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A Fuzzy Analysis Method for Measuring Impact of Some Climatic and Non-climatic Variables on Sorghum Production in Sudan

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ABSTRACT

The present study was conducted using the fuzzy Analysis Method to analyze the effect of total area under sorghum, GHG (Green House Gases) emissions, annual mean temperature, and annual mean rainfall on sorghum production discrepancies in Sudan for the period from 1991-2010. In the analysis, the production quantities of sorghum were designated as mother factor, while the total area under the crop (non-climatic variable) and climatic variables namely GHG emissions, mean annual temperature, and mean annual rainfall were designated as sub-factors. The relative differences between mother factor and sub-factors were calculated using the average data. The correlation degree coefficients of sub-factors to mother factor were computed as percentages using as a distinguishing parameter and the values were then ranked discerningly. The results of the analysis showed that the discrepancy in sorghum production was highly affected by area (66%), GHG emissions (55.1%), annual mean temperature (54.2%) and annual mean rainfall (53.8%). The differences between degrees of impact of different variables on production discrepancies found to be significant at $p \leq 0.001$. More work considering extra production inputs, climatic variables such as atmospheric carbon dioxide concentration and solar radiation intensity as well as sorghum prices should be conducted using fuzzy analysis method.

Keywords: Fuzzy system; climatic variables, sorghum production.

INTRODUCTION

Sudan like many least developed countries in Africa is highly vulnerable to climate change and climate variability. The interaction of multiple stresses endemic poverty, ecosystem degradation, complex disasters and conflicts, and limited access to capital, markets, infrastructure and technology have all weakened people's ability to adapt to changes in climate. Human activities have caused, and are continuing to cause, great changes to the composition of the atmosphere. The major concern of both scientific and public communities is the enhanced greenhouse effect caused by anthropogenic activities. The findings of the Intergovernmental Panel on Climate Change (IPCC) have shown that climate change is already having strong impacts on human societies and the natural world, and is expected to do so for decades to come (IPCC, 2007).

This situation is aggravated by the interaction of multiple stresses occurring at various levels, such as endemic poverty; institutional weaknesses; limited access to capital, including markets, infrastructure and technology; ecosystem degradation; complex disasters and conflicts. These in turn have weakened people's adaptive capacity and increased their vulnerability to projected climate change (IPCC, 2007). Sudan extends from the desert in the north, with its hot dry climate and almost no vegetation cover, to the African Sahel zone in the centre (dry to semi-dry climate) with its light and dense savanna in the south (Sumaya, 2009). Mean annual temperatures vary between 26ºC and 32ºC across the country. The most extreme temperatures are found in the far north, where summer temperatures can often exceed 43ºC and sandstorms blow across the Sahara from April to September. Rainfall is also very variable, and is becoming increasingly unpredictable (Fadel- El Moula, 2005; NAPA, 2007). The coefficient of rainfall variability (CV), or the percentage deviation from the norm, measures the uncertainty of rainfall: the higher the CV the more variable and uncertain the rainfall. In Sudan the CV decreases from north to south (190% to less than 15%) and it seemed to have increased between 1941 and 2000 according to data from some weather stations. Average rainfall also declined over the same period. Declining and uncertain rainfall makes life very difficult for traditional farmers and herders and severely affects their livelihoods (Fadel-El Moula, 2005). Due to fuzziness of these climatic and non climatic factors and their effects on crop production, grey analysis method is proposed to analyze these effects. The gray system analysis (fuzzy analysis) was developed in 1980's and has been applied in various fields such as agriculture, economics, engineering, sociology, and environment.

Correlation analysis, as a factor distinguishing approach and a factor analyzing tool, is a very typical method of a system analysis. Primal correlation analysis model calculates correlation coefficients of each point, and then gets correlation degree of each sub-factor with regard to the mother factor. Later weighted grey correlation analysis methods are presented in order to characterize the importance of different coefficients. Fuzzy analysis is a useful tool to quantify allocation of different resources in the production operation to facilitate right decision making. Sifeng and Yi (2000) mentioned the grey incidence decision and studied the concept of degree of incidences between the situation effect vectors and optimum effect vector. Sun (1996) applied the grey method for analyzing the development of agricultural mechanization in china. The objective of the present study is to apply Fuzzy analysis to measure the impact of grown area, GHG emissions, annual mean temperature, and annual mean rainfall on sorghum production discrepancies during the period 1991-2010.

METHODOLOGY

Fuzzy theory was used to determine the most effective some climatic and non-climatic factors on sorghum production in Sudan.

