cropped area. The rotation has an area of 450 Feddans divided into five equal blocks (numbers), each block (number) with an area of 90 Feddans in general. Each block (number) is divided into fields and sub fields, with an area of eight Feddans for the field and four or two Feddans for sub field. Cotton is grown on one block, wheat is grown on the second block, groundnuts on the third one, and the sorghum is grown on the fourth block and the last fifth one is left fallow. Next year the cotton moved to the fallow block, the wheat to the previous cotton block, the groundnuts to the previous wheat and sorghum to the previous groundnuts, while the previous sorghum block is to be left fallow. Each crop covers 20% of the rotation area. It is therefore called five courses rotation, and it is the rotation which had been adopted in the study (see Figure 4). Gezira scheme is neighboring the south boundaries of Khartoum lying between White River Nile and Blue River Nile Figure 1). The total area of the scheme is approximately 0.88 million hectares (about 2,095,238 Feddans). The annual water consumption is about 6×10^9 m^3 [8]. The allotment for the study area due to the ratio of the area is about 67,195,230.327m^3.

The Study Area

The study had been carried out for block number 26, which is known as Dolga block. It is located approximately between longitudes 33° 08' 17"E and 33° 17' 46"E and latitudes 14° 44' 28"N and14° 54' 32"N. The total area of this block is about 24616 Feddans, where 1301 Feddans is fringe (rain fed), 180 Feddans are forests and 20 Feddans are gardens, Figure1). The study area is receiving water requirements from main canal through two major canals (Talbab major and Sharafat major) to the minor canals which supplying fields with water through Abu Sittas.

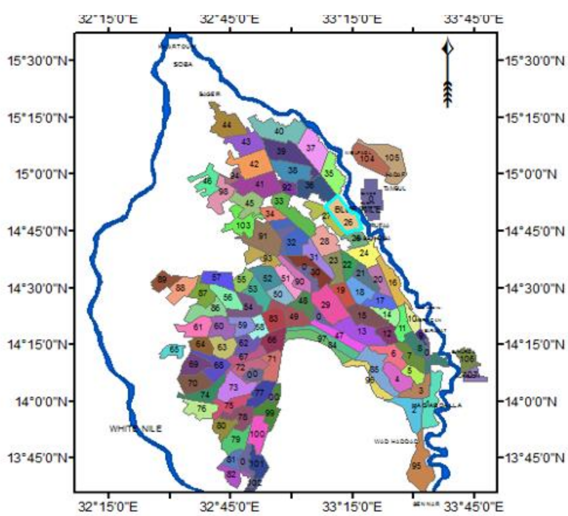


Figure 1: Gezira scheme and study area (block number 26)

MATERIAL AND METHODOLOGY

Data Sources

- Hard copy maps of irrigation network cultivated area and spot heights of the study area had been achieved from ministry of irrigation.
- Data of crops and rotation from farmers.
- Climatic Data and Kc Values for Gezira Scheme Main Crops as shown in Table1 1.
- Crop Calendars and Irrigation Schedule as shown in Table 5[9].

Table 1 shows the monthly, Reference Evapotranspiration ETO (mm/day), Effective rainfall Reff (mm/day) and Crop coefficient Kc for each crop during the cultivation season.

Table 2 includes crops water requirements scheduling, the actual amount of water supply delivered to the fields from ministry of irrigation for crops had been determined by 400 m3 per Feddan every 14 days for each crop including water losses and the crops only differ from each other by the number of irrigations [9].

Methodology:

Using ArcGIS 10.3 software, the scanned map of the study area had been spatially referenced using the apparent ground coordinates on the map applying georeferencing tool. WGS1984 datum had been defined as a coordinate reference system. The scanned raster map had been transformed to vector model. Layers of irrigation network, including main, major, Gannabia, minor, sub minor, Abu Ishreen and Abu Sitta canals as line feature class Figure 3 and a layer of cultivated area showing crops and rotation taking polygons as feature class Figure 4 had been created.

A layer for each crop had been extracted from crops and rotation layer applying Query Builder expressions Figure 5 a,b,c and d).

