Assessment of Climate Change Impacts on Crop Water Requirements Under Gezira Scheme Condition. Sudan

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ABSTRACT

Water rather than land (80 million hectare, mha) has limited the agricultural production and expansion in Sudan. Any further reduction in irrigation water availability thus would have severe detrimental impacts, especially on irrigated agriculture that is currently producing 50% of the crop yields. There is a very high confidence that the arid and semi-arid areas would suffer a decrease in water resources due to climate change. The specific objective of this study is to assess the impacts of climate change on the crop water requirements (CWR) of the main grown crops in the Gezira scheme. Two approaches were used for the assessment. The first is the HADGEM2-ES climate change model approach. The second is the Change Factor approach. Both indicated decreasing trends in rainfall and the opposite holds true for temperature. Accordingly, the CWR increased by 5-45% for cotton, 9-45% for groundnut, 9-51% for sorghum, 15-52% for wheat and 4-40% for small vegetables. Consequently, with the assumption that the irrigation efficiency is 100%, the command area of the scheme (2.1 million feddan) by the year 2040 would need an irrigation water supply of 6.6 - 9 km^3. Thus, the total CWR would be increased by 50% (3.0 km^3), which outweighs the drawn benefits of the Rosieres dam heightening project. Under the condition that the Sudan's share in Nile water (18.5 km^3) is remained constant the efficient use of irrigation water is the paved way to follow for bridging such tremendous expected deficit. This necessitates capacity building programs and win-win cooperation with Egypt and Ethiopia.

Keywords: Climate change, impact assessment, crop water requirements, Gezira scheme

INTRODUCTION

About 38% of the gross value of production comes from irrigated agriculture worldwide (De Fraiture and Wichelns 2010). Irrigation systems however are already under pressure to produce more with fewer water supplies (Molden et al. 2010). De Fraiture and Wichelns (2010) found that about 75% of the additional food supply by the year 2050 can be met by improving the productivity of the existing irrigated areas.

The projected dramatic growth of human population in the eastern Nile (EN) region (Ethiopia, Egypt, Sudan and Eritrea), that is estimated at 400 million by the year 2050 (UN, 2012), necessitates the production of more food and fibers let alone the expansion in hydropower which will significantly alter the hydrological regime. This projected food demand should be met by the irrigated agriculture since the repeated drought cycles in the region would drive the irrigation expansion. The planned irrigation expansion in the EN is projected to 3.8 mha with a total irrigation water requirement of 49 km^3 yr^{-1}, which is impossible to be met not considering other water uses (Eastern Nile Irrigation and Drainage Study, 2009).

Water rather than land has limited the agricultural expansion and production in Sudan where the irrigated agricultural sector occupies currently only 1.8 million hectare (mha), contributing more than 50% of crop yields (UNEP 2007). Under the terms of the Nile Water Agreement (1959), Sudan has the right to use only 18.5 km^3, measured at Aswan. Abdallah (2001) projected the irrigation water demand that needed by the year 2027 at about 30 km^3. Thus, there is a clear demand for water planners to focus more on the efficient use of the water resources.

There is a very high confidence that the arid and semi-arid areas, e.g. Gezira scheme would suffer a decrease in water resources due to the climate change (Kundzewicz et al., 2007). El-shamy et al. (2009) concluded that about 10 tested models of the Global Circulation Models (GCM) predicted a reduction pattern in the total annual precipitation in the upper Blue Nile catchment; whereas all the models predict increase in the temperature. Consequently the potential evapotranspiration would increased by 2–14%. Dile et al. (2013) found that due to climate change the monthly mean flow

