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Integrate GIS and Cropwat Model in Study Crop Water Requirement and Irrigation Scheduling

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Abstract :Water scarcity is a real threat to food production for millions of people in arid and semiarid areas. Due to the over use of available water resources, it has become very important to define appropriate strategiesfor planning and management of irrigated farmland. In this paper, Kenana–Sennar –New Halfa (Sugar cane) region was chosen as the case study area for its special political and economic status and its severe water problem. To achieve effectiveplanning, the information about crop water requirements, irrigation withdrawals, soil types and climatic conditions had beenobtained in the study area. In the meantime, a GIS had been adopted, which extends the capabilities of the crop modelsto a regional level. The Sugar cane region has seasonal water deficits, seriously in Sugar cane germination stage, which is the dominating reason for the low yield per unit area in this region. Under the fortnightly precipitation scenario, in Kenana irrigation was recommended two times in its growth period: 7May and 21May respectively. In Sennar irrigation was also recommended seven times:7 May, 21May, 4June, 18June, 2July , 16July and 27 August respectively. In New Halfa irrigation was recommended nine: 7May, 21May, 4June, 18June, 2July, 16 July, 30 July, 13 August and 27 August
Keywords: Sugar Cane , Climatic Water Deficit, Irrigation scheduling

I. INTRODUCTION

In the near future, irrigated agriculture will need to produce two-thirds of the increase in food products required by a large population increase(1).The growing dependence on irrigated agriculture coincides with an accelerated competition for water and increased awareness of unintended negative consequences of poor design and management. Irrigation systems are selected, designed and operated to supply the individual irrigation requirements of each crop field on the farm while controlling deep percolation, runoff, evaporation and operational losses to establish a sustainable production process. Considering the stupendous task and constraint of time in developing the ultimate irrigation potential, it is necessary to use the modern methods of surveying and analysis tools. Remote sensing and Geographic Information System (GIS) with their capabilities of data collection, manipulation, integration, analysis, presentation, dissemination etc.These systems become more efficient and effective tools for irrigation water management. The capability of GIS to analyze the information across space and time would help in managing such dynamic systems. Soil survey data and GIS are important tools in land use planning. Intertwined, they represent an invaluable and underutilized resource. (2)found that the GIS is an important tool that can be used for optimal allocation of water resources of an irrigation project. Mean water balance components results for different months were stored in GIS databases, analyzed and displayed as the monthly crop water requirements maps. (3)showed that satellite remote sensing coupled with GIS offers an excellent alternative to conventional mapping techniques in monitoring and mapping of surface and sub-surface waterlogged areas. (4) found that for center pivot irrigation under precision farming, remote sensing and GIS techniques have played a vital role in the variable rate of water applications that were defined due to management zone requirements. Fertilizers were added at variable rates. Crop water requirements were determined in variable rate according to the actual plant requirements using SEBAL model with the aid of FAO CROPWAT model. used the soils information recompiled from an uncorrected aerial photographic base to a USGS topographic base map. Soils data were added to numerous other data layers and images. The soil water and crop information required by the checkbook method and previously collected from field observations was estimated by the soil water and nitrogen management model.Geographic Information Systems has been used to improve the irrigation water management and for irrigation schedulinghave built a database program for enhancing irrigation district management, to manage detailed information about district water management and to promote better on-farm irrigation practices. The application of GIS has become popular in water resources management due to its dynamic process to incorporate data and display results. GIS techniques are more time and cost efficient than

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the conventional field techniques and can be used to formulate a management plan much more efficiently and link land cover data to topographic data and to other information concerning processes and properties related to geographic location.

A. The main objectives of the study are

1) To estimate the spatial distribution of the evapotranspiration of Sugar cane.
2) To estimate climatic water deficit.
3) To determine irrigation water use efficiency.