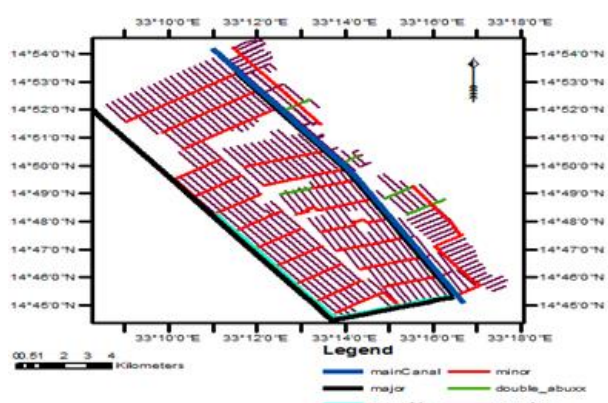


Figure 3: Irrgation network

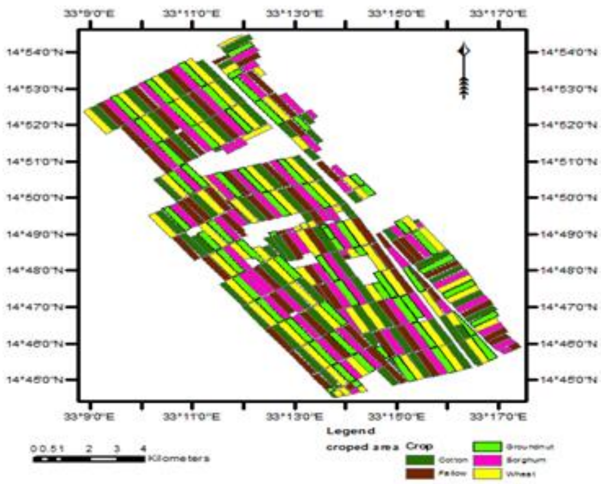
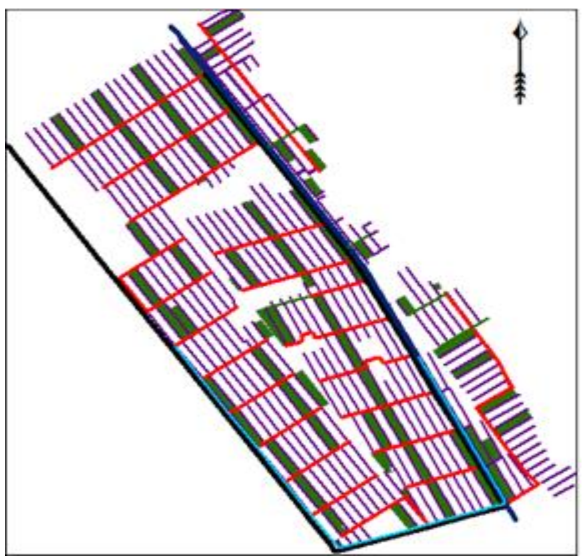
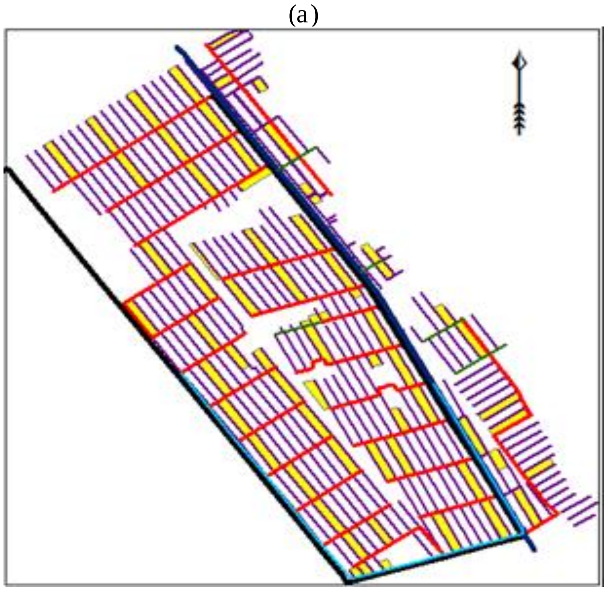


Figure 4: Crops and rotation



(a)