volume of the Gilgel Abay River, Upper Blue Nile Basin would be decreased between 40% and 50% during the period 2010-2040. However, the study of Kim and Jagath (2009) suggested mild increases in hydrologic variables(precipitation, temperature, potential evapotranspiration, and runoff) across the upper Blue Nile River Basin. Kim et al. (2008) predicted the following uncertain results (1) the climate in most of the Upper Blue Nile River Basin is likely to become wetter and warmer in the 2040-2069; (2) low flows may become higher and severe mid- to long-term droughts are likely to become less frequent in the entire basin. Shamseddin et al. (2014) stated insignificant decreasing trends in the seasonal rainfall of Wadmedani and Sennar stations, central Sudan. The IPCC (2013) report predicted a general increase in temperature of 1-2 ^{o}C in the Blue Nile Basin, including Gezira scheme using the baseline of 1986-2005. Thus, Gezira scheme water supply is expected to be reduced due to climate change.

Climate change on the other hand will likely increase the frequency of extreme events, i.e. droughts and storms (IPCC 2007). Such drought events would have severe impacts on the

Sudan's agriculture. The well known droughts of 1980s for instance resulted in uprooted changes in the cropping patterns of the Sudanese irrigated schemes since the governments became more willing to irrigate sorghum production that is used to be a rainfed-dependent, on the expensive of cash crops (Guvele 2002). The result was a massive misuse of irrigation water (Ahmed et al. 2002). Therefore, there is a clear demand for assessing the expected impacts of climate change and climate variability on the irrigated agriculture in Sudan. The specific objective of this study is to assess the impacts of climate change on the crop water requirements of the main grown crops in the Gezira scheme.

MATERIAL AND METHODS

CLIMATE CHANGE MODEL SELECTION

The Hadley Centre Earth System Model (HADGEM2-ES) is an applied climate change prediction model. This model uses feedbacks from ecosystems, aerosols and chemistry (Hadley Centre 2013). It was designed to run the major scenarios for the fifth Climate Change Assessment Report of the Intergovernmental Panel on Climate Change, IPCC-AR5, (Hadley Centre 2013). The model compromises an atmospheric GCM at N96 and L38 horizontal and vertical resolution, and an ocean GCM of a 1-dgree horizontal resolution (Hadley Centre 2013).The HADGEM2-ES model, among other models, is currently under testing for building the Sudan National Climate Change Adaptation Plan (NAP) by the Higher Environmental Council, Sudan, using the historical data of the period 1950-2005. This study applied the HADGEM2-ES model because the tag "ES" that stands for the "Earth System" refers to the fact that the model includes further processes than just represents the physical atmospheric and oceanic processes commonly included in GCM models. It is worth to mention that the applied model has some limitations as it underestimates the reductions in carbon emissions required to achieve atmospheric carbon dioxide stabilization at a given level (Hadley Centre, 2013).

PREPARATION OF NEEDED CLIMATIC PARAMETERS:

Rainfall and temperature datasets (2014 – 2040) was firstly screened and obtained using the Integrated Data Viewer (IDV 4.0u1) software. The climate parameters that are necessary for estimating the crop water requirements on the CROPWAT model were projected within a carbon dioxide (CO_2) concentration of 450 ppm. The remained required climatic parameters were estimated as follows:

Relative humidity:

The general circulation model (GCM) predicted no change in relative humidity, i.e. while temperature increases up, proportionally evaporated water from water surface (e,g, oceans) would increase (NASA 2013). Many scientists do not agree with this assumption (Sherwood et al. 2010). This study followed the prediction of GCM model, i.e. there is no change in relative humidity.

Wind speed:

The GCM expected that wind speed will tremendously increase at many parts of the world (Wind Power 2008). For the Gezira region, the GCM, with a coarse resolution, projected an annual increase (summer and winter seasons) in wind speed of 75% at 2 m height, which was considered for this study.

Radiation:

The Solar irradiance indicated by the radioactive force is increased by 0.12 watt/m^2 since the year 1750. Such increase could be considered negligible relative to the amble prevailed solar energy in central Sudan of 18-26 MJ/m^2 (Adam 2013). Thus, the study assumed no change in solar radiation.

