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An Investigation on the Effects of Climate Change and Variability in the Rainfall of Old Sudan

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Abstract: It was estimated that Old Sudan was facing water stress since the per capita annual share was 1500 m^3. It was evident that rainfall plays a determinant role in the socio-economic set up of Old Sudan. The study area showed marked variation regarding rainfall distribution since it is almost nil at the extreme north and about 1500 mm at the extreme Southwest. Isohyetal maps for the two climatic eras' 1941-1970 and 1971-2000 showed significant southward displacement. The rainfall of both Khartoum and Fashir showed a trend of decline whereas, maximum temperatures witnessed an increase. The total annual rainfall data for some meteorological stations, since their inception, were divided into three eras namely: the period up to 1950, the second half of the 20th century and the first ten years of the 21st century. Considering the period of up to 1950 as the base period a striking reduction was observed. For instance, a reduction of approximately 15% was witnessed in the central portion meanwhile it was about 20% in Darfur. In addition to that, most locations demonstrated significant further decline during the first ten years of the 21st century. On the other hand, the ENSO event proved to exert a determinant role in the variability of the rainfall of old Sudan. Contrary to El Nino the rainfall during La Nina is found to be above normal. Some adaptive options were recommended including modernization of irrigation and, adoption of supplementary irrigation and water harvesting.

Key words: Rainfall, ENSO, prediction, socio-economic development, water scarcity, sanitation.

Water is an essential resource for socio-economic development and it is vital for human existence, health and welfare. It is evident that problems associated with human development are progressively becoming related to water (Global Water Partnership, GWP, 2000). According to African Ministers' Council on Water (AMCOW, 2018) about 422 million people in Africa do not have an access to safely managed drinking water services; 660 million have no access to safely managed sanitation services; and 173 million practice open defecation.

Climate Change is defined as any long-term significant change in the "average weather" that a given region experiences. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years. Meanwhile, climate variability denote deviations of climate statistics over a given period of time (such as a specific month, season or year) from the long-term climate statistics relating to the corresponding calendar period. In this sense, climate variability is measured by those deviations, which are usually termed anomalies (El Gamri, 2012). Due to the rising global temperatures climate change is anticipated to accelerate the hydrologic cycle, causing increased frequency of both floods and droughts (NSF, 2003). Fredrick (1997) pointed out that the impact will be worse on the hydrology of the arid and semi-arid regions since comparatively little changes in temperature and precipitation in these areas might cause significant changes in runoff.

Recently different parts of the globe experienced extreme weather events as compared to earlier records (El Gamri, 2012). For instance, Pakistan has experienced severe flooding during the summer of 2010, when 1/5th of the country area was flooded, with devastating impacts since 20 million people were affected, thousands of schools and health centers inundated and 2.2 million hectares of

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crops were destroyed. Hence, climate change is a truth and Africa is the most vulnerable region to the impacts of global climate variability and change. Temperature analyses revealed the fact that Africa has been warmed considerably over the past 100 years (IPCCC, 2014). Future projections under medium emission scenarios showed that in the majority of Africa more warming is most likely. According to Abebe, (2011) the following factors contribute to Africa's high vulnerability:

- Natural fragility of its ecosystems;
- Exposure to frequent natural disasters (droughts and floods); and
- Dependence of livelihoods and economic activities on highly climate sensitive natural resources and rain-fed agriculture (70% population with 30% GDP from agriculture).

Jägerskog *et al.* (2007) pointed out that lack of infrastructure, low level of investment and hydrological variability are major constraints to the economy of the Nile Basin including Old Sudan. According to the Intergovernmental Panel on Climate Change, developing countries are highly vulnerable to the climatic changes since majority of them are situated in the arid and semiarid climates. Lack of their capacity to adopt appropriate adaptation actions (IPCC, 2007) further worsens the situation.

El Nino is caused when warm surface water from the western equatorial part of the Pacific Basin invades the eastern equatorial region (Salinger, 1992). Meanwhile, La Nina is the establishment of the cold pattern along the equator due to the drag of the warm surface water westward by easterlies and the mutual upwelling of cold water from deeper layers. The two phenomena (El Nino and La Nina) are grouped into the so-called El Nino Southern Oscillation or the ENSO event (El Gamri *et al*., 2009). ENSO events have also been correlated with droughts in Australia, Africa, India and Northeastern portion of South America. Africa demonstrates strong ENSO signals in southern, eastern and the far north and a notable signal in the Atlantic coast around the Equator and the Sahel. Meanwhile, various parts of eastern Africa exhibit correlation with El Nino event but with variations in extent and trend (World Climate Research Programme/Climate Variability and Predictability Programme, WCRP/CLIVAR, 2002).