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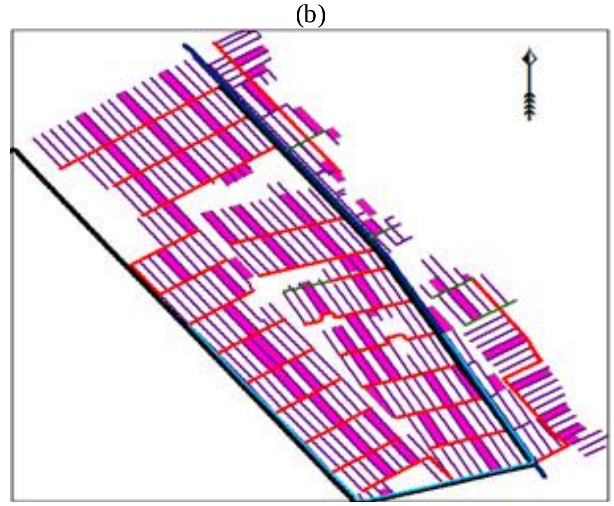
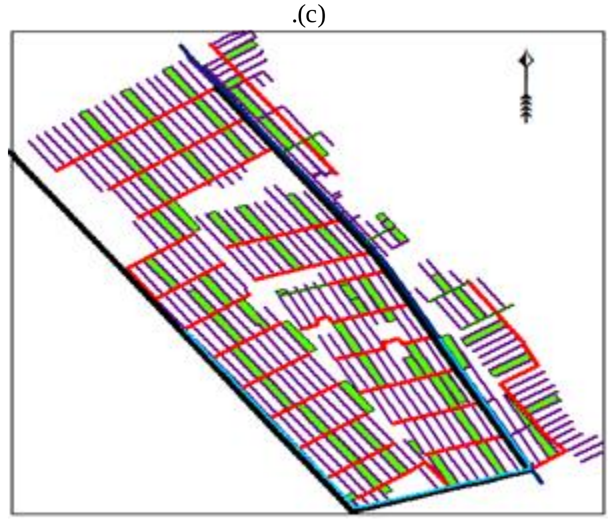


.(c)



(d)

Figure 5: Crops (a) Cotton farms (b) Wheat farms (c) Sorghum farms d: Groundnut farms (d) Groundnut farms

Crops’ water requirements had been calculated applying Penman-Monteith method (equation 1), Data of average climatic and Kc values for Gezira Scheme main crops (Table 1) had been used in the calculation of reference crop evapotranspiration. Crops, area, crop water requirement, effective rain, net irrigation water requirement and adequate water supply had been calculated applying ArcGIS calculation tools and saved in the attributes Table of crops and rotation layer Figure 4 as shown in Figure 6 and extracted to Table 3. A capture of part of attribute Table of crops and rotation layer had been chosen as an example as illustrated in Figure 6 because it is difficult to edit the complete attribute Table due to big number of fields and columns.