ESTIMATION OF CROP WATER REQUIREMENTS:

The water requirements of the main grown crops in the Gezira scheme were estimated using the CROPWAT 8.0 software on the basis of Penman-Montieth approach. The estimation was carried out according to two projections: the HADGEM2-ES model and the Change Factor. The Change Factor approach depends on setting a climatology baseline (Wilby et al. 2004). The time series of 1960-2010 was taken as a baseline; then the resulted changes were added to each month of the year. It is worth mentioning that under the Change Factor approach only changes on rainfall and temperature were applied. The trend and magnitude of change time series were estimated following the Mankendall nonparametric test and the Theil and Sens's method, respectively as follows (Nasri and Modarres 2009):

$$S = \sum_{i=2}^{N}\sum_{j=1}^{i-1} sign(x_i - x_j) \qquad (1)$$

$$Sign(x_i - x_j) = \begin{cases} 1 if\ (x_i - x_j) \succ 0 \\ 0 if\ (x_i - x_j) = 0 \\ -1 if\ (x_i - x_j) \prec 0 \end{cases}$$

Where, the x_j are the sequential data values. The mean, *E*, and variance, *Var*, were estimated as follows:

$$E(S) = 0 \qquad (2)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)}{18} \qquad (3)$$

Where, t_p and q are the number of ties for pth values and the number of tied values. To calculate the standardized statistical test (Z_{MK}), three cases might exist:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \rightarrow S \succ 0 \\ 0 \rightarrow S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \rightarrow S \prec 0 \end{cases} \qquad (4)$$

Positive and negative Z_{MK} values indicate increasing and decreasing trends, respectively. The significance of such decreasing and increasing trends are determined at two P values (p = 0.01 and 0.05). The change magnitude, expressed as percentage of mean, is determined by the Theil and Sens's method (Basistha et al. 2009):

$$Q_i = \frac{x_j - x_i}{j-k} \text{ ...... for i =1, 2-----N} \qquad (5)$$

Where, x_j and x_k are data values at times j and k ($j > k$), respectively. The median of the N values of Q_i is the slope estimator. The percentage change equals the median slope multiplied by the period length divided by the corresponding mean.

RESULTS

HADGEM2-ES MODEL PREDICTION

The downscaled datasets (rainfall and temperature) of a 0.5 degree resolution were obtained from the HEC, Sudan. The datasets was projected to the Gezira scheme through the integration of two GIS based maps that are the Nile river shape file, so as to locate the Gezira scheme, and the downscaled datasets using the IDV 4.0u1 software. This procedure expected to result in coarse resolution results. The model calibration yielded a good rainfall trend relationship (Figure 1a), however it showed a very poor relation based on the determination coefficient (R^2) of 0.23 (Figure 1b). The model was validated using temperature values for the period 2005-2013, resulting in a weak determination coefficient of 0.38 (Figure 2). The model is respectively over-predicted and under-predicted rainfall and temperature. Thus, the model results present here would be rather optimistic. Table (1)
shows the monthly obtained means of rainfall and temperature (2007-2040). The annual rainfall showed a decreasing trend with a range of 139 - 291 mm.

The annual temperature is explicitly experienced an increased trend (Figure 3), averaged in 30 ^{o}C. Table (2) summarizes the monthly trend analysis of rainfall and temperature. Monthly rainfall showed mixture results as the period July-August experienced a decreasing trend, contradicting the trend of the period June-September. With the exception of January and March the monthly maximum temperature showed increasing trends, while the April-June period showed no change. The minimum temperature showed an increase pattern for during November – April; while the remained months showed no change.

