Determination of Crop Productivity Based on Climate Change using Geographic Information Systems

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Abstract: This study is aimed at designing an algorithm to analyze the effects of climate on crops. Two different crops named sorghum and sesame were selected as a case study in Doka area in Sudan because this area receives good amount of rain suitable for the production of the selected crops, **so** ***GIS technology was used to determine the vegetation map of the study area. The idea applied was to select a sample of data for a period of ten years and determine the productivity of the crop in this period and then the production values of these years were arranged from the highest value of productivity to the lowest value and then determined the highest value of productivity in these years and note to the values of the climate effects (the best climatic conditions led to high productivity) which led to predicate and determine the crop productivity based on climate affected values, cultivated area (CA) ,Harvested Area (HA) , Damage Area (DA) and the area affected by Evapotranspiration Negatively (AEVN), so the results which have been accessed are that the algorithm can calculate crop yield with high accuracy because it depends on all climatic elements that affect crop growth, so all meteorological organizations in the world can use this algorithm principle to assess crop yields and Accurate assessment of production.***

Keywords : Cultivated Area(CA), Harvested Area(HA), Damage Area(DA), Area affected by Evapotranspiration Negatively(AEVN).

I. INTRODUCTION

Sorghum and sesame are among the cereal crops that have been the main food for man since ancient times. These crops are cultivated in various parts of the world. Sorghum is cultivated during the second half of April after the early winter harvests such as wheat and barley. Early cultivation is preferred as it allows sorghum to grow well and agriculture after May causes a clear crop shortage. Idris(1990) the rainfed subsector produces the bulk of the sorghum food grain, all the sesame, and a very large share of the country's groundnuts production[8]. Mavi(2004) The agriculture industry is the most sensitive to variability in weather and climate[15].

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The factors that affect the growth of crops and the amount of crop need for water, note that the climatic factors that affect any rain crop are the amount of rain, evaporation, solar radiation, soil type, temperature, and wind speed. Evapotranspiration is a term that reflects the amount of water loss from the leaves of plants and from the soil surface.

It is also found that all areas in the same latitude are similar in climatic characteristics and the same crops can be produced if the same climatic conditions are available. Savva(2002) Once the crop water and irrigation requirements have been calculated, the next step is the preparation of field irrigation schedules[13].

Sorghum is a major food grain crop in Sudan. It is produced in mechanized and traditional irrigated and rain fed subsectors. It is also an important food crop in many African and Asian countries and is used in the United States of America as feed for livestock and also used in the bread industry.

Harpal (2004)The first half of the twentieth century saw great contributions toward the quantification of water loss and use by plants[7].The Sudan Meteorological Authority is working to monitor and analyze the weather elements to provide the required services for the safety of field agriculture, so the lack of rain is the main factor limiting plant growth and agricultural production in general.

In addition to the above, this study is distinguished from the previous studies in the following:

1- It should be noted that most of the previous studies done in this area are theoretical studies that are not computerized and have been based on the calculation of productivity on the rate of rain only, which led to errors in forecasts and inaccuracies in the results.
2- Most of the previous studies were unable to spatially analyze the maps and cannot display the maps from the satellite, which is available in this study.
3- All the data for this study is saved in a database in the form of tables and each table represents the entity of the environmental impact assigned with all its characteristics with the possibility of adding and modification and carry out all operations whenever it is established and this is not available in all previous studies.
4- This study deals with GIS in terms of concepts, technologies and apply these technologies to the Dokka region in Sudan.

5- Through personal interviews the researcher found that these concepts is not available at the competent authorities were dealing with the spatial analysis and link descriptive information maps of agricultural areas, resulting in an information system can answer all queries for these agricultural areas.

6- At the end of the study recommendations were proposed that we believe are necessary to clarify the vision of agricultural meteorology in the study area and perhaps the most important need to use modern technologies and the concept of e-government and GIS on the Internet.

The rest of this paper is organized as follow. Section II describes study area. Section III presents the related work.