Fuzzy analysis model approaches:

i- Observed data of mother factor and sub-factors at n points could be shown as follows

$$\begin{matrix} X_1 & X_2 & ..... & X_n \\ X_{21} & X_{22} & ..... & X_{2n} \\ ..... & ..... & ..... & ..... \\ X_{m1} & X_{m2} & ..... & X_{mn} \end{matrix}$$

Where X_i and X_{ij} are mother factor and sub-factors respectively.

ii. Data averaging:

The data were symbolized and averaged as follows

$$\overset{(0)}{X}_0(k) = \frac{X_k}{\bar{X}_k}$$

$$\overset{(0)}{X}_1(k) = \frac{X_{1k}}{\bar{X}_1}$$

$$\overset{(0)}{X}_2(k) = \frac{X_{2k}}{\bar{X}_{2k}}$$

....

$$\overset{(0)}{X}_m(k) = \frac{X_{mk}}{\bar{X}_m} \qquad k = 1,2,\ldots\ldots, n. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The series can be denoted in form of sets

$$X_0 = \{X_0^{(0)}(1), X_0^{(0)}(2), \ldots\ldots\ldots\ldots, X_0^{(0)}(n)\}$$
$$X_1 = \{X_1^{(0)}(1), X_1^{(0)}(2), \ldots\ldots\ldots\ldots\ldots, X_1^{(0)}(n)\}$$
$$X_2 = \{X_2^{(0)}(1), X_2^{(0)}(2), \ldots\ldots\ldots\ldots, X_2^{(0)}(n)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$X_m = \{X_m^{(0)}(1), X_m^{(0)}(2), \ldots\ldots\ldots\ldots, X_m^{(0)}(n)\}$$

Where,

$X_0 =$ mother factor.

iii. Determination of the coefficients, *Δ1, Δ2, Δ3* and *$d_{oi}(k)$*

Assume that *M = {1, 2, 3,.........., m} and N = {1, 2, 3,………., n}*

Then,

$$\Delta_1 = \min_{i \in M}\left\{\min_{k \in N}\left|X_0^{(0)}(k) - X_i^{(0)}(k)\right|\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\Delta_2 = \max_{i \in M}\left\{\max_{k \in N}\left|X_0^{(0)}(k) - X_i^{(0)}(k)\right|\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$\Delta_3 = \left|X_0^{(0)}(k) - X_i^{(0)}(k)\right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

iv. Calculation of relative differences

The relative difference of X_i sub-factor and mother factor X0 at k-th point can be calculated as follows

$$d_{oi}(k) = \frac{\Delta_1 + \lambda\Delta_2}{\Delta_3 + \lambda\Delta_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Where,

$d_{oi}(k) =$ relative differences at different points.

$\lambda =$ distinguishing coefficient taken between 0 – 1.

v. Computation of the correlation degree coefficients:

In order to work out the comprehensive correlation degree coefficients, considering the importance of different observed points according to globally observed points. If the weight coefficients vector for n points is given by:

$$W = (w_1, w_2, ..., w_n)$$

Satisfy,

$$\sum_{k=1}^{n} w_k = 1$$

$w_k \geq 0$, $k \in N$ then,

$$\gamma_{oi} = \sum_{k=1}^{n} w_k d_{oi}(k), i \in M \quad (7)$$

If all weight coefficients are equal each other as follows

$$w_k = \frac{1}{n}, k = 1,2,........, n$$

Then,

$$\gamma_{oi} = \frac{1}{n}\sum_{k=1}^{n} d_{oi}(k) \quad (8)$$

Applications of fuzzy mathematical approaches and models

Data collection:

The secondary data in Table 1 were collected from the FAOSTAT DATA BASE Site.

Table 1: Production of Sorghum, areas, and climatic variables (1991-2010)

year	Sorghum production, Tons	Sorghum area, ha	GHG, Gigagram	Mean Temp., C^0	Mean rainfall, mm
1991	3581000	5100190	38835.93	28.3	249.9
1992	4042000	6200000	44465.73	28.0	279.6
1993	2386000	4683840	49135.66	29.4	342.6
1994	3648000	6427260	53452.19	29.2	303.1
1995	2450000	5045000	55014.60	29.4	329.7
1996	4179000	6552840	57424.18	29.0	352.9
1997	2870000	6555000	59742.57	28.6	352.0
1998	4284000	6314000	61909.18	28.8	355.0
1999	2347000	4529600	64484.10	29.8	380.0
2000	2488000	4195000	67203.79	29.8	348.8
2001	4394000	5742240	70154.87	29.7	360.5
2002	2025000	5003000	70734.70	29.8	372.9
2003	5188000	7081000	74110.99	29.7	374.1
2004	2704000	3819000	74765.51	29.5	357.3
2005	5002000	9864960	76637.80	29.7	419.2
2006	4327000	6485420	77798.36	28.4	387.4
2007	4999000	6522920	78312.23	28.1	403.1
2008	3869000	6619330	78292.77	28.8	390.9
2009	4192000	6652500	78988.00	28.6	438.9
2010	2630000	5612880	78889.27	29.5	430.3