CHANGE FACTOR

The analysis of regional rainfall (1975-2010) and temperature (1960-2010) time series, i.e. the average of Wadmedani, Sennar, El-Obied and Gedarif stations resulted in a significant decreasing trend in rainfall (P = 0.01) and a significant increasing trend in temperature (P = 0.01). Following the Theil and Sens's slope estimator method the decreasing amount in rainfall since 1975 is estimated at 27 mm (0.77 mm/year) and 1.33 ^{o}C (0.05 ^{o}C/year) in temperature since 1960. For applying the worst conditions, changes in rainfall and temperature of 70 mm and 2 ^{o}C were considered, respectively. Figure (4) shows the results of the randomness test based on the regional datasets. The datasets were found to be random since the autocorrelation coefficients do not cut the upper and lower confidence intervals of 95%. Thus, the datasets quality is good.

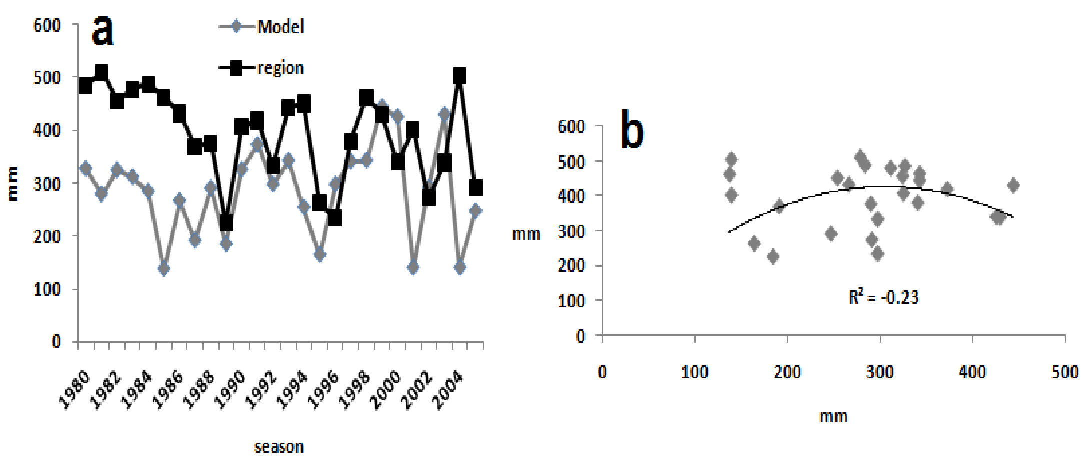


Figure 1. The HADGEM2-ES calibration with the regional rainfall for the period 1980-2005: **a** for general trend and **b** is the polynomial trend

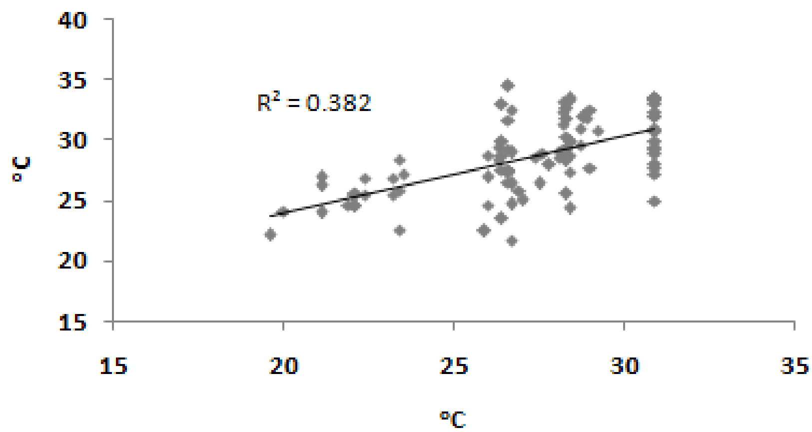


Figure 2. The model validation using temperature dataset (2005-2013)

Table 1. Gezira scheme monthly means of rainfall (mm), minimum (Tmin) and maximum (Tmax) temperature (°C) based on HADGEM2-ES model by the year 2040