Name	Minor	Area	Crop	Code	CWR	Irr_Requ	Eff_Rain	Season	Water_supp
NO 1	Gadelein	70	Cotton	1	271009.2	287000	56154	From mid of July to first of February	336000
NO 2	Gadelein	87	Wheat	1	259543.62	215151	365.4	From mid of Novemeber to mid of Mar	278400
NO 3	Gadelein	87	Groundnut	1	174661.2	356961	81849.6	From first ofJune to mid October	348000
NO 4	Gadelein	87	Sorghum	1	160702.92	267612	77830.2	From end of June to mid of October	139200
NO 5	Gadelein	87	Fallow	1	0	0	0		0
NO 6	Gadelein	87	Cotton	2	336825.72	356700	69791.4	From mid of July to first of February	417600
NO 7	Gadelein	87	Wheat	2	259543.62	215151	365.4	From mid of Novemeber to mid of Mar	278400
NO8	Gadelein	87	Groundnut	2	174661.2	356961	81849.6	From first ofJune to mid October	348000
NO9	Gadelein	87	Sorghum	2	160702.92	267612	77830.2	From end of June to mid of October	139200
NO10	Gadelein	87	Fallow	2	0	0	0		0
NO11	Gadelein	87	Cotton	3	336825.72	356700	69791.4	From mid of July to first of February	417600
NO 12	Gadelein	87	Wheat	3	259543.62	215151	365.4	From mid of Novemeber to mid of Mar	278400
NO 13	Gadelein	87	Groundnut	3	174661.2	356961	81849.6	From first ofJune to mid October	348000
NO 14	Gadelein	87	Sorghum	3	160702.92	267612	77830.2	From end of June to mid of October	139200
NO 15	Gadelein	87	Fallow	3	0	0	0		0
NO 16	Gadelein	87	Cotton	4	336825.72	356700	69791.4	From mid of July to first of February	417600
NO 17	Gadelein	87	Wheat	4	259543.62	215151	365.4	From mid of Novemeber to mid of Mar	278400
NO 1	Toba	90	Cotton	5	348440.4	369000	72198	From mid of July to first of February	432000
NO 2	Toba	90	Wheat	5	268493.4	222570	378	From mid of Novemeber to mid of Mar	288000
NO 3	Toba	90	Groundnut	5	180684	369270	84672	From first ofJune to mid October	360000
NO 4	Toba	90	Sorghum	5	166244.4	276840	80514	From end of June to mid of October	144000
NO 5	Toba	90	Fallow	5	0	0	0		0
NO 6	Toba	90	Cotton	6	348440.4	369000	72198	From mid of July to first of February	432000
NO 7	Toba	90	Wheat	6	268493.4	222570	378	From mid of Novemeber to mid of Mar	288000
NO 8	Toba	90	Groundnut	7	180684	369270	84672	From first ofJune to mid October	360000
NO 9	Toba	90	Sorghum	7	166244.4	276840	80514	From end of June to mid of October	144000
NO 10	Toba	80	Fallow	7	0	0	0		0
NO 11	Toba	90	Cotton	7	348440.4	369000	72198	From mid of July to first of February	432000
NO 12	Toba	90	Wheat	7	268493.4	222570	378	From mid of Novemeber to mid of Mar	288000
NO 13	Toba	90	Groundnut	4	180684	369270	84672	From first ofJune to mid October	360000

Figure 6: Capture of part of the Attribute Table of crops and rotation layer

Irrigation water requirements are based on recommendation of the Agricultural Research Corporation (ARC) at field outlet pipe for cotton, wheat, sorghum, and groundnut are estimated as 4100 m^3, 2473 m^3, 3076 m^3 and 4103 m^3 per feddan respectively. Daily crops water requirements had been calculated every decay (10 days) for each month and saved in attributes Table of crops and rotation layer Figure 4) and extracted to Table 4.

Irrigated area for each crop, crop water requirement and water supply for each minor had been derived from the attribute Table of irrigation network layer Figure 3) applying ArcGIS query builder expressions (minor= Gadelein and crop=cotton) as shown in Figure 7 and saved in Table 5.

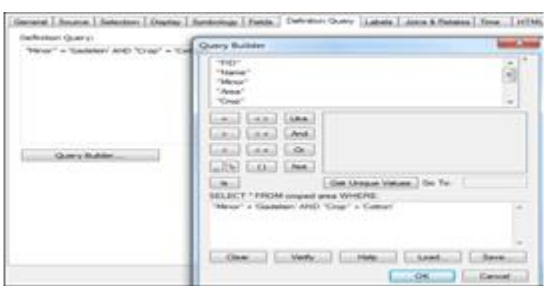


Figure 7: Query and results of cotton fields

A contour map of study area had been prepared applying ArcGIS spatial analyst surface tools, taking the spot heights of the study area that had been achieved from ministry of irrigation as an input data and choosing 0.3 meters as a vertical interval, as shown in Figure 7 and spatially overlaid on the irrigation network layer Figure 8.