Source: FAOSTAT (2012)

Hypothesis

It is assumed that sorghum production in Sudan depends on total area under sorghum, GHG (Green House Gases) emissions, annual mean temperature, and annual mean rainfall consequently, the following hypothesis was considered:

$X_0 \}$ = mother factor.

$$\left.\begin{matrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{matrix}\right\} = \text{Sub-factors.}$$

Where

$X_0 =$ total production of sorghum.

$X_1 =$ area under sorghum crop.

$X_2 =$ GHG emissions.

$X_3 =$ annual mean temperature.

$X_4 =$ annual mean rainfall.

2.2.3 Computations

Each value of mother factor and sub-factors were averaged as shown in Table 2 using equation 1.

Table 2: Average value of mother factor and sub-factors of sorghum production (1991-2010)

Year	x_0	$X_{0\ avg.}$	x_1	$X_{1avg.}$	x_2	$X_{2avg.}$	x_3	$X_{3avg.}$	x_4	$X_{4avg.}$
1991	3581000	1.000209	5100190	0.857132	38835.93	0.592756	28.3	0.972342	249.9	0.691458
1992	4042000	1.128971	6200000	1.041964	44465.73	0.678684	28.0	0.962034	279.6	0.773637
1993	2386000	0.666434	4683840	0.78716	49135.66	0.749961	29.4	1.010136	342.6	0.947954
1994	3648000	1.018923	6427260	1.080157	53452.19	0.815845	29.2	1.003264	303.1	0.83866
1995	2450000	0.68431	5045000	0.847857	55014.6	0.839692	29.4	1.010136	329.7	0.91226
1996	4179000	1.167237	6552840	1.101262	57424.18	0.876469	29.0	0.996392	352.9	0.976453
1997	2870000	0.80162	6555000	1.101625	59742.57	0.911855	28.6	0.982649	352/0	0.973963
1998	4284000	1.196564	6314000	1.061123	61909.18	0.944924	28.8	0.989521	355.0	0.982264
1999	2347000	0.655541	4529600	0.761239	64484.1	0.984225	29.8	1.023879	380.0	1.051437
2000	2488000	0.694924	4195000	0.705007	67203.79	1.025736	29.8	1.023879	348.8	0.965109
2001	4394000	1.227289	5742240	0.965034	70154.87	1.070779	29.7	1.020443	360.5	0.997482
2002	2025000	0.565603	5003000	0.840798	70734.7	1.079629	29.8	1.023879	372.9	1.031792
2003	5188000	1.449061	7081000	1.190024	74110.99	1.131161	29.7	1.020443	374.1	1.035112
2004	2704000	0.755255	3819000	0.641816	74765.51	1.141151	29.5	1.013572	357.3	0.988628
2005	5002000	1.397109	9864960	1.657893	76637.8	1.169728	29.7	1.020443	419.2	1.159901
2006	4327000	1.208575	6485420	1.089932	77798.36	1.187442	28.4	0.975777	387.4	1.071913
2007	4999000	1.396271	6522920	1.096234	78312.23	1.195285	28.1	0.96547	403.1	1.115354
2008	3869000	1.080651	6619330	1.112437	78292.77	1.194988	28.8	0.989521	390.9	1.081597
2009	4192000	1.170868	6652500	1.118011	78988	1.205599	28.6	0.982649	438.9	1.21441
2010	2630000	0.734586	5612880	0.943294	78889.27	1.204092	29.5	1.013572	430.3	1.190615
Average	3580250		5950299		65517.62		29.105		361.41	

Values of Δ_3 were calculated as in equation 5 and presented in Table 3.