II. STUDY AREA:

Dokka town is located in the eastern part of Sudan between longitudes $33-3^{\circ}$ and latitudes $14-16^{\circ}$ with an area of approximately 78,000 km^2. Adam (2010)The area is known for its production of sorghum and sesame[6], so 90% of the population works in the field of agriculture with an estimated average population density of about 10 people per square kilometer. The survey was conducted in the rural town of Dokka where mechanized farming has been introduced to the southern part of Gadarif Region for the first time. divided into agricultural areas in Gedarif into three main regions. Hussein(2013) The southern region with the highest rainfall ranging from 600 to 900 mm, the central region with medium rainfall about 500-600 mm, a northern region is scarce in rainfall, with an average rainfall of less than 500 mm[10]. The Dokka area planted sorghum and sesame and it produces about 1/3 of the national production of sorghum or about 17% - 30% of production and thus have a significant impact in providing food requirements of the country[5]. Magboul et al (2015). Geographical location of the study area covers an area of about 55*40 square kilometers.

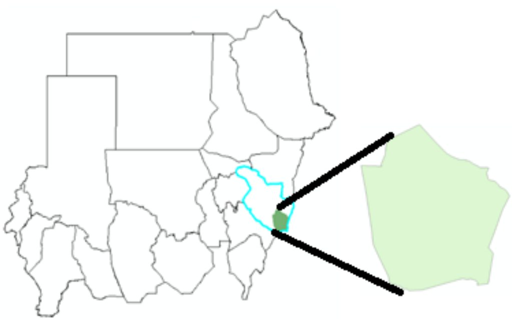

Fig.1 location of study area Dokka state

III. LITERATURE REVIEW

Sulieman (2007) Agriculture is the main economic activity, followed by livestock raising in the traditional seasonal transhumance pattern[1]. Bithell (2011) The sustainable management and use of water resources for food production is an important issue [2]. Goomes (1986) Over most of the simi-arid world, rainfall controls final crop yields[3]. Babiker (2015) Climate change extremes such as flooding and seasonal drought are already undermining the economies of countries in the Horn of Africa[5]. Richard(2000) A commonly used approach for predicting consumptive use of water by irrigated crops is the crop coefficient - reference evapotranspiration [9]. Omer (2011)The primary source of water for agricultural production for most of the world is rainfall[11]. Ibrahim(2009) Expansions of mechanized farming in Gadarif state have attracted many migrants from within and outside Sudan [12].

The steps of the algorithm are defined as about 17 steps in which the yield of the crop is calculated by entering the values of all environmental influences and then calculating the productivity. This algorithm was designed based on several hypotheses. A sample of the yield of the previous ten years of sorghum and sesame yields was taken Comparing the yield of the crop with the environmental effects of each effect separately and other elements that affect the crop other than environmental effects and the steps of this algorithm can be described as follows:

1. Determine the cultivated area and compare it with the yield of the year.
2. Determine the harvested area and compare it with the yield of the same year.
3. Calculate the difference between cultivated area and harvested area.
4. Compare the productivity of this year with the amount of daily rainfall, evapotranspiration, temperature, wind speed, relative humidity.
5. Compare the productivity of this year with the crop water requirement.
6. Calculate the crop growth coefficient for the year.
7. Compare the crop yield with the beginning of the agricultural season, the end of the season and the length of the season as the delayed season is detrimental to the yield.
8. Repeat these same comparisons and processes for that year with the other 10 years.
9. Determine the highest productivity in those ten years and compare with each effect, i.e. we say that when the highest productivity was such that the value of temperature was such and when the highest productivity was such that the value of evapotranspiration of such and so on for the rest of the elements.
10. Determine the worst productivity in those ten years and compare it with each factor, i.e. we say that when the worst productivity was such that the temperature value was such and when the worst productivity was such that the value of evapotranspiration was such and so on to the rest of the elements, so Khairy(2019) Measurement of evaporation is of importance in many scientific fields. It is one of the main components of the water budget[16].
11. Identify and classify the values of environmental effects and group a set of values for each element separately within a certain range and determine the best value for the element, which led to the highest productivity in the ten years and then the next value and so on (ranking from the best to the worst).
12. Put these values in a range, noting that the closer the value of the environmental effect to that value (higher productivity value) this is an indicator of high productivity and the further away the value of the environmental effect from that value is an indicator of poor productivity and so on.

