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Review

Climate Change Impacts on Water and Agriculture Sectors in Southern Africa: Threats and Opportunities for Sustainable Development

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Abstract: Agriculture remains important in driving economic transformation, sustainable livelihoods, and development in developing countries. This paper provides a comprehensive analysis and discussion of climate change impacts on water and agriculture sectors and implications for the attainment of developmental outcomes such as food security, poverty reduction, and sustainable development in Southern Africa. The review gives policy messages for coping, adapting, and building resilience of water and agricultural production systems in the face of projected changes in climate and variability. The aim is to guide the region towards the achievement of the Sustainable Development Goals. Future projections for Southern Africa indicate reduced rainfall, increased temperatures, and high variability for the greater part of the region with severe reductions on the drier and marginal western parts. These impacts have profound implications for agriculture performance and contribution to national and regional developmental goals. The region is projected to experience reductions of between 15% and 50% in agricultural productivity, a scenario that would exacerbate food insecurity in the region. The challenge is to increase productivity on current arable land through efficient and sustainable management of available water and energy, and at the same time reducing pressure on the environment. Affordability and accessibility of innovative adaptation measures on water resources remain critical and these strategies should be part of broader sustainable development efforts. Overall, efforts to enhance agricultural productivity need to emphasise investments in sustainable management and use of water and energy resources in agriculture to achieve sustainable economic growth and livelihoods.

Keywords: climate change; adaptation; resilience; water resources; food security; sustainability

1. Introduction

The agriculture and water sectors remain important in driving economic transformation, sustainable livelihoods, and development, particularly in emerging economies of the developing world [1,2]. For example, efforts to enhance agricultural productivity are central to the African Union's 2014 Malabo Declaration that position the sector as an engine to drive inclusive economic growth, employment creation and ending malnutrition and hunger in Africa [3]. Together with the water sector, agricultural development is critical for economic development and attainment of the Sustainable Development Goals (SDGs) such as SDG 1 (no poverty); SDG 2 (zero hunger); SDG 3 (good health and wellbeing); and SDG 6 (clean water and sanitation). However, climate change and variability threaten to derail these efforts and offset economic development plans to achieve food and water security, reduce poverty, and attain sustainable development [4–7]. Projected changes in climate include recurring climate extremes like droughts, flooding, and outbreaks of pests and diseases exposing the region to the vulnerabilities of the changing environment. In addition, the agriculture sector still faces challenges to provide sustainable livelihoods to millions who rely on the sector and ensuring national and regional food security in many African countries [4].

Climate change is projected to result in increased warming conditions, changes in rainfall patterns and distribution, and increase in the intensity and frequency of droughts and floods [8–10]. Furthermore, the changing climate exacerbates water stress and hydrologic variability especially in semi-arid and arid regions that include Southern Africa [11]. Hydrologic variability manifest in different dimensions that include: (a) Intra-annual variability (monthly and seasonal); (b) inter-annual (year-to-year), and (c) timing and intensity of extreme events difficult to predict [12]. Variability in water resources affects availability of water for competing economic sectors and natural ecosystems. The impacts of climate change and variability on water resources have significant effects on the performance of the agriculture. In Southern Africa, such impacts are already derailing economic growth and development, and continue to increase the vulnerability of over 60% of the population living in rural areas relying on agriculture and natural resources for their livelihoods [13].

Currently, climate change and variability are already impacting agricultural food supply and demand; and local food systems threatening progress in achieving food security [8,14–16]. Empirical climate change impacts research on African agriculture such as [14,16–19] demonstrate that the agriculture sector performance adversely suffers from changes in climatic variables such as increased warming and drying conditions [13]. Socio-economic challenges such as poverty, food insecurity, low adaptive capacity, and lack of financial resources and technology worsen the susceptibility of African agriculture systems to changes in climate. With this background, the challenge for the agriculture sector is threefold: (a) To adapt to changing climatic conditions; (b) produce enough food and fibre to feed the growing population; and (c) to reduce and/or minimise the sector's contribution to greenhouse gas (GHG) emissions [4].

This review provides a comprehensive analysis and discussion of impacts of climate change on water and agriculture sectors in Southern Africa; and implications for regional goals on integrated development outcomes such as food security, poverty reduction and sustainable development. The focus is on the interactions between climate change impacts on water sector and agriculture and subsequent effects on development goals. For Southern Africa where almost 95% of agriculture is rainfed [20,21], understanding how climate change impacts on water resources affect performance of the agriculture sector and subsequently on developmental goals is important. This review broadens the analysis of climate change impacts on water and agriculture sectors and enhances the understanding of the complex interactions between changes in climate and associated impacts in the two sectors. The review aims to provide policy and decision-making with evidence-based strategic pathways that lead to climate change adaptation and resilience in the water and agriculture sectors. These efforts also contribute to continental commitments, such as Aspiration 1 (A prosperous Africa based on inclusive growth and sustainable development) of Agenda 2063 and the 2014 Malabo Declaration to build resilience and adaptive capacity of agricultural production systems to improve performance of the agriculture sector to attain inclusive sustainable livelihoods and development [3].