Table 3: Values of Δ_3 for areas of sorghum and climatic variables

X_1	0.143	0.087	0.121	0.061	0.164	0.066	0.300	0.135	0.106	0.010	0.262	0.275	0.259	0.113	0.261	0.119	0.300	0.032	0.053	0.209
X_2	0.407	0.450	0.084	0.203	0.155	0.291	0.110	0.252	0.329	0.331	0.157	0.514	0.318	0.386	0.227	0.021	0.201	0.114	0.035	0.469
X_3	0.028	0.167	0.344	0.016	0.326	0.171	0.181	0.207	0.368	0.329	0.207	0.458	0.429	0.258	0.377	0.233	0.431	0.091	0.188	0.279
X_4	0.309	0.355	0.282	0.180	0.228	0.191	0.172	0.214	0.396	0.270	0.229	0.466	0.414	0.233	0.237	0.137	0.281	0.001	0.044	0.456
Min	0.028	0.087	0.084	0.016	0.155	0.066	0.110	0.135	0.106	0.010	0.157	0.275	0.259	0.113	0.227	0.021	0.201	0.001	0.035	0.209
max	0.407	0.450	0.344	0.203	0.326	0.291	0.300	0.252	0.396	0.331	0.262	0.514	0.429	0.386	0.377	0.233	0.431	0.114	0.188	0.469

From equation 3 and equation 4, the values of Δ_1 and Δ_2 were extracted from Table 3 and they were as follow

$\Delta_1 = 0.001$

$\Delta_2 = 0.514$

RESULTS AND DISCUSSION

From equation 6, the relative differences *(d_{0i})* were calculated and shown in Table 4 while correlation degree coefficients (γ_{0i}) were calculated using equation 7 and equation 8 and they were shown Table 5.

Table 4 Relative differences of X_i sub-factor at k-th (1991-2010)

Year	d_{01}	d_{02}	d_{03}	d_{04}
1991	0.645	0.389	0.905	0.456
1992	0.750	0.365	0.608	0.422
1993	0.683	0.757	0.429	0.479
1994	0.811	0.561	0.945	0.590
1995	0.613	0.626	0.443	0.532
1996	0.799	0.471	0.603	0.576
1997	0.463	0.703	0.589	0.601
1998	0.658	0.507	0.556	0.548
1999	0.711	0.440	0.413	0.395
2000	0.966	0.439	0.440	0.489
2001	0.497	0.623	0.556	0.531
2002	0.485	0.335	0.361	0.357
2003	0.500	0.449	0.376	0.385
2004	0.697	0.401	0.501	0.527
2005	0.498	0.533	0.407	0.522
2006	0.686	0.928	0.527	0.655
2007	0.463	0.563	0.375	0.479
2008	0.893	0.695	0.741	1.000
2009	0.832	0.884	0.579	0.857
2010	0.554	0.355	0.481	0.362

d_{01}: area under sorghum crop, d_{02}: GHG emissions, d_{03}: annual mean temperature,

d_{04}: annual mean rainfall.

Table 5: Correlation degree coefficients

γ_{0i}	Ratio	%
γ_{01}	0.660	66.0^{a}
γ_{02}	0.551	55.1^{b}
γ_{03}	0.542	54.2^{c}
γ_{04}	0.538	53.8^{d}

Values of γ_{0i} in the last row not share same superscript letters showed significant difference at $P \leq 0.001$ as tested by New-man Keul method.

γ_{01}: area under sorghum crop, γ_{02}: GHG emissions, γ_{03}: annual mean temperature,

γ_{04}: annual mean rainfall.

Table 5 showed that $\gamma_{01} > \gamma_{02} > \gamma_{03} > \gamma_{04}$ which indicated that the area under crop as non-climatic variable affected the discrepancy in total production of sorghum by 66 %, the GHG emissions by 55.1 %, mean annual temperature by 54.2 %, and annual mean rainfall by 53.8 %. It is deduced that the area under sorghum crop has the highest effect on the crop production discrepancy, while GHG emissions as the climatic variable demonstrated the highest impact on crop production discrepancy, followed by mean annual temperature and mean annual rainfall which showed the lowest impact in crop production inconsistency.

It can be concluded that the cultivated area as non-climatic variable has noticeable effect on production discrepancy of the crop, while in case of climatic variables, sorghum crop found to be affected perceptibly by GHG emissions. The differences between degrees of impact of the climatic and non-climatic variables on production discrepancies for crop were found to be significant at $P \leq 0.001$.

CONCLUSION

Climatic and non-climatic variables have a visible impact on crop production. Area under crop as non-climatic variable and GHG emissions as climatic variable found to have the greatest effect on total sorghum production discrepancy but more elaborated fuzzy analysis considering more variables of production inputs such as level of mechanization, fertilizers, pesticides, and more climatic factors such as atmospheric carbon dioxide concentrations, solar radiation intensity as well as sorghum prices need to be examined.

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