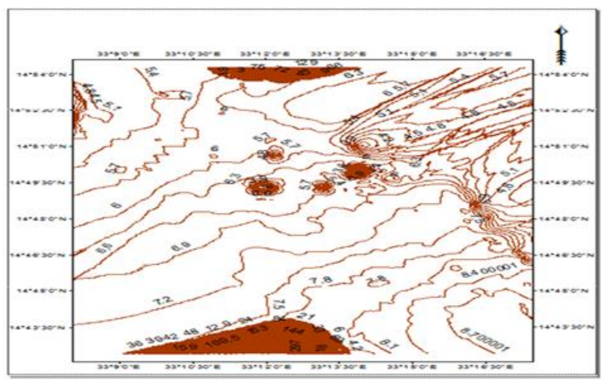


Figure 7: Contour map of the study area

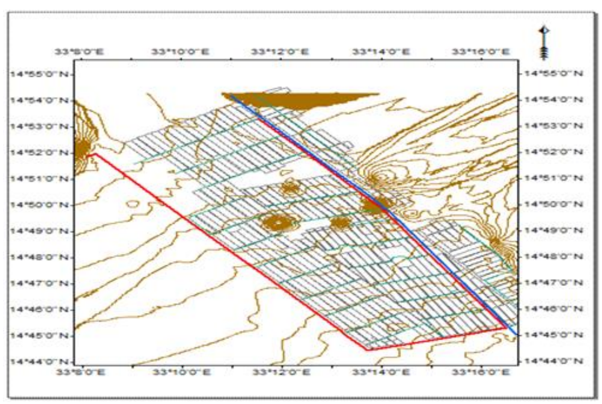


Figure 8: Contour map spatially overlaid on the irrigation network layer

RESULTS AND DISCUSSION

Scanning and vectorization of study area hard copy maps had resulted in the editing of shape files of irrigation network and crops and rotation layers

Figure3, Figure 4). Layers of cultivated area for each crop had been derived from crop and rotation layer applying ArcGIS query expressions and it had been found that the total rotational area is 23,465 feddans, 18,771.50 feddans are cultivated by cotton, sorghum, groundnut, and wheat crops while 4,693.5 feddans are left fallowFigure5).

Analysis of Table 3 had resulted in the followings:

- Allotment water calculated according to the ratio of the study area is 67,195, 230.327m^3.
- The total crops' water requirements are 64,537,716.5 m^3.
- The seasonal effective rain is 12,398,549.1 m^3.
- The crops' net irrigation water requirements are 50,254,962.66 m^3.
- Actual water supply is 63,817,600 m^3.

For Cotton water supply is 22,519,200 m^3 while the irrigation water requirement is 19,235,150 m^3 and rainfall water is 3,763,521.3 m^3 which reflects that cotton consumes more than its water requirement from water supply only regardless of rainfall water. Cotton consumes the largest volume of the total water supply; the maximum volume is in October and November and the minimum is in July and September (see Table3).

For groundnut water supply is 18,772,000 m^3 while the irrigation requirement is 19,255,379 m^3 with a small deficit which can be substituted by rainfall water (4,415,174.4 m^3), the maximum water requirement is in August and September, and the minimum in June and July (see Table3).

For sorghum water supply is 7,512,000 m^{3}while water requirement is 14,441,820 m^3 and rainfall water is 4,200,147 m^3 with a deficit of 2729673 m3, the maximum water requirement is in August and September, and the minimum in June and July. Sorghum adequate water supply is less than water requirement because the maximum water requirement is at autumn where rainfall water can substitute part of the deficit (see Table 3). For wheat water supply is 15,014,400 m^3 while water requirement is 11,603,316 m^3 where water supply exceeds water requirements, the maximum water requirement is at December, January and February, and the minimum is in November (see Table 3).

Rainfall water is about 19.2% of the seasonal crops water requirements but only about 6.5% is used for the complementary irrigation for sorghum. The amount of rainfall water differs seasonally, so proper quantitative, spatial, and temporal observations, documentation and analysis can help in making full use of it in crops irrigation (see Table 3). Statistical histogram showing the amount of Water Supply, Irrigation Water Requirements, Crop Water Requirement and Effective Rainwater for each crop had been created from the attribute Table of Crops and Rotation Layer, applying statistics tool of ArcGIS, as shown in Figure 9.

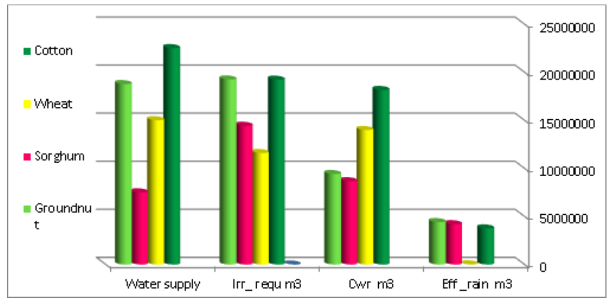


Figure 9: Crops, water supply, irrigation water requirements, crop water requirement and effective rainwater.

Contour map had shown that the general slope of the study area is from South to North (approximately $\frac{1}{7000}$) which enables natural flow of water by gravity without mechanical pumping Figure 7).