2. Overview of Water and Agriculture Sectors in Southern Africa

Seventy-five percent of Southern Africa (Southern African Development Community (SADC) countries but excluding islands) is marginal with arid to semi-arid conditions (particularly in the south), where annual rainfall is less than 650 mm [22]. Countries near the equator fall in the sub-humid region and consist of the other 25% which receive annual rainfall ranging from 651 to 2000 mm [13]. Rainfall is highly variable and unevenly distributed in Southern Africa ranging from 100 to 2000 mm per annum [22]. As a result, 75% of the region is water scarce, with a low mean annual runoff volume of 650 km^3 [23]. Agriculture water withdrawals consumes about 70% of the total renewable freshwater resources per annum while domestic consumption is 20% and industry uses the remaining 10% [24]. Most of the surface water resources (at least 70%) in region are in fifteen transboundary river basins, meaning that water resources are shared between countries and some of the countries have a water dependency ratio of more than 50% [25].

In 2015, the total irrigated area in the region stood at 9 million ha, representing only 9% of total cultivated land of 107 million ha, yet it consumes over 70% of the available freshwater resources [26,27]. Most of the irrigated area is concentrated in countries on the east and south, that is, South Africa, Zimbabwe, Mozambique, and Tanzania (Figure 1).

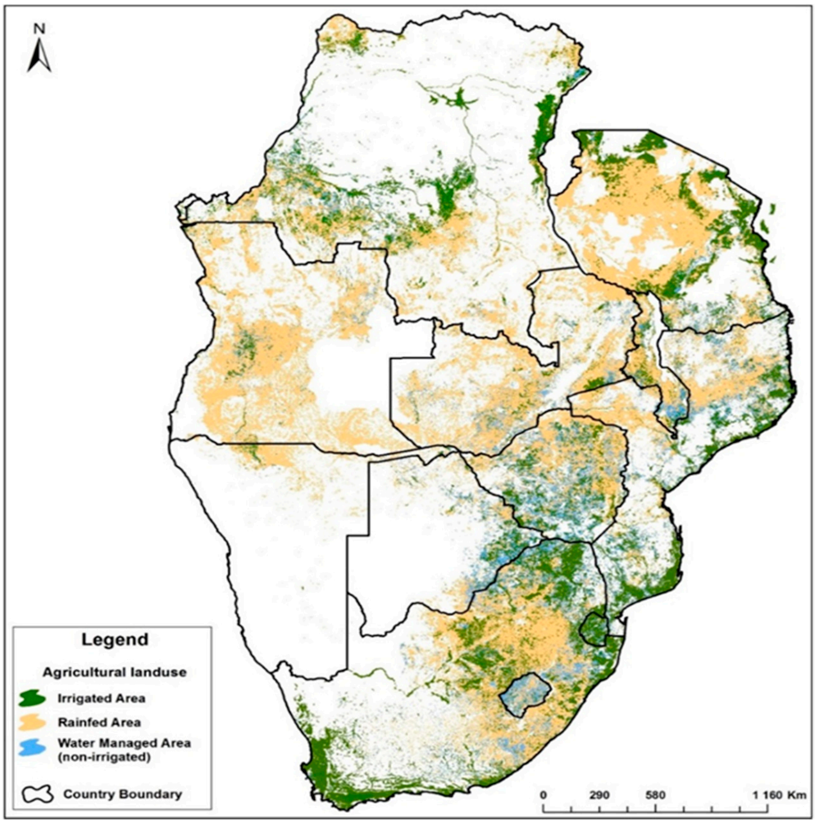

Figure 1. Cultivated landuse by agricultural system in Southern Africa.

Twenty-one percent of cultivated land is under water management (non-equipped flood recession cropping area and non-equipped cultivated wetlands and inland valley bottoms) and 70% is under rainfed agriculture (Table 1).

Table 1. Land area of agricultural systems in Southern Africa

Agricultural System	Area (km^2)
Irrigated area	93,658.61
Rainfed area	744,665.78
Water managed area (non-irrigated)	227,467.44
Total cultivated area	1,065,791.84

The agriculture sector is important for the regional economy of Southern Africa, contributing about 17% of the region's Gross Domestic Product (GDP) and up-to 28% GDP when middle incomes countries are excluded [27]. The sector also supports over 60% of the population depending on agriculture and natural systems for their livelihoods [27]. The performance of agriculture has implications for the welfare of millions and developmental outcomes such as food security, poverty reduction, and attainment of sustainable development goals [28]. Agriculture has been prioritised as an engine for economic transformation and inclusive development at the continental level as highlighted in the Malabo Declaration [3]. At the regional level, the Regional Agricultural Policy (RAP) and the Revised Regional Indicative Strategic Development Plan (RISDP) further position the agriculture sector as critical for achievement of food security, poverty reduction and sustainable economic development [27,29]

3. Changes in Climatic Variables in Southern Africa

3.1. Changes in Climatic Variables (Temperature and Rainfall)

The expected climatic changes in Southern Africa include increasing temperatures and drying conditions, and the increase in the intensity and frequency of extreme weather events. The maps shown on Figure 2, obtained from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) shows the trends in mean annual temperatures (historical and simulated) for the African continent [2].

The historical evidence for Southern Africa indicates an increase in warming conditions for most parts of the region [2]. In addition, the AR5 further indicates that the Southern African region will experience further warming at a rate higher than global averages with the semi-arid and drier south western areas expected to experience higher rates of temperature increases [2]. Parts of Botswana, Namibia, and South Africa would be most affected by worsening warming conditions (Figure 2).