II. MATERIALS AND METHODS

A. Study Area

The projects are located in N 15°28 E 35°34.3, N 14°51.55 E 33°15.62 was chosen as a typical study area, which includesSennar, Kenana and New Halfa）(Fig. 1).It lies in the climate zone with hot-wet summer and cold-dry winter. The mean annual temperature is 27-42C^{o}, and the annual precipitation ranges from200-600mm. Now this area is severeshortage of water resource due to fast economic development and the waste of water in agriculture. Water availability has been one of the main factors limiting economic development and agricultural productivity in this .area. Water management, especially agricultural irrigation water management has become an extremely essential measure to take in this area.

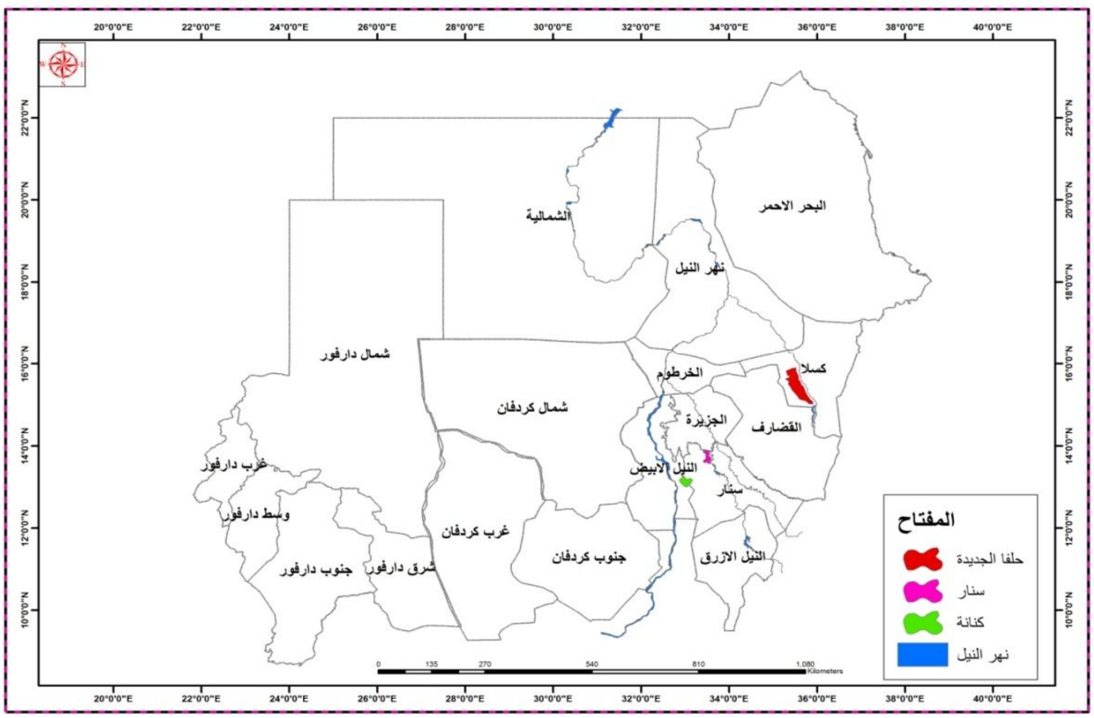

Figure.1. The Study area

B. Methodology

The data we use in this study are mainly meteorological data, including monthly solar radiation, precipitation relative humidity, sunshine time, average yearly air temperature, minimum air temperature, maximum air temperature and wind speed from 2005 to 2010 in 3 meteorological stations. Arc/Info grid spline method is used to interpolate the point climate data into the 1km×1km grid data. Then the grids are converted from geographic projection to Lambert Cylindrical Equal-Area projection.

C. Methods

CropWat for Windows is a decision support system developed by the Land and Water Development Division of FAO, with the assistance of the Institute of Irrigation and Development Studies of Southampton of UK and National Water Research Center of

Egypt. The model carries out calculations for referenceevapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules un various management conditions and scheme water supply.(5)

It allows the development for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rainfed conditions or deficit irrigation. CropWat for Windows uses the FAO Penman-Monteith method for calculation reference crop evapotranspiration (6). The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigationmanagement conditions. Scheme water supply is calculated according to the cropping pattern provided inthe program (7). Studies have shown that the Penman-Monteith method is more reliable than methods that use less climatic data (8). In this paper, the Penman-Monteith equation below was adapted as the sole means of calculating the reference evapotranspiration of sugar cane.