According to El Gamri *et al.* (2007) the following factors were found to affect the rainfall of the Sudan among others:

- Tele-connection with the ENSO event,
- The four sub-tropical anti-cyclones around Africa these are namely Mascarene, St. Helena, Azores and the Arabian high pressure systems and
- Climate change

Temperatures are generally high predominantly in the North of the country where it may reach 52°C in summer. During winter the mean daily temperature varies between 16°C in the North and 29°C in the South. The difference between the daily maximum and minimum temperature ranges between 18 and 24°C in the desert area in the North and 12 and 14°C in the South of the country (Bashar, 2008).

Over the climatic era of (1971-2001), more than ten million inhabitants of Sudan and South Sudan were severely hit by drought. For instance the drought of 2000 reduced food reserves and caused three-fold price spikes as compared to those of 1999 (Zakeldeen, 2009).

Despite its severe water scarcity, floods are also common in Old Sudan. The most overwhelming occurred on the Blue Nile, primarily caused by land degradation at the Ethiopia Plateau (UNEP, 2007).

The highly devastating river floods are those of 1946, 1975, 1988, 1994, 1998, 1999, 2006, 2007 and 2013. Although flash floods are less frequent yet they may cause severe impacts, the most destructive of which occurred in 1978, 1999, 2007, 2009 and 2013. However, recent floods from seasonal streams (flash floods) have caused more destruction than river flooding.

UNEP (2007) estimated the population of Old Sudan to be in the range of 35 to 40 million of which about 70% live in villages, hamlets or semi-nomads meanwhile 30% are town and city dwellers or live in displaced persons settlements. Recent estimates showed that Old Sudan is witnessing water stress since the water availability here is less than 1500 m^3 per capita per annum. After a long history of civil war and political instability South Sudan organized a referendum for self-determination in the year 2011. Unfortunately the process culminated into the separation of Old Sudan into two countries.

Fig. 1. Location of Sudan and South Sudan.

The newly separated countries belong to the Inter-government Authority on Development (IGAD, 2016). Figure 1 shows the location of both the countries as Sudan and South Sudan.

Rainfall has major impact on the socio-economic conditions of the study area. There is an increasing belief that the decline in precipitation in the Sudan exerted great stress on rural societies, particularly in Darfur and Kordofan, and consequently contributed to the conflict (El Gamri, 2012).

The main objective of this study is to assess the impacts of climate change and variability in the rainfall of the Sudan.

Materials and Methods

Impacts of climate change

Annual rainfall data for some meteorological stations were obtained from the Data Bank of the Sudan Meteorological Authority. The assumption is that the impacts of climate change were manifested during the second half of the previous century and after wards due to the huge industrial development.

- A general investigation of rainfall trends was made through the production of isohyets maps using the Server software to compare Old Sudan's rainfall during the two climatic eras' of 1941-1970 and 1971-2000.
- Trends in annual rainfall and maximum temperatures were estimated for Fashir station (1960-2006) and Khartoum station (1901-2001).
- Investigations on climate change impacts were made for three meteorological stations; these are namely Khartoum, Medani and Fashir. The rainfall records for the three stations start in 1901, 1919 and 1917, respectively. The data were divided into three eras' namely the period since inception up to 1950, the second half of the previous century and the first 10 years of the new millennium. The first era was considered as the base period.

Impacts of climate variability

The aim of this analysis is to investigate the ENSO signals in the rainfall of the dry portion of the study area. Each year was divided into four seasons (3 months each). Each season is denoted by the initials of its months e.g. the first season (January to March) is denoted as JFM. Likewise, the other three acronyms are AMJ, JAS and OND, respectively.

JAS rainfall of the region for the period 1950-1999 (50 years) was arranged in a descending order and divided into three groups as described by (El Gamri, 2005). The top 17 years correspond to the above-normal, the normal group represented by the next 16 years and the last 16 years represent the below-normal group.