The projected increases in warming conditions across most parts of the region would worsen the challenges associated with water insecurity (mainly due to reduced rainfall), adversely affecting both rainfed and irrigated agriculture production, as well as negatively impacting energy generation [25]. In addition, increased warming conditions would increase the water demand for agriculture (particularly irrigation agriculture) on already stressed water resources systems. The increased demand for water in agriculture would aggravate water, energy, and food insecurity as experienced during the 2015/16 drought. Increasing warming and drying conditions in the region are already being aggravated by other stressors that include increased population growth, migration, and rapid urbanisation. These stressors have detrimental effect on agricultural sector performance, and economic development [5], and therefore are a threat to the attainment of SDGs. Overall, water, energy, and food insecurity affect socio-economic and environmental systems with adverse impacts on regional efforts for economic transformation, growth, and sustainable development.

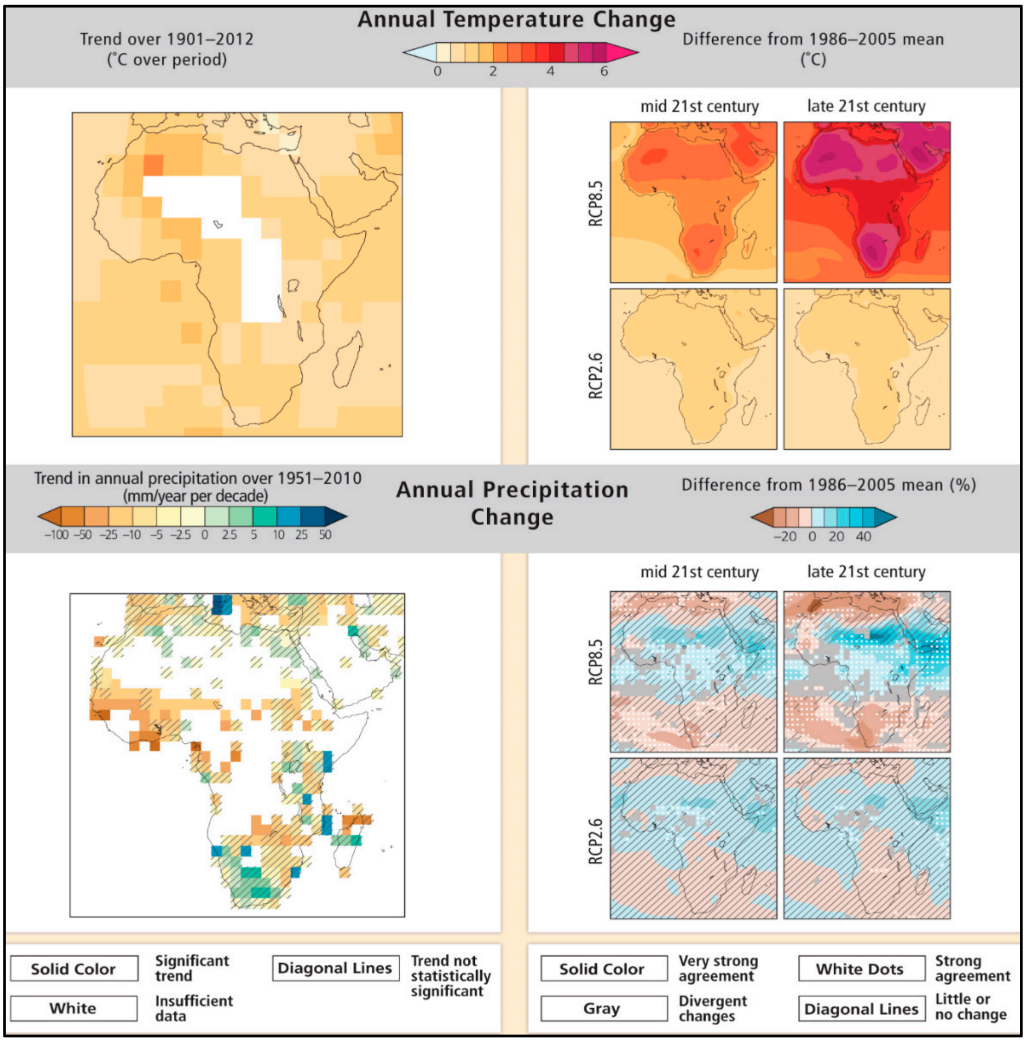

Figure 2. Observed and simulated variations in past and projected future annual average temperature and precipitation over Africa. The maps illustrate temperature and precipitation changes observed to date and projected warming under continued high emissions and under ambitious mitigation. Reproduced with permission from IPCC, *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*; published by Cambridge University Press: Cambridge, 2014.

3.2. Changes in Rainfall, Aridity, and Water Scarcity in Southern Africa

The spatial distribution of observed annual rainfall in Southern Africa is shown in Figure 3. The data are from the Food and Agricultural Organization (FAO) and are at five 10-year intervals from 1960 to 2000 and also 2007. Rainfall patterns indicate significant changes in the region during the 47 years under consideration. The results indicate significant decline in total annual rainfall in the region. Rainfall totals in the region declined by 25.6% between 1960 and 2007 [13]. Detailed analysis of Figure 3f (representing rainfall pattern for 2007) indicates that almost half of the region's surface area is now arid. In addition, annual rainfall data for 2007 shows that greater parts of the region received less than 350 mm of rainfall, classifying the region into a water scarce category, and thus becoming a climate hotspot region. Reduced rainfall is exacerbating regional vulnerabilities, which already suffers water, energy, and food insecurity.