(1)

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma(900/T + 273)U_2(ea - ed)}{\Delta + \gamma(1 + 0.34U_2)}$$

where, $ET0$ is the reference evapotranspiration (mm/a),
Rn is the net radiation (MJ/(m2·d)),
G is the soil heat flux density (MJ/(m2·d)),
$U2$ is the wind speed at a height of2m (m/s),
es is the saturated vapor pressure (kPa).
$ea$is the actual vapor pressure of the air at standard screen height (kPa),
$\gamma$is the psychrometer constant (kPa/°C),
Δ is the slope of the saturation vapor pressure curve between the average air temperature and dew point (kPa/°C),
T is the mean daily air temperature (°C).
ETc is termed as the crop water requirement (CWR) (mm/a). It is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (9); (10) . ETc can be calculated by Equation (2)

$$ET_c = K_c * ET_o \quad \textbf{(2)}$$

Where Kc is the crop coefficient. The crop water requirement (ETc) of sugar cane was computed by multiplying the crop coefficient (Kc) with $ET0$ at different growth stages. The Kc in various germination periods is 0.40 in tellering stage (1.25) in grand or boom period (0.75) in last stage maturity period (0.4) (11).

$$WDR = (ET_c - P)/ETc \times 100\% \quad \textbf{(3)}$$

Where WDR is the water deficit ratio (%),
ETc is the crop water requirement (mm),
P is the difference between rainfall and runoff

III. RESULTS AND DISCUSSION

A. *Crop water requirements*

From the water requirement results computed by the evapotranspiration model, the peak period of suagr cane water use was from early July to late Augest . The average daily ETc was usually more than 8mm. The calculated total sugar cane ETc varied between 2000mm and 3500m within the period of (2005-2010), with an average of 2750. mm (Fig. 2).

B. *Spatial distribution of ETc and climate water deficits*

The spatial distribution of sugar cane evapotranspiration (ETc) in different stages of growing season was estimated by two steps. First, aDEM-based and GIS-assisted methods were employed to estimate the spatial distribution of reference crop evapotranspiration ($ET0$) according to Penman-Monteith model. Then, sugarcane evapotranspiration (ETc) of different stages of growing season was calculated by $ET0$ and crop coefficient (Kc) (Fig. 3).Figure 3 shows that ETc value has temporal variation during growing seasons. Highest value of ETc appears in the（Grand period or boom stage（17 SEP - 1 JUL ） which is varied from 903mm to 1676mm, and lowest *ET*c is seen in the germination stage (15 JUL -10 AUG) which is varied from 92mm to 545mm.

C. Crop water deficits

The average water deficit of suger cane from natural precipitation was 125.5–325.5mm in the first stage in2005–2010 in sugar cane region , while its *ET*c is 364.4–545.5mm (Table1).

Table.1.Water Requirements and Irrigation Scheduling of sugar cane Using GIS and CropWat Model Average water deficit of suger cane in 2005–2010.

Growth Stages	Period		Halffa	Sennar	Kenana
Germnation	15july-10august	ETC mm	418.32	545.50	364.40
	(stage1)	P mm	292.75	220.00	171.20
		ETC-P	125.57	325.50	193.20
		WDR(%)	30.02	59.67	53.00
Tillering	10Augest-17Septmber	ETC mm	509.88	559.60	449.90
	(stage2)	P mm	565.50	902.00	153.80
		ETC-P	-55.62	-342.40	296.10
		WDR(%)	-10.91	-61.19	65.81
Grand or boom	17Septmber-1July	ETC mm	903.11	1001.40	116.94
	(stage3)	P mm	6.10	870.60	173.80
		ETC-P	897.01	130.80	-56.86
		WDR(%)	99.32	13.06	48.60
Maturity	1July-8Augest	ETC mm	1019.70	1299.15	594.30
	(stage4)	P mm	420.52	331.50	146.30
		ETC-P	599.18	967.65	448.00
		WDR(%)	58.76	74.48	75.38