CONCLUSIONS

Cotton consumes the largest volume of water supply by an amount that exceeds its water requirements. Rainfall water is 19.2% of water requirement and only 6.5% is used for the complementary irrigation of sorghum, if it is efficiently observed and managed it can reduce the water supply from canals for crops grown during rainy season. Implementation of GIS techniques enables the creation of spatial database, including layers of irrigation network and crops cultivation fields, for efficient analysis, optimization of water consumption, control of cultivation operations, addition, and updating for future data changes. Layer of contour map of the study area is useful for monitoring the topographical changes of the study area to apply the appropriate maintenance.

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TABLE1: AVERAGE CLIMATIC DATA AND KC VALUES FOR GEZIRA SCHEME MAIN CROPS.

Crops/Month		ETO	Effective Rainfall Reff	Cotton	Groundnut	Sorghum	Wheat
		mm/Day	mm/Day	Kc	Kc	Kc	Kc
June	I	8.3	0.5		0.5		
	II	8.6	0.6		0.5		
	III	8.1	1.2		0.5	0.5	
July	I	7.5	1.7		0.5	0.5	
	II	7.0	2.3	0.5	0.6	0.6	
	III	6.5	2.3	0.5	0.8	0.9	
August	I	6.1	2.3	0.5	0.9	1.1	
	II	5.6	2.2	0.5	1.0	1.2	
	III	5.6	2.2	0.6	1.1	1.2	
September	I	5.6	2.1	0.8	1.1	1.2	
	II	5.6	2.0	0.9	1.1	1.1	
	III	5.7	1.5	1.0	1.0	1.0	
October	I	5.8	1.0	1.1	0.9	0.8	
	II	5.8	0.5	1.2	0.7	0.7	
	III	5.9	0.3	1.2			
November	I	6.0	0.3	1.2			
	II	6.0	0.1	1.2			0.5
	III	5.8	0.0	1.2			0.5
December	I	5.6	0.0	1.2			0.8
	II	5.5	0.0	1.2			1.0
	III	5.5	0.0	1.1			1.2
January	I	5.4	0.0	1.0			1.2
	II	5.4	0.0	0.9			1.2
	III	5.7	0.0	0.8			1.2
February	I	5.9	0.0	0.7			1.2
	II	6.1	0.0				1.1
	III	6.5	0.0				0.9
March	I	6.9	0.0				0.7
	II	7.3	0.0				0.6
	III	7.4	0.0				

TABLE 2: CROP CALENDARS AND IRRIGATION SCHEDULE

Crop	Sowing	irrigation schedule (400 M^3 every 14 days)
Cotton M. S	15 July-31 July	12 Irrigations
Cotton L. S	End july-10 August	15 irrigations
Sorghum	1 July-15 July	4 irrigations
G/nut	End April-Early June	10 irrigations
Wheat	Mid October-end November	8 irrigations

TABLE 3: CROPS, AREA, SEASONAL CWR, EFFECTIVE RAIN, CROP WATER REQUIREMENTS, IRRIGATION REQUIREMENTS AND WATER SUPPLY M^3/FEDDAN

Crops	Area/ Feddan	Water requ m^3 /Feddan	Eff rain m^3 /Feddan	seasonal Eff rain m^3	Crop water requ m^3	irr_ requ m^3	Water supply
Cotton	4,691.5	3,871.56	802.2	3,763,521.3	18,163423.74	19,235,150	22,519,200
Wheat	4,692	2,983.26	4.2	19,706.4	13,997455.92	11,603,316	15,014,400
Sorghum	4,695	1,847.16	894.6	4,200,147	8,672,416.2	14,441,820	7,512,000
Groundnut	4,693	2,007.6	940.8	4,415,174.4	9,421666.8	19,255,379	18,772,000
Fallow	4,693.5						
Total	23,465.00			12,398,549.1	50,254,962.66	64,537,716.5	63,817,600