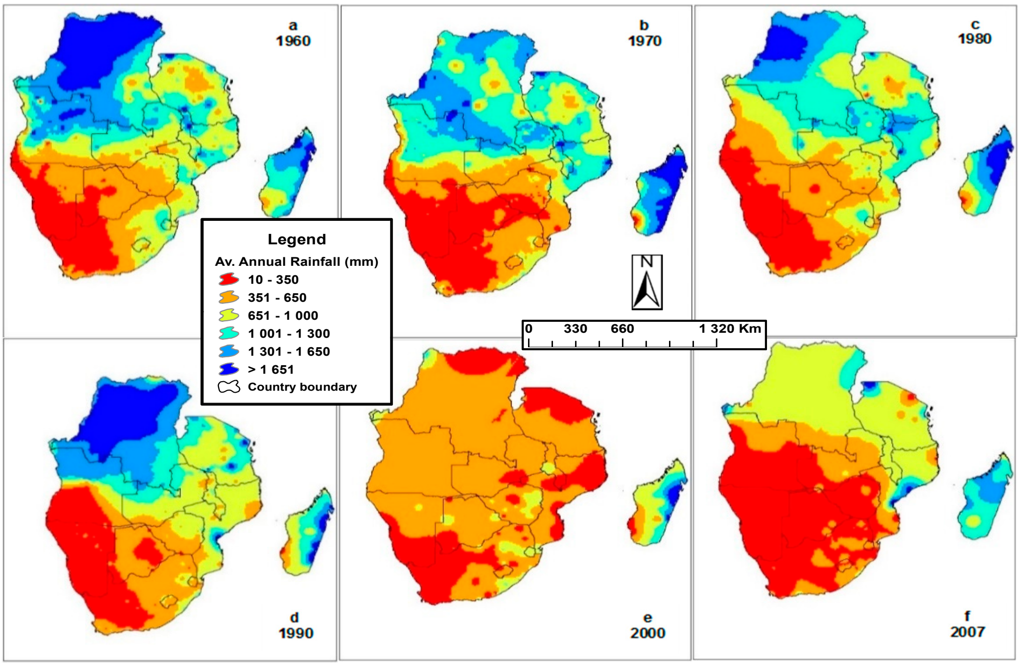

Figure 3. Spatio-temporal changes in rainfall distribution and pattern in Southern Africa over time from 1960 to 2007 (**a**–**f**). Rainfall has drastically reduced in the most recent years (from 1990 to 2007).

There is a noted decreasing trend in rainfall except for islands and countries closer to the Equator where rainfall totals tend to be constant over the years. The general trend and changing pattern in rainfall indicates the high rainfall variability, with incidences of floods and droughts [25]. Examples of extreme weather events are the 1991/92 and the 2015/16 droughts [30,31] and the 2002 floods [32].

Table 2 presents the country-wise rainfall trends of SADC countries from 1960 to 2007. The trends indicate that rainfall is highly variable in the region. The intensity in rainfall variability is more pronounced in the most recent years. This is shown by the coefficient variation values of annual rainfall (Table 2), which is highest at 0.71 in 2007 compared to 0.45 in 1960. The country wise plot of annual rainfall over the years shows that total annual rainfall for most of the countries has been decreasing in the region as indicated by the negatives in percentage changes in most countries of the region from 1980 to 2007. The decreasing annual rainfall is a major contributing factor to the worsening water scarcity in the region.

Table 2. Temporal change in total annual rainfall in the Southern African Development Community (SADC) countries from 1960 to 2007

Country	Area Weighted Average Annual Rainfall (mm)						Percentage Change				
	1960	1970	1980	1990	2000	2007	1960–1970	1960–1980	1960–1990	1960–2000	1960–2007
Angola	1088.9	940.5	696.1	751.09	576.2	766.3	−13.6	−36.1	−31.0	−47.1	−29.6
Botswana	418.5	300.8	459.5	349.19	510.9	252.2	−28.1	9.8	−16.6	22.1	−39.7
Congo DR	1473.8	1268.4	1224.0	1427.79	477.6	932.7	−13.9	−16.9	−3.1	−67.6	−36.7
Lesotho	807.7	548.5	487.8	576.11	547.5	381.7	−32.1	−39.6	−28.7	−32.2	−52.7
Madagascar	1335.8	1585.5	1428.5	1158.60	988.2	1228.6	18.7	6.9	−13.3	−26.0	−8.0
Malawi	1062.4	1154.5	1172.0	752.70	346.2	920.0	8.7	10.3	−29.1	−67.4	−13.4
Mauritius	1669.5	1734.0	2505.0	1203.00	1270.3	1495.7	3.9	50.0	−27.9	−23.9	−10.4
Mozambique	933.4	847.1	915.9	792.00	445.3	554.2	−9.3	−1.9	−15.2	−52.3	−40.6
Namibia	263.1	212.9	261.2	145.36	360.6	141.6	−19.1	−0.7	−44.7	37.1	−46.2
Seychelles	1880.0	1977.0	1780.0	2048.00	1390.7	1979.0	5.2	−5.3	8.9	−26.0	5.3
South Africa	532.6	437.8	467.9	449.83	435.0	324.9	−17.8	−12.1	−15.5	−18.3	−39.0
Swaziland	1004.3	612.7	872.7	630.87	704.2	367.9	−39.0	−13.1	−37.2	−29.9	−63.4
Tanzania	1004.3	1058.7	963.1	1010.65	414.9	873.8	5.4	−4.1	0.6	−58.7	−13.0
Zambia	921.5	910.5	949.5	835.26	460.7	491.5	−1.2	3.0	−9.4	−50.0	−46.7
Zimbabwe	650.8	489.8	711.5	658.05	507.5	283.7	−24.7	9.3	1.1	−22.0	−56.4
SADC av.	1203.2	998.0	1001.2	961.6	731.2	895.3	−17.1	−16.8	−20.1	−39.2	−25.6
Mean	1003.11	938.56	992.99	852.57	629.05	732.91	-	-	-	-	-
Standard dev.	450.45	531.35	580.77	470.92	325.66	519.06	-	-	-	-	-
Coefficient var	0.45	0.57	0.58	0.55	0.52	0.71	-	-	-	-	-