During 2005–2010, there are (10) times of water deficit occurring in the germination stage, there are (3) times of deficit in the tillering(1) stage, times of deficit in the grand and boom(3) and (3)in the maturity stages. The serious water deficit in the seeding stage is the primary reason for low cane yield in this area, since the water deficit is from 13.06% to 99.32% of ETc. So the crop yield may obviously increase if irrigation water is supplied during the critical growth stage.

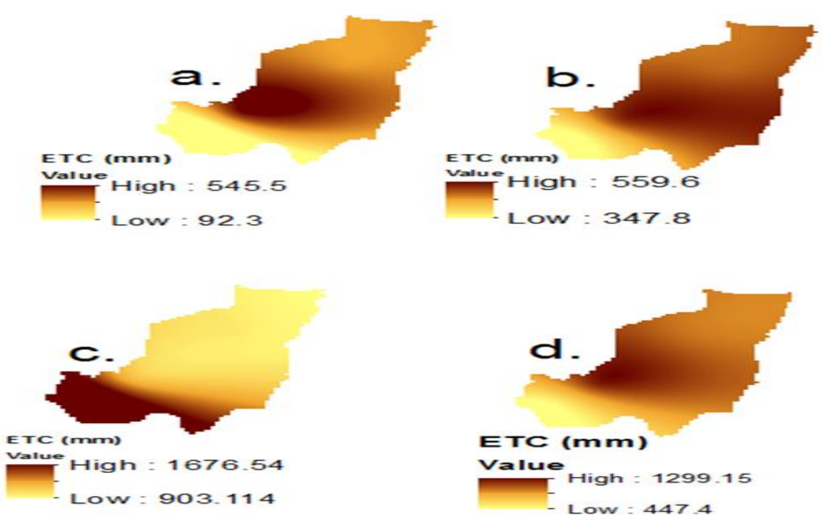

Figure 3. Spatial distribution of ETc in New Halfa, Kynana and Sennar in 2005-2010

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a. Germination (15 JUL - 10 AUG) b. Tillering (10 AUG - 17 SEP) c. Grand period or boom stage (17 SEP - 1 JUL) d. Maturity (1 JU - 8 AUG)