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	0.0	0.0	0.0	0.0	0.0	21.7	79.7	109.3	34.2	244.9	0.0	0.0
Tmin	17.7	19.2	21.6	24.2	24.5	24.5	24.5	24.5	24.5	24.5	22.9	19.1
Tmax	34.7	36.0	38.3	38.5	38.5	38.5	37.9	36.8	37.4	38.3	37.7	35.0

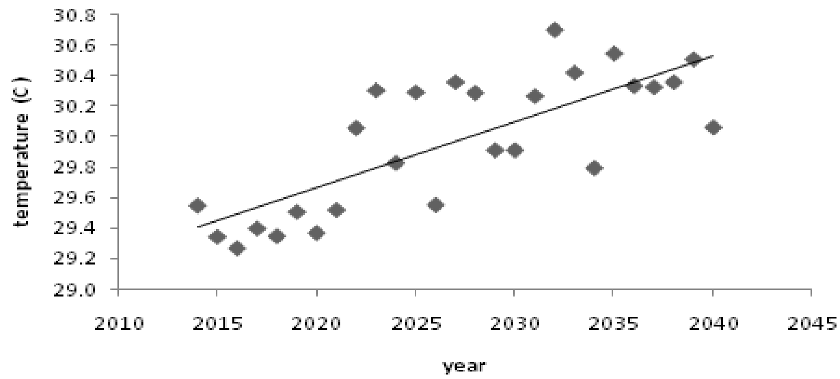
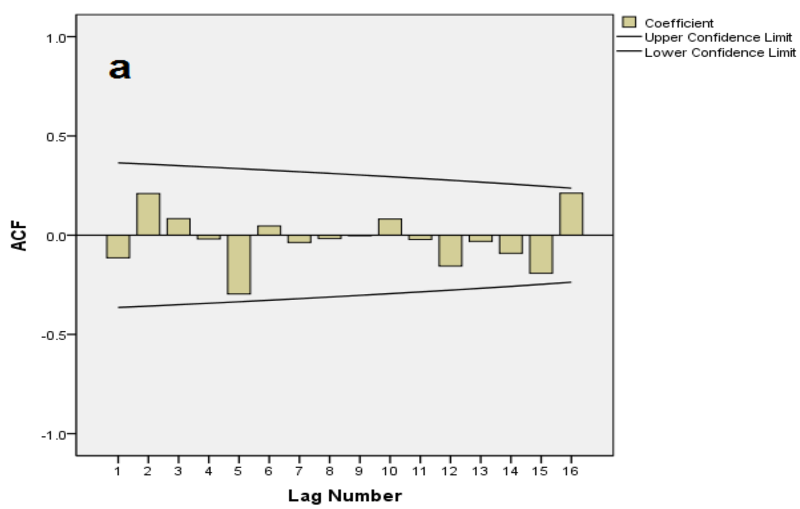


Fig
. The model annual temperature trend in the Gezira region fig ure 3

Table 2. The model monthly percentage trends in rainfall, minimum (Tmin) and maximum (Tmax) temperature by the year 2040, indicated by Mankendal test. The positive and negative signs indicate increasing and decreasing trend, respectively.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall	0	0	0	0	0	15	-80	-86	4	0	0	0
Tmax	-40	77	- 40	0	0	0	84	100	126	44	99	119
Tmin	91	90	93	16	0	0	0	0	0	0	101	179