The spatio-temporal changes in aridity and water scarcity over time (1980–2007) in the region is given in Figure 4. The Climate Moisture Index (CMI) values for the region are negative or below zero, which is an indication that potential evapotranspiration (PET) is higher than precipitation [33]. Vörösmarty et al., [33] argues that CMI values and climate situation in a given area are linked and are classified as follows: Arid (CMI less than −0.6); semi-arid (CMI between −0.6 and 0); sub-humid (CMI between 0 and 0.25) and humid (CMI above 0.25). The Southern Africa region's estimated CMI value was −0.80 indicating that it is water scarce and arid. The observed negative changes in rainfall, water scarcity and continued aridness in Southern Africa compliments results from other studies, which also showed negative changes in rainfall and other climatic conditions in the region [2,33,34]. Overall, aridity in the region increased by 10.8% during the period 1980–2007, exposing the worsening aridness and water scarcity in the region. Figure 4 shows that the aridness in the region has been increasing over time, a bad scenario affecting local agriculture production conditions and hence performance of the agriculture sector.

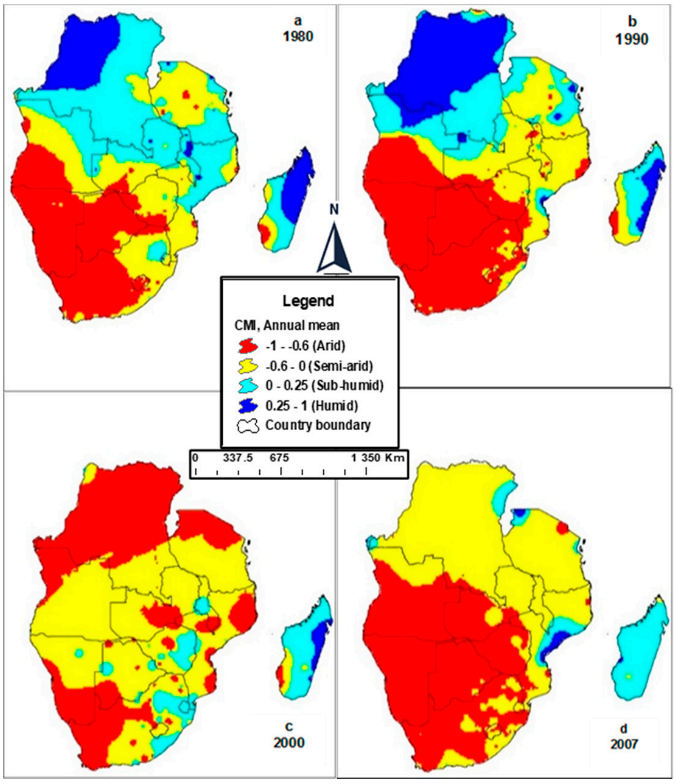

Figure 4. Spatial−temporal changes in water scarcity and level of aridity in the Southern Africa. The degree of aridity is has worsened with time as depicted by the difference in the arid area (−1−0.5) between 1960 and 2007 (**a**–**d**).

The availability of water resources is important for attaining regional developmental goals such as improving agricultural productivity for sustainable livelihoods, and for achieving the SDGs. The projected impacts on water resources resulting in reduced water availability and increased water demand will have significant effects on socio-economic development in the region [2,35,36]. However, the continuing reductions in available freshwater resources demands the adoption of modern agricultural water management practices that increase productivity with less or same water resources at a time of increased demand from a growing population [21]. Reduced rainfall in upstream river basin systems affect availability of water in downstream systems and subsequent uses across various economic users. Significant adverse impacts in upstream water resources systems adversely affect economic activities and natural ecosystems [37].

3.3. Intensity and Frequency of Droughts and Floods

The intensity and frequency of extreme droughts and floods has increased in recent years across the region and these are expected to worsen in the future [2,35]. Figure 5 shows the number of drought and flooding events that occurred in selected Southern African countries between 1960 and 2018. Flooding is the most frequent of the two extreme events, occurring at an average of once in every two years, with Malawi, Mozambique, Zambia, Zimbabwe, and Madagascar being the most affected (Figure 5). The same countries are also the most affected by drought events, which are occurring at an average of once in every three years [7]. The frequency of droughts further confirms the drying conditions in Southern Africa. Agricultural output is affected the most by extreme events (mainly droughts and floods) and extreme variability in climatic variables resulting in both direct short-time and long-term impacts on agriculture output and overall sector performance [12].