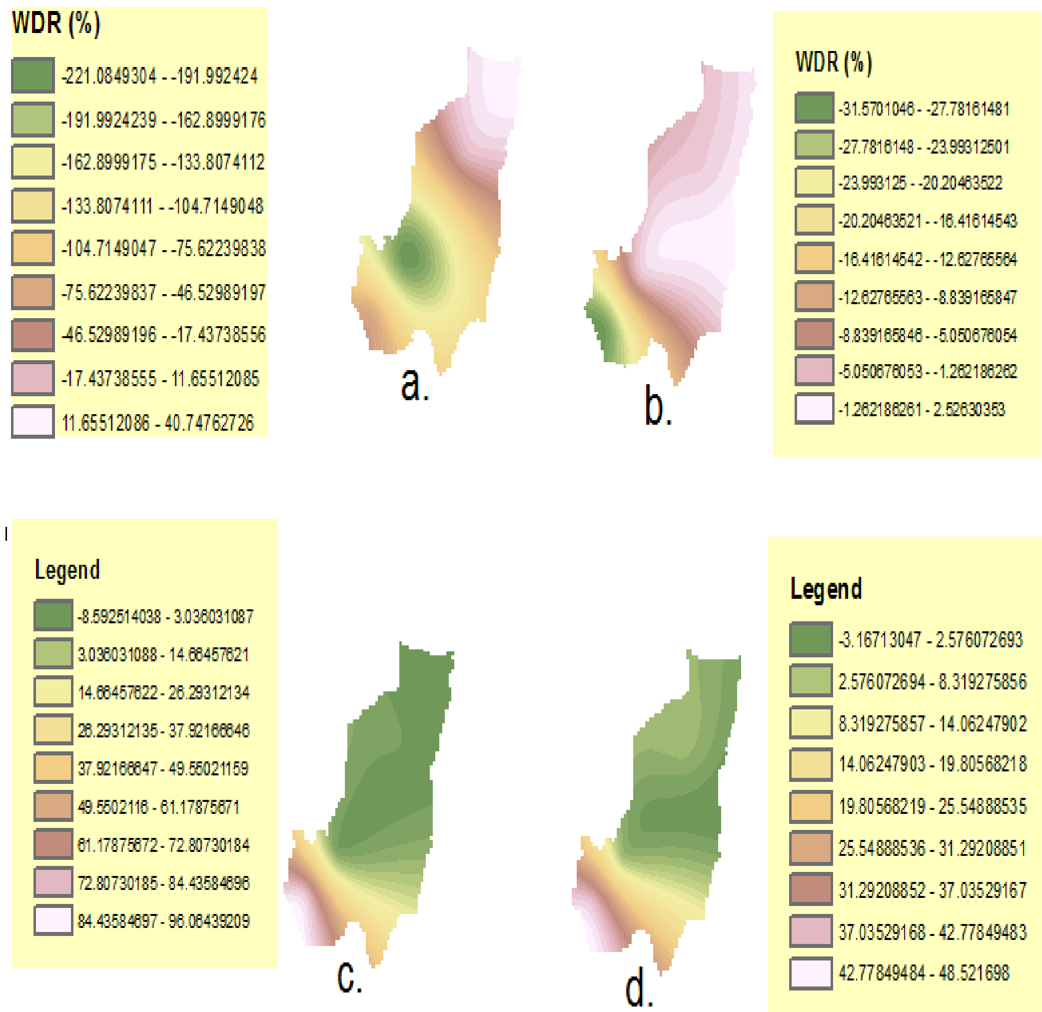

Figure 4. Spatial distribution of WDR in New Halfa , Kynana and Sennar in 2005-2010 a. Germination (15 JUL - 10 AUG) b. Tillering (10 AUG - 17 SEP) c. Grand period or boom stage (17 SEP - 1 JUL) d. Maturity (1 JUL - 8 AUG)

Figure 3 shows the spatial distribution characteristic of water deficit in different growing stages. In the first stage (Fig. 4a, germination) ,Fig. 4c, grand or boome stage and four stages (Fig. 4d), and maturity stages), the average water deficit of sugar cane very high in the whole area, since there is little rainfall in the three stages. In order to reduce the loss of production, farmers should irrigate once or twice in this period. In the second stages (Fig. 4bTillering stage;), the water deficit was different in different areas: waterdeficit ratio (*WDR*), which is about 65%; in Kenana area.

D. Irrigation schedule

In order to compute the irrigation schedule using the CropWat model, the information on soil type, such as total available moisture, readily available moisture and initial available moisture are also required. The results are as follows: In dry years, it needs irrigation to minimize the loss of production. So in the study we analyze one scenario: Under fortnightly precipitation condition and under these weather situations if the sugar cane has not obtained enough water, the production will drop heavily. The irrigation schedule for sugar cane was planned for two or three times under the one scenario. The irrigation scheduling in Kennan ,Sennar and New Halfa in Tables 2.