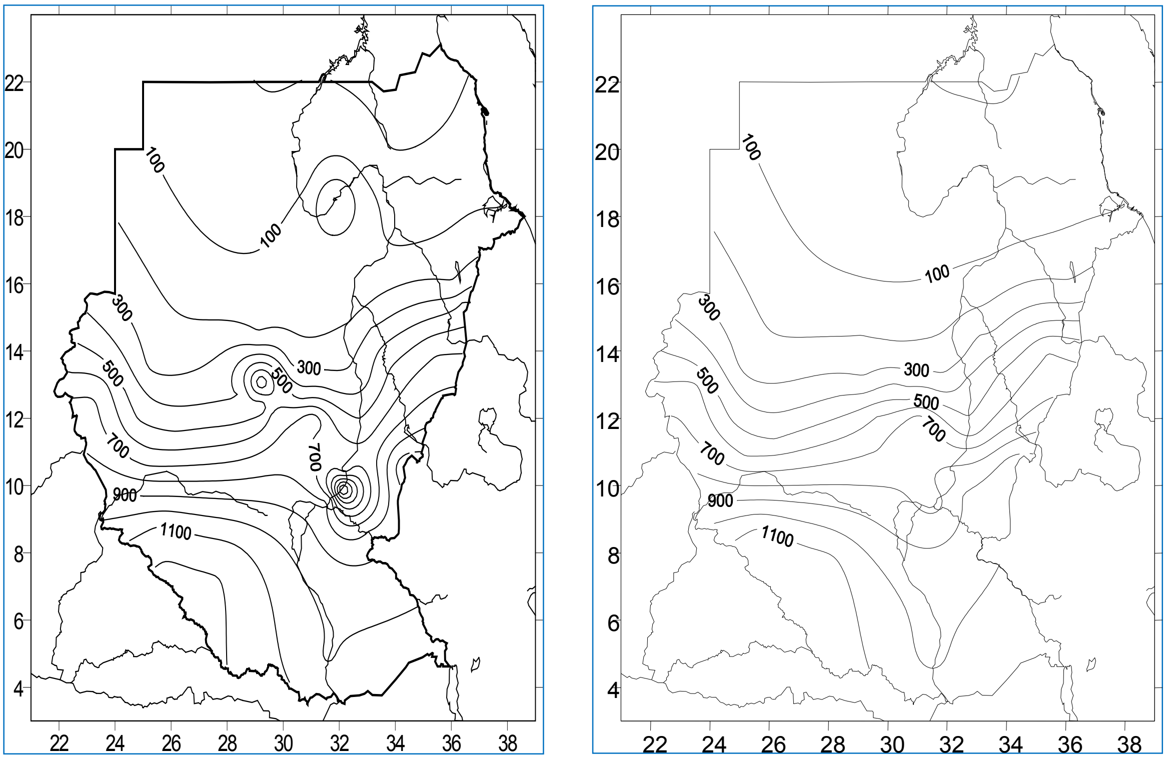

Fig. 2. Isohyets of Sudan for the periods (1941-1970) and (1971-2000) depicting distribution of rainfall (mm).

Subsequently the seasonal Sea Surface Temperatures (SSTs) (four seasons) were studied in relation to the JAS rainfall of each particular year. The SSTs data were prepared by the Climate Prediction Centre/National Centre for Environmental Prediction (CPC/NCEP).

The years of prolonged El Nino/La Nina (years of 3 or 4 seasons of continued warm/cold SSTs) were identified. Hence, 1956, 1950, 1999, 1971 and 1974 (in a descending order) are categorized as prolonged La Nina years. Meanwhile, 1992, 1958, 1957, 1997, 1969, 1972, 1987, 1993, 1966, 1982 and 1991 (in a descending order) as prolonged El Nino.