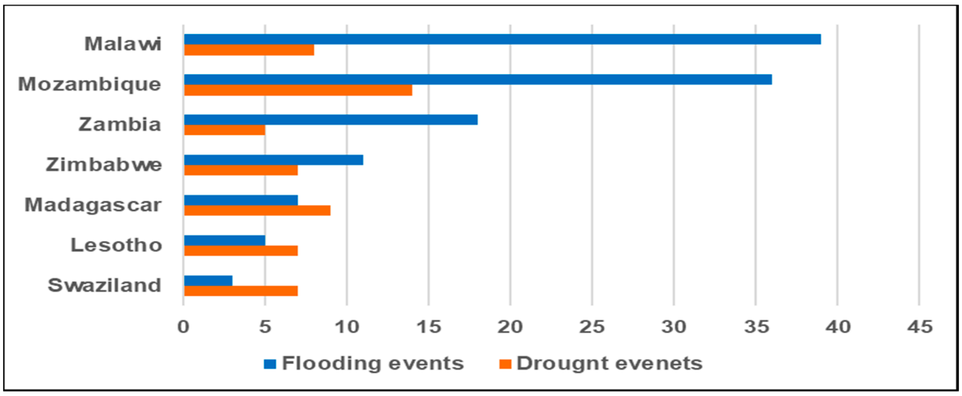

Figure 5. Drought and flooding events in selected Southern Africa countries from 1960 to 2018. Source: Graph plotted from data obtained from the International Disaster Database. Data used with permission from Guha-Sapir, EM-DAT (The International Disaster Database, Centre for Research on the Epidemiology of Disasters (CRED); published by Université Catholique de Louvain: Brussels, Belgium, 2020.

Future projections indicate that the intensity and frequency of extreme weather events would increase in Southern Africa resulting in higher risks and uncertainties in agriculture food systems [2]. Drought conditions contribute to environmental degradation, and encroachment of marginal conditions on agriculture production areas and desertification [38]. Extreme flooding results in infrastructure destruction (including water and irrigation infrastructure); damages to crop and livestock production activities; increased disease incidences, among others [2,38]. These changes have detrimental effects on progress gained on reducing poverty, hunger, and attainment of SDGs.

4. Implications of Water and Food Insecurity on Sustainable Development

The hydrological impacts of climate change range from changing rainfall distribution patterns, spatio-temporal changes, reduced crop productivity and energy generation and increased evapotranspiration [39]. The short-term variability and long-term availability of water resources is affected by climate change [9]. The challenge of water scarcity is aggravated by other factors such as hydrological variability and political boundaries cutting through transboundary river basins, as well as increasing population [5,40]. Therefore, the quality and quantity of water resources in the region are having direct impacts on agricultural production systems and economic development and attainment of the SDGs. In addition, reliable and sufficient supply or availability of water resources and other complementary inputs are critical for improving and sustaining agricultural sector performance.

The projected climate change impacts on water resources in the region makes food production a delicate challenge that should be met while sustainably using limited water resources. The challenge for agriculture is to increase productivity on current arable land through efficient and sustainable management of water and other resources and reducing pressure on the environment [41]. Sustainable utilization of water resources is paramount in contributing to agriculture production and economic development [42] in the face of climate change.

Agriculture food systems remain sensitive to changes in climate and variability as well as severity and frequency of extreme climatic events [8,43]. Climate change and variability impacts in agriculture include biophysical and socio-economic impacts. Biophysical impacts include changes in quantity and quality on land and water resources; physiological impacts (quantity and quality) on agricultural crops, livestock, forests, pasture, and livestock; increased challenges of pests, weeds, and diseases [44]. The biophysical impacts results on alterations on agricultural production conditions for crops, livestock, and fisheries due to increasing temperatures, variability in rainfall patterns, intensity, and frequency of extreme events. For example, the agriculture production season could be affected by change in climate and variability through altering suitability of agricultural production conditions and shortening the length of the production season [45]. Socio-economic impacts of climate change on agriculture range from: Reduced yields and production; reduced agriculture GDP; increased hunger and food security risks and number of people affected; changes in trade pattern and regimes across regions; fluctuations in world food prices; and civil and migration unrest [44]. These impacts affect attainment of sustainable development goals, particularly those related to agriculture.

Empirical evidence indicates that agriculture food systems and communities vulnerable to extreme weather changes are expected to be more vulnerable in future climate change shocks [8,15,19,43]. Differential climate change impacts on agriculture food systems will be experienced across locations depending on the severity of warming and changes in rainfall patterns and its distribution [8]. Results from Lobell et al. [46] found that Southern Africa is one region that would likely experience adverse impacts on multiple major crops (such as maize, wheat and sugarcane) important for food security due to increased warming and decreases in rainfall. The impacts are expected to be severe in semi-arid and arid regions such as the western parts of Southern Africa. Figures 6 and 7 below demonstrates the projected climate change impacts on cereal and agriculture productivity in Africa, respectively.

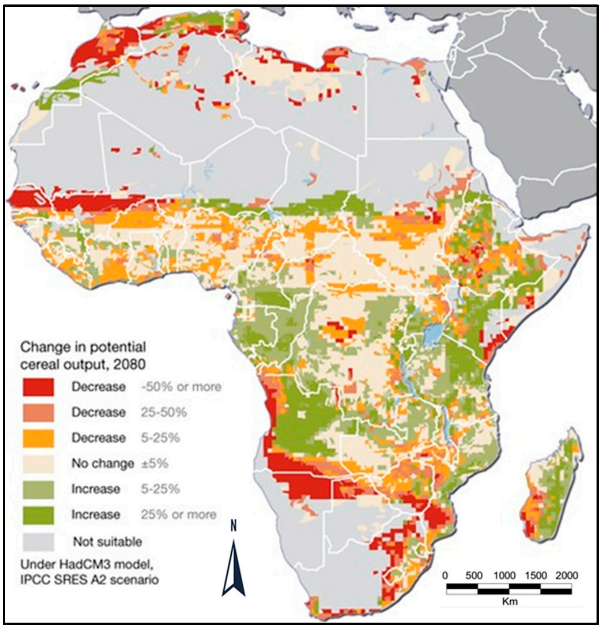

Figure 6. Projected changes in cereal productivity in Africa, due to climate change—current climate to 2080. Reproduced with permission from Ahlenius, H, *The Environmental Food Crisis—The Environment's Role in Averting Future Food Crises*, published by UNEP/GRID-Arendal, 2009.