Table 2. Irrigation scheduling in Kenana Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	1.03	86.43	8	70.4	0
21\May	270	162	1.23	108.8	8.7	68.9	0
4\Jun	270	162	3.6	65.6	0	0	0
18\Jun	270	162	9.6	46.7	0	0	0
2\Jul	270	162	21.7	62.1	0	0	0
16\Jul	270	162	13.8	15.9	0	0	0
30\Jul	270	162	10.7	2.13	0	0	0
13\Aug	270	162	10.1	2	0	0	0
27\Aug	270	162	11.6	5.6	0	0	0

Notes: SMD—soil moisture deficit;
RAM—readily available moisture;
TAM—total available moisture;
Net Irr.—irrigation depth applied;
Lost Irr.—irrigation water that is not stored in soil; The same in the below tables

Table3.Irrigation scheduling in Sennar Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	0	104.22	8.8	104.22	0
21\May	270	162	2.62	82.18	4.6	64.16	0
4\Jun	270	162	0.42	104.06	6.4	86.28	0
18\Jun	270	162	1.58	98.32	6.2	85.62	0
2\Jul	270	162	0	107.88	8.4	107.88	0
16\Jul	270	162	2.08	57.62	4	43.4	0
30\Jul	270	162	5.22	33.4	10.42	0	0
13\Aug	270	162	7.26	36.76	0	0	0
27\Aug	270	162	2.22	68.94	4.4	41.46	0

Table 4. Irrigation scheduling in New Halfa Region (fortnightly precipitation)

Date	ATM	RAM	Total rain fall	SMD(NoIrr)	SMD(Irr)	Net(Irr)	Lost Irr
7\May	270	162	0.16	95.58	8.4	85.48	0
21\May	270	162	0.32	98.7	8.4	85.3	0
4\Jun	270	162	3.56	95.1	8.8	83.3	0
18\Jun	270	162	1.5	73.3	3.6	43.3	0
2\Jul	270	162	2.02	66.92	2	20	0
16\Jul	270	162	3.14	61.94	2	20.4	0
30\Jul	270	162	4.92	63.34	22.5	42.6	0
13\Aug	270	162	2.94	77.54	25.7	67.3	0
27\Aug	170	162	3.34	38.84	10	60.32	0

In irrigation scheduling for Sugar cane at three sites, the daily soil moisture balance option was selected to show the status of the soil every day, the soil moisture changes in the growing season and estimated total yield reduction. First, we will analyze the irrigation scheduling under the fortnightly precipitation scenario. Table 2, Table 3 and Table 4 shows soil moisture changes during the Sugar cane growing season in Kenana, Sennar and New Halafa sites using the scheduling criteria: irrigating at fixed intervals of 14 days and variable depths (the soil is returned exactly to field capacity with no or less excess irrigation), when the soil moisture deficit reaches the readily available moisture. Scheduling option with 2 times of irrigation of 70.5mm (7May), 68.9mm (21 May) at Kenana can be applied when soil moisture deficit falls below the readily available moisture, which seems to be the most suitable option will be the best choice (Table 2) .According to the analysis. In Sennar , scheduling with seven times of irrigation of 104.2 mm (7 May), 64.1mm (21May) and 86.2mm (4 June) , 85.6mm(18June), 107.8 mm(2July) , 43.4mm(16July) and 41.4 mm(27August) seems to be the best option Table 2). In New Halfa , scheduling with nine times of irrigation of 85.4mm (7 May) , 85.3mm (21 May) , 83.3mm(4June) , 34.3 mm(18June) , 20.0mm (2July) , 20.4mm (16 July) , 42.6mm(30 July), 67.3mm (13 August)and 60.3 mm (27August) (Table 6).

V. CONCLUSIONS AND RECOMMENDATIONS

The Sugar cane region has seasonal water deficits, seriously in Sugar cane germination stage, which is the dominating reason for the low yield per unit area in this region. To remedy the water deficits during its critical growth periods and avoid the waste of water in the mean time, precise supplemental irrigation schedules were recommended in different weather conditions (the fortnightly precipitation).Under the fortnightly precipitation scenario, in Kenanairrigation was recommended two times in its growth period: 7May and 21May respectively. In Sennar irrigation was also recommended seven times:7 May, 21May, 4June, 18June, 2July , 16July and 27 August respectively. In New Halfa irrigation was recommended nine: 7May, 21May, 4June, 18June, 2July, 16 July, 30 July, 13 August and 27 August.Precise supplemental irrigation in critical growth periods is valuable for reducing the loss of sugar cane production, especially during the dry season.

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