Results and Discussion

Impacts of climate change

Significant southward movement of the isohyets was observed during the two periods of 1941-1970 and 1971-2000 (Fig. 2). The displacement is most conspicuous for the 200 mm isohyets in the Region of Darfur. Meanwhile the 1200 mm isohyets is no longer prevailing in Old Sudan. This is consistent with Osman *et al. (*2001) who revealed the fact that the annual values of average rainfall of the Sudan have decreased markedly since early sixties. Similar results were obtained by Adam (2002) who estimated a decrease of 19% in the rainfall of dry lands of the country comparing the two rainfall averages of (1941-1970) and (1970-1999). In addition to that an analysis done by UNEP (2007) showed that a southward shift of 50 to 200 km of the boundary between semi-desert and desert has occurred since rainfall and vegetation records were first done in the 1930s. According to HCENR (2003) the decline in rainfall associated with an increase in temperature is anticipated in the future also. Using MAGICC/SCENGEN software, Kordofan states were projected to likely witness high temperatures and less rainfall. For instance the mean annual temperature is expected to increase by 1.2°C and the mean annual rainfall is likely to decrease by 5.8% by the year 2030 for Obied (HCENR, 2003).

Anomalies and trends at Fashir meteorological station during the period (1960-2006) showed a decline in the annual rainfall which coincided with an increase in temperature (Fig. 3). Similar results were obtained for Khartoum also (Fig. 4).

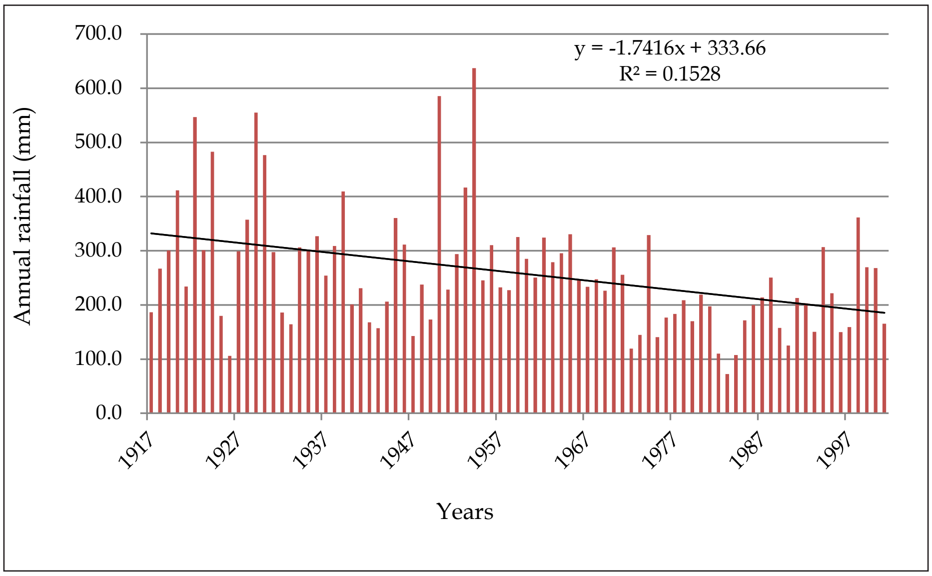

Fig. 3. Annual rainfall and its trend at Fashir (1917-2001).

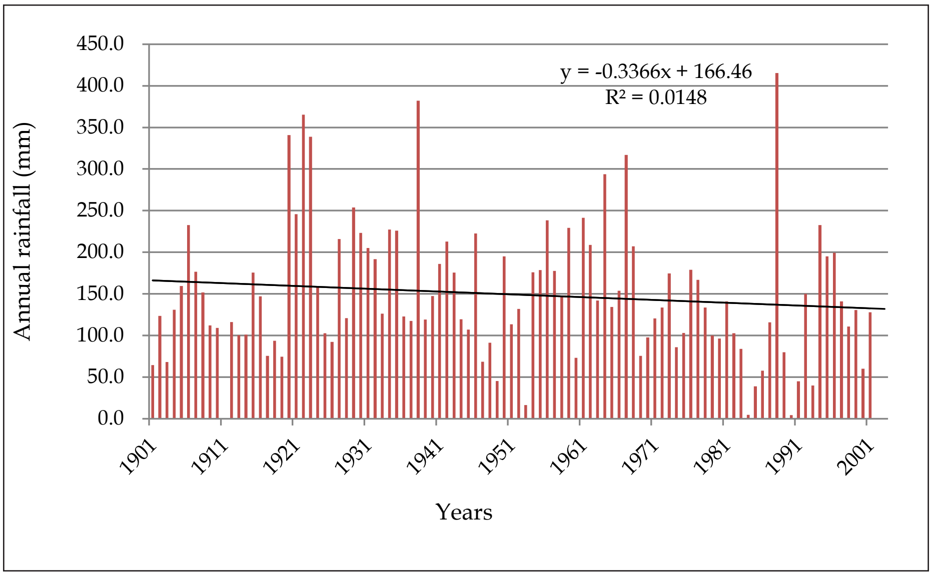

Fig. 4. Annual rainfall and its trend at Khartoum (1901-2001).