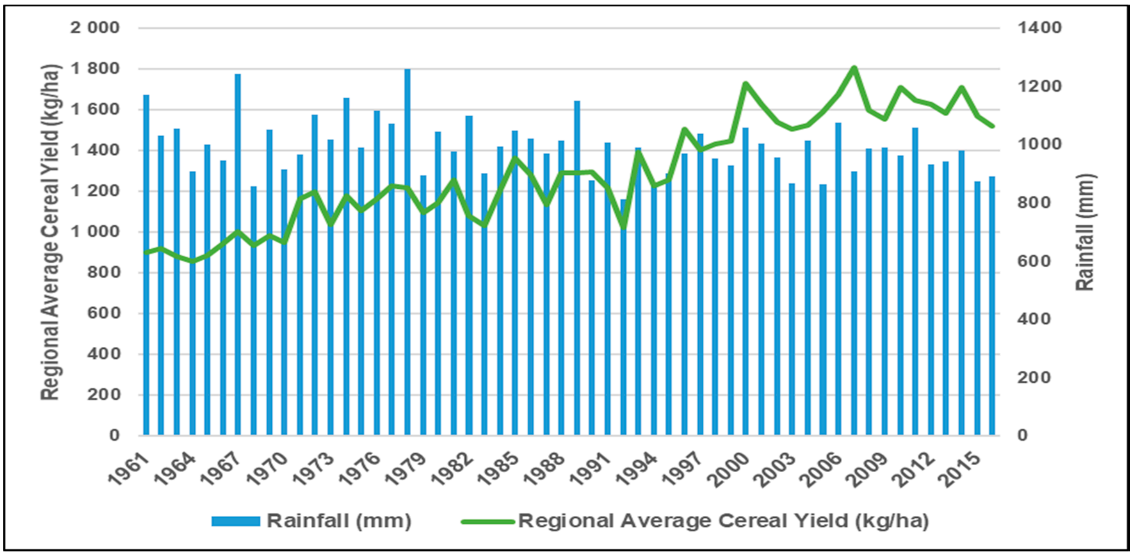

Figure 7. Relational trends between rainfall variability and cereal production in Southern Africa over time. Reproduced with permission from FAO, AQUASTAT Database; and World Bank, World Bank Indicators, 2020.

Most western parts of Southern Africa will be unsuitable for cereal productivity (Figure 6), while cereals are a major staple in the region. Other parts in the north and east would experience decreases in potential cereal output by 50% or more by 2080. One of the contributing factors to these impacts is increased water scarcity resulting from changes in climate and higher demand for water [1]. Areas in the further north in Angola, The Democratic Republic of Congo (DRC), parts of Zambia and Mozambique in the east would experience increases of 25% or more, however, these are small compared to the larger areas that would be unsuitable for cereal production and or would experience substantial decreases of at least 50%.

The changes in agricultural productivity are projected based on expected increases in warming, changes in rainfall patterns and carbon fertilization for plants [1]. Again, the western parts covering Botswana, Namibia, South Africa, Zambia, and Zimbabwe; and Madagascar in the east would experience reduced agricultural productivity by between 15% and 50%. The rest of the region would experience reductions of up to 15%. These projections have serious implications on the regional goals to improve livelihoods and achieve developmental outcomes such as food and nutrition security, poverty reduction and overall sustainable development goals.

Figure 7 presents relational trends between rainfall variability and cereal production in Southern Africa based on observed data of both variables from 1961 to 2015. There is a correlation between changes in rainfall and cereal production in the region (Figure 7). Some periods of lows in rainfall coincide with lows in cereal production (Figure 7) indicating the impacts of drought on crop production in the region. Rainfall variability is, therefore, impacting on agricultural performance, although the figure does not mean causality between the two variables.

Relational trends between rainfall variability and cereal production in Southern Africa over time depicts a decreasing trend with high levels of variability, which has been intensifying in recent past as rainfall totals decrease. The Mann–Kendall trend test shows a significant decreasing trend of $\alpha < 0.01$ in rainfall totals in the SADC region over the years. Despite the declining trend in annual rainfall, cereal productivity has maintained an increasing trend, mainly due to increased investment in the agriculture sector, as well as expansion of the cultivated land [24,47]. This sector performance would be attributed to potential investments in technology adoption. However, besides the increase in cereal production, food insecurity remains a major challenge in Southern Africa due to increasing population [21]. The increase in yields could also be due to combined effect of other factors such as improved seed varieties, fertilizer and pesticide application, adoption of improved agricultural practices and contribution of irrigated agriculture towards total cereal production. However, increased crop production could not match the pace of population growth during the same period, hence the constant shortfall of cereals due to the growing demand.