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HA= CA – DA (1)

After calculating the damaged area, it becomes easier to calculate productivity.

CP = HA – AEVN (2)

Steps of this algorithm are:

1- Start.
2- Select the values of the cultivated area and the damaged area for the crop to agricultural season.

3- Select the values of all climate variability.
4- Calculate the amount of effective rainfall to benefit the crop for this year and the rate of evapotranspiration.
5- Calculate the highest production value in ten years.
6- Print a range of all the effected values that helped increase.
7- Calculate crop yield based on these values.
8- End.

Algorithm : Calculate productivity.

1. START.
   / The numbers 1,2,3,...,12 Represent the MONTHS JAN,FEB,MARCH,...,DECEMBER/
2. Initially make Cultivated Are=CA, Harvested Area=HA, Damaged Area=DA, Crop Productivity=CP, Agricultural Season=AS, Area effected with Evapotranspiration Negatively=AETN, Excellent= EX, Bad =BA
3. INSERT VALUES OF ET, RF, WS, TEMP.
4. IF (AS > 4) II (AS < 5)
5. THEN
6. EX ← CP
7. ELSE
8. BA ← CP
9. END IF
10. IF [ET, RF,WS, TEMP]== EX
11. THEN
12. GO TO 8
13. GO TO 10
14. HA= CA – DA
15. CP=HA-AETN
16. RETURN 3
17. END

Table -I : productivity of sorghum and sesame crop and the rate of temperature, rainfall, wind speed, and evapotranspiration for years from 2014 to 2018

Years 2014_2018	Temp (mean)	Rainfall (mean)	Wind speed (mean)	Evapotranspiration	Productivity (Kg/Fedan)	
					sesame	sorghum
2014	33.3	557.7	1.6	914.7	111	92
2015	33.4	669.3	1.7	867.4	130	183
2016	31.1	611.7	2	1065.8	117	65
2017	28	629.4	1.8	886.4	180	304
2018	27.3	542.3	1.6	942.9	117	180

Table- II: Productivity of sorghum and sesame crop and the rate of planted area and Harvested area for years from 2014 to 2018

Years 2014_2018	planted area (Kg/Fedan)		Harvest area (Kg/Fedan)		Productivity (Kg/Fedan)	
	Sesame	Sorghum	sesame	sorghum	sesame	sorghum
2014	892	3597	688	1995	111	92
2015	400	4567	344	3750	130	183
2016	1050	4619	966	3030	117	65
2017	576	4347	475	3232	180	304
2018	474	5260	457	3671	117	180

IV. EXPERIMENTAL RESULTS ANALYSIS

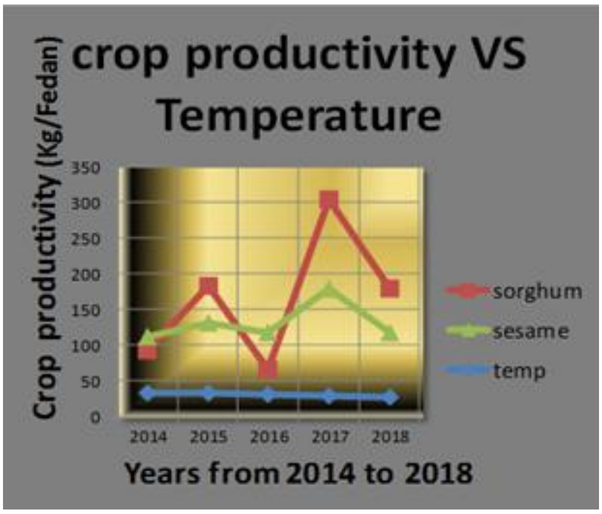

Fig.2 :productivity of sorghum and sesame depended on mean Temperature for years 2014 to 2018.

In the same way, the evapotranspiration element is compared with productivity in order and observing the degree of change in the increase or decrease of the productivity with the evapotranspiration element should be linked to all these factors at the same time, for example when choosing the best value for the rate of rain can't be said that productivity is high unless considered the rate of evapotranspiration, temperature and other factors at the same time, because it may be a good proportion of rain but the crop is damaged.