During the second half of the previous century rainfall declined by 20%, 14.3% and 17.5% for El Fashir, Khartoum and Medani, respectively (Table 1). As mentioned earlier this is consistent with the findings of Adam (2000) and Osman *et al.* (2001). The trend is most obvious in Fashir which is located in the region of Darfur. This is consistent with UNEP (2007) wherein it was revealed that average rainfall decreased from 300 mm per annum to approximately 200 mm, since its inception. Moreover, the last season when the rainfall of Fashir surpassed 400 mm was only in 1955, (UNEP, 2007). Furthermore, during the first ten years of the 21st century both Khartoum and Fashir showed further decline of 26% and 33% respectively meanwhile Medani showed restoration at previous levels.

Table 1. Impacts of climate change in the rainfall of dry Old Sudan

	Years	Average	Change
Fashir	1917-1950	295.1	0%
	1951-2000	236	-20%
	2001-2010	197.1	-33%
Khartoum	1901-1950	163.1	0
	1951-2000	139.9	-14%
	2001-2010	120.7	-26%
Medani	1919-1950	385	0
	1951-2000	317.5	-18%
	2001-2010	410.15	+ 7%

Impacts of Climate Variability

The prolonged La Nina years of 1956, 1950 and 1999 was associated with above-normal rainfall, while 1971 and 1974 with normal rainfall and not a single year showed below-normal rainfall. The last two years were less than the year 1998 (the least of the above-normal class) by only 0.4% and 3.3%, respectively. Hence, it can be concluded that prolonged La Nina is associated with above-normal rainfall. Additionally considering prolonged El Nino, the two years of 1992 and 1958 (two out of 11 years) are in the above-normal class while only 1957 was within the normal class and eight years (1997, 1969, 1972, 1987, 1993, 1966, 1982 and 1991) were below-normal. Thus, about 18% of prolonged El Nino years were above-normal, 9% within the normal range and 73% were at the below-normal range. Hence, it can be concluded that there is a great tendency (about 75%) for below-normal rainfall during prolonged El Nino. This is in agreement with the results of Cobon *et al*. (2003) for several locations (in southern Africa). It can also be concluded that the skill in the forecasts occurred for La Nina rather than El Nino Conditions.

Table 2 shows season-by-season breakdown of sub-surface temperatures (SSTs) conditions at the area of Nino 3.4 which extends along the equator from longitude 150° W to the date line (180°) in the tropical Pacific. Weak episodes are designated as C- or W-, moderate strength episodes as C or W, strong episodes as W+ or

Table 2. Descending arrangement for JAS rainfall of the dry region of the Sudan and the corresponding SSTs at Nino 3.4

Dry region of the Sudan						Corresponding SSTs at Nino 3.4					
Year	Season					Year	Season				
	JAS	JFM	AMJ	JAS	OND		JAS	JFM	AMJ	JAS	OND
1956	394	C	C	C	C-	1955	193	C	C-	C-	C+
1950	363	C	C	C	C	1970	192	W-	N	N	C
1964	359	N	N	C-	C	1968	189	N	N	N	W-
1954	340	N	N	C-	C	1975	185	C-	C-	C	C+
1988	327	W-	N	C-	C+	1963	183	N	N	W-	W
1953	303	N	W-	W-	N	1996	176	C-	N	N	N
1994	303	N	N	W	W	1981	175	N	N	N	N
1959	296	W-	N	N	N	1979	171	N	N	N	N
1999	290	C+	C	C-	C	1997	163	N	W	W+	W+
1962	288	N	N	N	N	1969	151	W	W-	W-	W-
1992	261	W+	W+	W-	W-	1972	145	N	W-	W	W+
1958	260	W+	W	W-	W-	1973	144	W	N	C-	C+
1961	259	N	N	N	N	1987	141	W	W	W+	W
1952	254	N	N	N	N	1983	135	W+	W	N	C-
1995	252	W	N	N	C-	1989	133	C+	C-	N	N
1965	244	C-	N	W	W+	1993	132	W-	W	W	W-
1998	241	W+	W	C-	C	1966	132	W	W-	W-	N
1971	240	C	C-	C-	C-	1982	132	N	W-	W	W+
1951	239	C	N	N	W-	1985	108	C-	C-	N	N
1974	234	C+	C	C-	C-	1991	108	W-	W-	W	W
1967	226	N	N	N	N	1990	87	N	N	W-	W-
1976	224	C	N	N	W-	1984	87	C-	C-	N	C-
1978	221	W-	N	N	N						
1957	215	N	W-	W-	W						
1960	209	N	N	N	N						
1977	206	N	N	N	W-						
1986	204	N	N	W-	W						