TABLE 4: DECAY CROPS WATER REQUIREMENTS IN M^3/FEDDAN

Crops/Month		Effective Rainfall Reff	Cotton	Groundnut	Sorghum	Wheat
		m^3./Day	m^3./day	m^3./.day	.m^3./day	m^3./day
June	I	2.1	0.0	15.33	0.0	0.0
	II	2.52	0.0	15.54	0.0	0.0
	III	5.04	0.0	11.97	11.97	0.0
July	I	7.14	0.0	8.61	8.61	0.0
	II	9.66	5.04	7.98	7.98	0.0
	III	9.66	3.99	12.18	14.91	0.0
August	I	9.66	3.15	13.398	18.522	0.0
	II	9.24	2.52	14.28	18.984	0.0
	III	9.24	4.872	16.632	18.984	0.0
September	I	8.82	9.996	17.052	19.404	0.0
	II	8.4	12.768	17.472	17.472	0.0
	III	6.3	17.64	17.64	17.64	0.0
October	I	4.2	22.596	17.724	15.288	0.0
	II	2.1	27.132	14.952	14.952	0.0
	III	1.26	28.476	0.0	0.0	0.0
November	I	1.26	28.98	0.0	0.0	0.0
	II	0.42	29.82	0.0	0.0	12.18
	III	0.0	29.232	0.0	0.0	12.18
December	I	0.0	28.224	0.0	0.0	18.816
	II	0.0	27.72	0.0	0.0	23.1
	III	0.0	25.41	0.0	0.0	27.72
January	I	0.0	22.68	0.0	0.0	27.216
	II	0.0	20.412	0.0	0.0	27.216
	III	0.0	19.152	0.0	0.0	28.728
February	I	0.0	17.346	0.0	0.0	29.736
	II	0.0	0.0	0.0	0.0	28.182
	III	0.0	0.0	0.0	0.0	24.57
March	I	0.0	0.0	0.0	0.0	20.286
	II	0.0	0.0	0.0.	0.0	18.396
	III	0.0	0.0	0.0	0.0	0.0

TABLE 5: AREA, CROPS, CWR AND WATER SUPPLY PER MINOR

Minor name	Cotton/ Feddan	Wheat/ feddan	Sorghum/ feddan	Ground nut/feddan	Fallow/ feddan	Total area/ Feddan	CWR/ m3	Eff_rain / m3	Irr_reqire/ m3	Water_ supply / m3
Toba	270	270	270	270	260	1080	2891586.6	713286	3713040	3672000
Elku	280	256	360	270	360	1526	3054780.96	801763.2	3996258	3819200
Elshourab	180	210	270	270	180	1110	2364150.6	640836	3195660	3048000
Elhuleila	280	270	180	180	200	1110	2583373.8	556122	3107930	3216000
Dolga	80	70	100	10	60	320	723345	163338	849740	808000
Ganneb	233	178	170	180	268	1029	2108478.96	509086.2	2656954	2680000
Timeid	90	183	175	120	175	743	1458541.98	342417.6	1852219	1777600
Mustafa	90	150	180	240	205	865	1610242.2	459648	2278350	2160000
Karabi	180	180	237	170	90	857	2012936.52	517108.2	2609662	2499200
Maiah	180	180	90	90	270	810	1580796	310338	1829250	1944000
Elkamil	90	90	180	180	270	810	1310790.6	402948	1883790	1728000
Tayba	67	140	140	160	120	627	1256869.32	330107.4	1708040	1633600
Gubara	180	180	90	180	180	810	1761480	395010	2198520	2304000
Abu sin	270	180	180	90	80	800	2095480.8	463050	2475090	2520000
Elbasir	180	180	180	180	90	810	1927724.4	475524	2475360	2448000
Hagel said	40	200	90	171	90	591	1261058.4	274318.8	1637053	1660000
Abufru	465	457	44505	474	472	2313.5	4938137.4	1219425.9	6351841	6303200
Zerrug	160	90	150	160	178	738	1486233	413448	1996450	1936000
Angado	90	90	90	180	330	450	1144546.2	322434	1606950	1584000
Sobir	290	245	363	337	180	1565	3200731.38	875456.4	4294184	4104800
Debba	223	90	180	119	180	792	1703244.48	452251.8	452251.8	2122400
Gadelein	331	348	261	261	261	1462	3325753.2	746029.2	4091423	4164000
Sobir (xx)	40	85	85	80	80	370	726056.1	183750	963905	920000
Sheikh	281	248.5	106.5	198.5	171.5	1006	2424479.61	508485.6	2908680	3108400
Wastani	121.5	121.5	122	122.5	123	610.5	1304145.15	322366.8	1676509	1657200