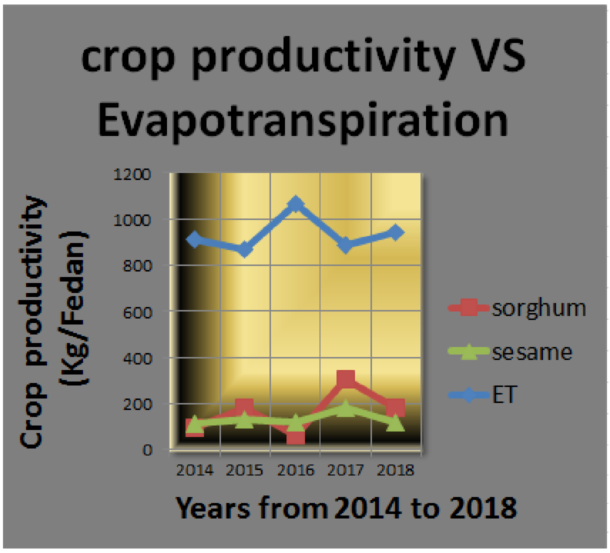

Fig.3 :productivity of sorghum and sesame depended on mean evapotranspiration for years 2014 to 2018.

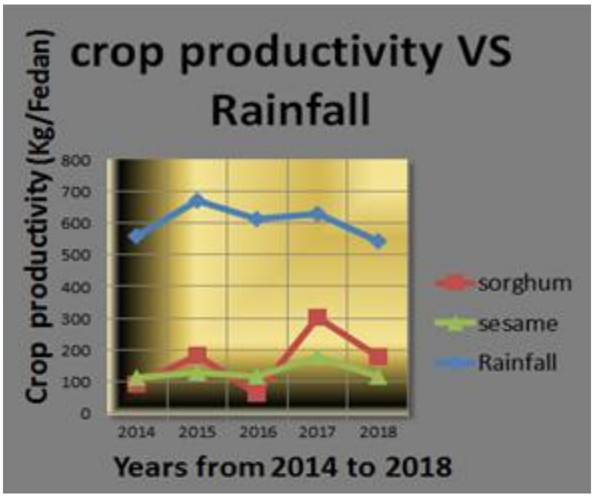

Fig.4 :productivity of sorghum and sesame depended on mean Raifall for years 2014 to 2018.

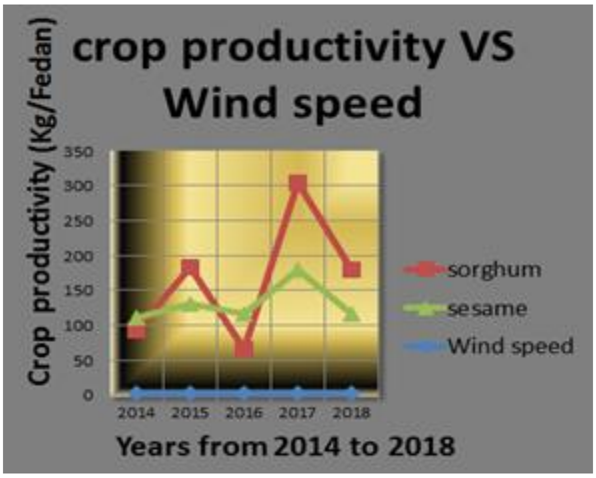

Fig.5 :productivity of sorghum and sesame depended onmean Wind speed for years 2014 to 2018.

Comparison of vegetation cover for the study area in 2017 vs 2018:

Alhuseen (2012) Analysis of resource satellite images has been identified as an appropriate means of acquiring information on land-cover and land-use[4]. Sulieman (2013) The distribution of natural vegetation in the region depends largely on two factors: rainfall and soil[10]. Motzkin(1999) Interpretations of modern vegetation must consider the importance of historical factors in addition to current environmental conditions[14].