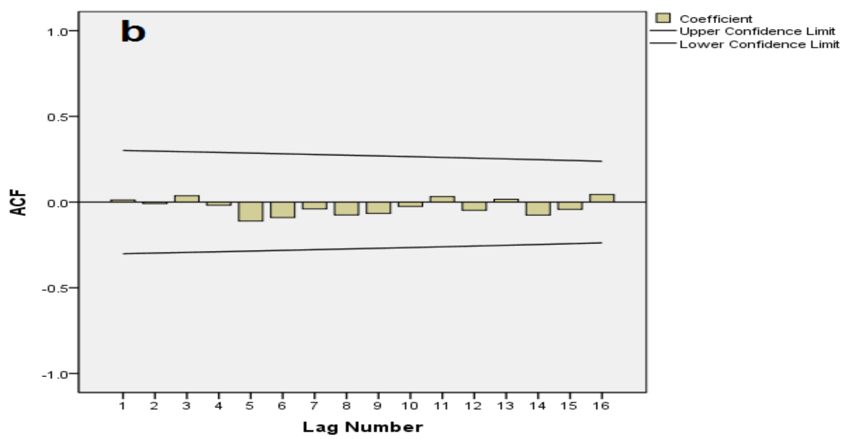


Figure 4. Regional rainfall (a) and temperature (b) randomness test using the autocorrelation function (ACF). Solid lines are confidence intervals

ESTIMATED CROP WATER REQUIREMENTS
HADGEM2-ES

Figure (5a) shows the predicted crop water requirements of the main grown crops in the Gezira scheme compared with the current crop water requirements, based on the current prevailing climate conditions following the Penman-Montieth formula (CROPWAT).

CHANGE FACTOR
Figure (5b) shows the predicted crop water requirements based on the Change Factor approach, relative to the current ones for the main grown crops in the scheme.

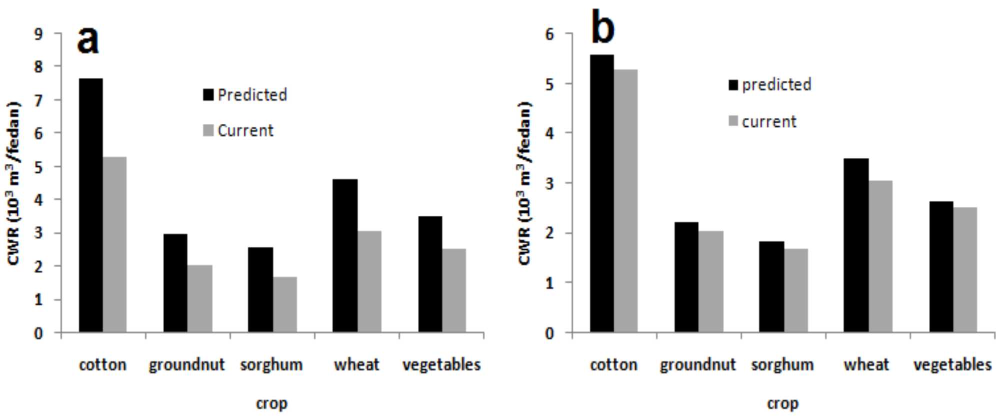


Figure 5. Projected crop water requirements (CWR): **a** using the HADGEM2-ES data and **b** using Change Factor approach

DISCUSSION

Both the HADGEM2-ES model and Change Factor approaches resulted in decreasing trends in rainfall coupled with increasing trends in temperature. Thus, the aridity of the region is expected to increase and in turn the scheme irrigation water consumption would be increased. Based on the HADGEM2-ES approach, the percentages of change in crop water requirements (CWR) would be 45% for cotton, 45% for groundnut, 51% for sorghum, 52% for wheat and 40% for small vegetables compared with the current CWR. The projected changes in CWR using the Change Factor approach would be 5%, 9%, 9%, 15% and 4%, respectively. It is obvious that the latter approach showed lower changes compared to the first. This is attributed to that the Change Factor approach considered no-changes in wind speed. Consequently, the expected average irrigation water consumption, using irrigation efficiency of 100%, would be 9–6.6 km^3 compared to the current of 6 km^3 to irrigate the command area of the scheme that is 2.1 million fedan (0.88 mha). Thus, by the year 2040 the current CWR would be increased by 50% (3.0 km^3), which would deplete the majority (70%) of the water that expected to gain from the Rosieres dam heightening project.