C+ and neutral periods as N, where C stands for cold and W for warm SSTs.

Generally, it can be stated that the ENSO event has a great signal in dry Sudan with La Nina years associated with above-normal rainfall and the reverse during El Ninos. This deduction is confirmed by the findings of Abdalla and Fota (2001); Osman and Shamseldin (2002) and El Gamri (2005). Hence, the correlation of the ENSO event with the rainfall of Old Sudan can be used in rainfall prediction (Cobon *et al.*, 2003).

Combined effect

According to IFAD (2013) both increase and decrease in annual rainfall are already in different parts of the country. Starting from 1970, rainfall declined in the north by 5% and by 10-20% in the west and southwest. Meanwhile, the southeast witnessed an increase of 10%. As mentioned earlier the anticipated reduction in the rainfall of Kordofan states was projected by the HCENR to be less than 6% by the year 2030. However, the results obtained seem to be inconsistent with the current climate models since the observed reduction ranged between 14.3-20% during the second half of the previous century. This may be due to the fact that El Nino which is generally associated with low rainfall in the country is becoming more frequent. Hence, this drastic reduction may be attributed to the combined effect of both climate variability and change.

Impact analysis

It is evident that the problems faced by water resources and agriculture sectors will be aggravated due to climatic changes with serious implications for socioeconomic development (Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region, 2017). Climate change will impact agriculture through global warming, changes in precipitation patterns and increased occurrences of extreme weather events (droughts and floods). Most significantly reduced precipitation coupled with high temperatures will lead to increased demand for irrigation water and consequently escalate conflicts over the limited renewable water supplies. Extreme precipitation events may cause flooding (suffocation of roots), soil erosion and physical damage to plants. Meanwhile, prolonged droughts may have detrimental effects on crops, livestock and ecology. Due to the rise in the sea level, fertile lands and residential areas may be inundated and groundwater quality will be reduced by seawater intrusion (IPCC, 2014). Figure 5 shows