Here is compared to the vegetation cover of the study area for months 7,8,9,10 for the year 2017 where it is noted that the agricultural season has begun in July as shown in map No (1) and the proportion of vegetation cover is low, and in August increased the proportion of vegetation as a result of the amount of rainfall as shown in Map No (2) and continued to increase vegetation cover in September in Map No(3), while in Map No (4), which represents the month of October increased the rate of vegetation cover the whole area of the study as a result of intensified rainfall and the figure shows comparisons of vegetation cover. For the 2017 agricultural season, these images were obtained from the US website USGS where the site loads and takes pictures through the Modis satellite as shown in the figure below:

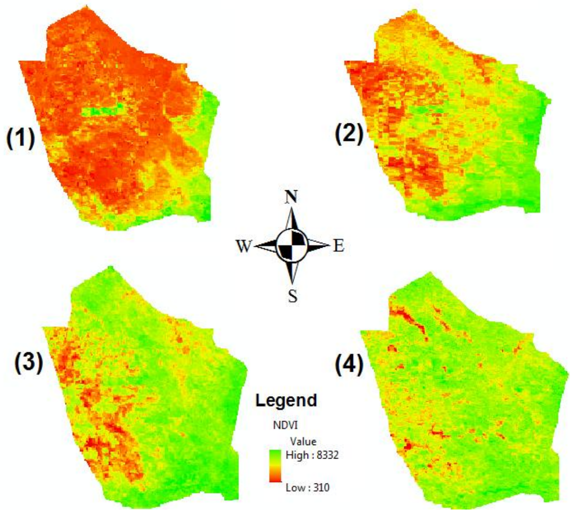

Fig.6 shows a comparison of the vegetation cover of the study area for the months 7,8,9,10 for the year 2017

With the same comparison method above for 2017 was compared here for 2018 for the months of July, August, September, October, which is the months of the agricultural season and we find the same observations, that is increase the vegetation gradually starting from July to reach the plant in October, where the whole area is green and also obtained These images from the USGS website, which in turn uploads images from satellites, especially Modis. When compared to 2017 and 2018, we find that the productivity of sorghum and sesame crops in 2017 is higher than the yield of these two crops in 2018, due to the abundant rainfall in 2017 meets the needs of these crops with appropriate conditions for all other elements that affect the productivity of these crops, which led to increased productivity In 2017 and its decline in 2018 .

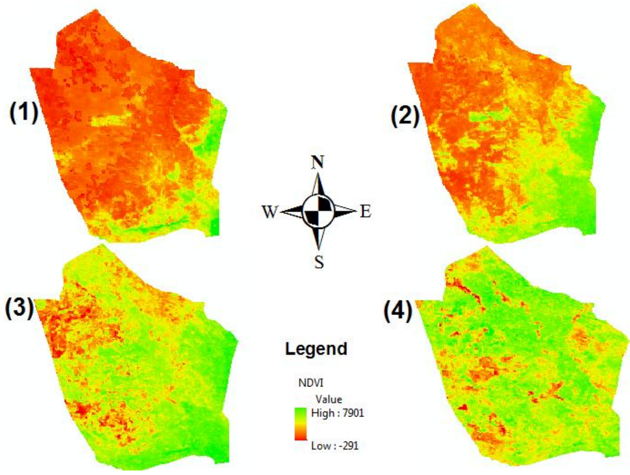

Fig.7 shows a comparison of the vegetation cover of the study area for the months 7,8,9,10 for the year 2018

We note that from the two previous maps the productivity of sorghum and sesame would increase or decrease based on climatic change, so the algorithm determines the rate of productivity according to the equations by calculating all the elements affect the crops.

V. CONCLUSION

In this study, an algorithm is proposed to determine the productivity of sorghum and sesame in Dokka state in Sudan based on all factors which effects on the productivity so as to help authorities, so it was found that the rate of productivity with rainfall alone does not give accurate results also average temperature does not give accurate results and so on with wind speed, but we found that evapotranspiration led to more accurate results because evapotranspiration contains all of the previous elements and represents the outcome of these factors by Penman equation which all of these elements taken into account to calculate evapotranspiration, so all recent studies now begun to use the evapotranspiration element to evaluate crop yields because it leads to accuracy of results compared to those obtained based on rainfall.

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