The expected increase in the crop water requirements would jeopardize the agricultural developmental plans of Sudan, e.g. developing newer irrigation projects such as the Rahad phase II agricultural project. Albeit with the obtained calibration and validation results of the HADGEM2-ES model were generally poor, however, strategically, the planners should base the Gezira scheme climate change adaptation plans using the HADGEM2-ES model so as to sustain the scheme for the worst climate conditions.

The irrigation scheduling in the Gezira scheme is dependent on the crop sowing dates. Thus, any delay in sowing dates of summer crops, e.g. sorghum groundnut would result in overlapped irrigation conditions. This jeopardizes the irrigation water supply to winter crops since the accumulated crop water requirements would exceed the canals capacity. Thus, the projected increase in temperature would disturb the scheme

sowing dates, leading to detrimental impacts on water management in general and on the irrigation scheduling in particular unless in-advance measures are taken, of which physical rehabilitating the canalization systems is the most important. Plusquellec, (1990) stated that the Gezira scheme distribution of water is only equitably fair under the conditions that the major and minor canals are silt-free. Also, the current crop varieties under the expected climatic change conditions need to be revisited so as to keep pace with the expected increase in temperature.

CONCLUSION

Most of the GCM models expected a reduction trend in the total annual rainfall in the upper Blue Nile catchment coupled with an increasing trend in the temperature. Thus, the Gezira scheme supply-demand relationship would be detrimentally changed, necessitating efficient use of irrigation water, especially at farm levels. This calls for conducting a deep multi-criteria assessment of climate change impacts on the scheme in order to sustain the scheme.

The approaches applied in this study (HADGEM-ES model and Change Factor approach) projected different results of crop water requirements. However, both of them indicated increasing trends in crop water requirements by the year 2040. The results of the GCM models in general and HADGEM-ES model in particular suit strategic planning (long-term objective), while the Change Factor approach suits tactical planning (short-term objectives).

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تقييم آثار التغير المناخي على احتياجات المحاصيل المائية تحت الظروف المناخية بمشروع الجزيرة، السودان

الخلاصة

المياه وليس الأرض (88 مليون هكتار) هي المحدد للتوسع و الإنتاج الزراعي في السودان. لذلك أي نقصان في مياه الري المتاحة حاليا سيترتب عليها آثار سلبية خصوصاً في القطاع المروي و الذي ينتج حالياً 50 % من الإنتاج الزراعي . إن المناطق الجافة و شبه الجافة سوف تعانى، بدرجة عالية من الثقة، من تناقص المياه وذلك بسبب التغير المناخي. هدفت هذه الدراسة إلي إجراء تقييم لأثر التغير المناخي علي حوجه المحاصيل الرئيسية للمياه فى مشروع الجزيرة. تم تقييم هذه الحوجة باستخدام طريقتين: نموذج مناخي (HADGEM2-ES) و طريقة معامل التغير (Change Factor). باستخدام كلا الطريقتين، وجد أن هنالك نقصان معنوي في الامطار مصحوبة بازدياد في درجات الحرارة. علية فإن حوجت المحاصيل للمياه يتوقع أن تزداد ما بين 5 – 45 % للقطن، 9 – 56 % للفول السوداني، 9 –51% للذرة، 15 – 52 % للقمح و 4 – 40 % للخضروات. بافتراض كفاءة ري 100% فان جملة مساحة مشروع الجزيرة (2.1 مليون فدان) سوف تحتاج إلي 6.6 – 9.0 كلم مكعب من المياه مقارنة بالاستخدام الحالي 6.0 كلم مكعب مما يعني استهلاك المشروع لجملة المياه المتوفرة من مشروع تعلية خزان الرصيرص. بافتراض ثبات حصة السودان من مياه النيل(18.5 كلم مكعب) فإن الاستخدام المرشد للمياه هو السبيل الوحيد للسودان لمقابلة هذه الاحتياجات المستقبلية و الذى يتطلب برامج لبناء القدرات فى مجال إدارة المياه مع إحكام التعاون مع مصر وأثيوبيا.