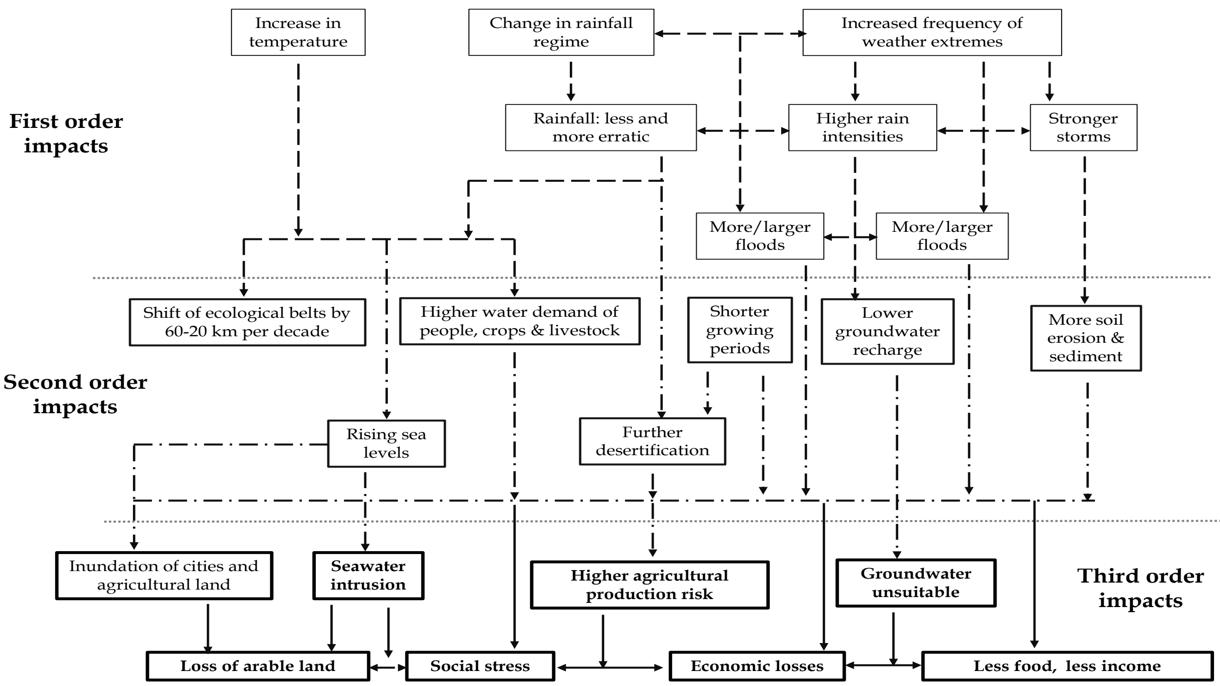

Fig. 5. First, second and third order impacts of climate change on agricultural production in the Arab region. Source: ESCWA, 2011.

an approach towards vulnerability assessment to assess the impacts of climate change on agriculture. The analysis was done in three orders:

- First order (or primary) impacts the climate due to the build-up of greenhouse gases (GHGs') in the atmosphere e.g. increased temperatures and higher evapo-transpiration (ET) values.
- Second order impacts include the changes in ecosystems and ecosystem services e.g. agriculture.
- Third order impacts are the changes in the anthroposphere (with special reference to the agricultural sector) e.g. degradation of arable lands and economic losses.

The productivity of the agricultural sector in the study area will be very much reduced due to the significant impacts witnessed in the rainfall coupled with increased temperature. Since, agriculture is the major livelihood in the country hence the whole socio-economic conditions of Old Sudan are expected to dwindle.

Adaptive Water Resources Management

As illustrated earlier water reources are under increased pressure particularly under aridity conditions. In addition dry land that are characterized by variable rainfall witness climate change leading to further rainfall reductions. This urged serious initiatives from decision-makers. Various means and ways were devised with a view to conserve, develop and properly manage water resources to satisfy essential requirements. Besides the technical and economical viability, impacts on the environment, social, institutional and political aspects are also to be taken into consideration.

Some of the promosing techniques include the following:

i. Water harvesting and supplementry irrigation
ii. Modernization of irrigation systems
iii. Controlled agriculture
iv. Irrigation with saline and brackish water
v. Reuse of treated wastewater
vi. Introduction of integrated management approaches
vii. Adoption of smart water management

Conclusions

The following conclusions could be drawn from the present study

- Considerable southward movement of isohyets was observed between the two climatic areas of (1941-1970) and (1971-2000).
- Trends and anomalies at Fashir and Khartoum meteorological stations showed decline in the annual rainfall which coincided with an increase in temperature.
- For the duration of the second half of the previous century rainfall declined by 20%, 14.3% and 17.5% for El Fashir, Khartoum and Medani, respectively.
- Furthermore, during the first ten years of the 21st century both Khartoum and Fashir showed further decline of 26% and 33% respectively but Medani showed restoration of previous levels.
- The ENSO event has strong indications in dry Sudan since prolonged La Nina is associated with above-normal rainfall meanwhile, there is a strong tendency (about 75%) for below-normal rainfall during prolonged El Ninos.

Recommendations

To meet the future challenges in this domain the presented results recommends

- Expanding the national meteorological station network and enhancing the capacity of hydro-meteorological services on the analysis, interpretation and disseminate of the generated information
- Sustaining the capacity of the relevant national institutions to ensure availability of qualified national personnel at all level
- Raising of public awareness on the different aspects of climate change including impacts, mitigation and adaptation
- Provision of adequate financial resources for the implementation of the adaptation and mitigation programs including policy and strategic planning development.

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