5. Adaptation Options and Achieving Sustainable Development Outcomes

Given current and future climate change impacts on water resources and agriculture sectors, adaptation remains imperative to build resilient systems that can withstand the projected impacts and sustainably contribute to economic growth and development. Adaptation interventions include autonomous changes of local management practices as farmers respond to changes in rainfall patterns and seasonal changes in growing conditions. Examples of autonomous adaptations include changes in timing of planting dates, changes in crop varieties, and crop mixes [44,46,48]. Planned adaptation interventions entail conscious policy decisions to invest in specific adaptations with the aim to improve adaptation capacity of water/agricultural systems or communities, for example, investments in development of adapted crop varieties and livestock breeds; efficient irrigation systems [44,46,48]. Planned adaptation would require substantial investments by farmers, government, private sector, and development partners to address the vulnerability of the water and agriculture sectors and their contribution to sustainable development.

Investments in agricultural water management are necessary to reduce the risks presented by changes in climate variability and change. These include: Inter-annual water harvesting techniques to store excess rainfall and flood control measures; using resource efficient irrigation technologies; land conservation techniques to improve residual soil moisture; mulching and zero tillage techniques [44]. In addition, water harvesting technologies and soil water management provide important sources of agricultural water to improve and sustain production during dry-spells and in drought-prone regions [49]. Adaptations in the broader water sector will also be important to address vulnerability and impacts of water resources in river basins and aquifers that are often transboundary [44]. The additional risk on water resources from climate change and competing demands for water from different economic sectors would require more efficient use of water in the agriculture sector.

Efficiency and improvements in irrigation systems have potential to save water that can be reallocated to other economic sectors [50,51]. In addition, adaptation in water resources should consider opportunities to increase soil water availability through interventions that maximize soil water infiltration, minimize evapotranspiration, innovative water conservation measures, harvest surface runoff to provide supplemental water for irrigation, and expand area under irrigation using saved water (improve irrigation systems) [51]. These interventions contribute to improving efficiency in water, agriculture, and other sectors saving water for food production and other competing needs [52]. The increasing demand for water resources from other economic sectors and natural ecosystems require agricultural systems to effectively use the limited water resources while simultaneously producing enough food and fibre to meeting the growing demand. Such investments include adoption of crop varieties with less water requirements more suitable to drier and warmer agricultural production conditions.

Climate change impacts on water and agriculture sectors require more financing to be able to transform farming systems in the region to become more water efficient. The region should prioritise investments in national agriculture investment plans that build resilience of farming systems while simultaneously improving the productivity of the sector and its contribution to sustainable development. The investments would range from short-term adjustments in agricultural production management practices (such as changes in crop varieties, planting dates) to proactive investments in development of water efficient irrigation systems, crop varieties and other technologies.

Adaptation measures in the water and agriculture sectors include measures that promote resource use efficiency and are a catalyst for sustainable development. Such measures contribute to efforts to transform water resource use in the agriculture sector towards efficient and sustainable systems that can sustain growing demand for food and fibre with less water resources. Implementation of adaptation and resilience building measures on water resources (especially at the farm-level) are critical for farmers (especially smallholder farmers) to improve and sustain agricultural productivity. For example, such measures should include farmer awareness to enhance the role of adapting water resources in addressing productivity. Affordability and accessibility of innovative adaptation measures on water resources remains critical and these strategies should be part of broader adaptation and sustainable development efforts in the region.

Technological developments in the agriculture and water sectors are always important pathways towards sustainability and food and water security and for balancing resource management and development [53]. Technology, particularly hydrological and water management tools, and models have emerged as essential components of water management. Examples of technologies that are transforming the agriculture and water sectors include the development of smart plants that are more drought tolerant through genetic modification and genome editing [54]. Some plants can also be engineered to use more efficient photosynthetic pathways that fully use the sun's available energy [55]. This development holds promise for the hot and dry climates and water scarce regions such as Southern Africa. Remote sensing, and particularly the of use unmanned aerial vehicles (UAVs), also called drones, has become an important components of agricultural water management, particularly in irrigation scheduling for both commercial and smallholder sub-sectors [56]. Developments in precision farming have been aided by freely available remotely sensed products and high and user-defined spatial and temporal resolution drone images. These products can be used to precisely locate wet and dry zones of a cultivated field as well as for estimating crop water requirements. Such information is vital for variable irrigation scheduling. Mobile apps and other social media platforms can be used to provide information on weather, rainfall, and soil humidity to allow better farm management and productivity, as well as information on markets [57].

Remotely sensed information from unmanned aerial vehicles (UAVs) is useful in disaster situations, particularly when crops are damaged in extreme weather events [58]. UAVs can precisely estimate crop loss by comparing the pre- and post-disaster images [59]. This pre- and post-crop damage data is critical for insurance companies as it provides information that allows assessment of the damage incurred by farmers [56]. This is particularly relevant as insurance companies move towards insuring smallholder farmers against extreme weather events [60,61]. Drone images provide the required evidence on the state of damage through the development of an index-based crop insurance. The current impact, frequency, and intensity of extreme weather events on smallholder agriculture requires urgent insurance mechanisms that promote adaptation and enhance resilience against climate change [62]. Thus, high-resolution drone images (both spatial and temporal) are well suited for the development of accurate index-based crop insurance for the benefit of both smallholder farmers and insurers.

6. Conclusions

Climate change poses the great threat on water and food security, and it has huge implications on attaining developmental outcomes such as poverty reduction and sustainable development. Understanding climate change and variability impacts on water resources and agriculture systems is important in designing response mechanisms to build resilient systems. This review has broadened the understanding of climate change impacts on water resources and agriculture and subsequent contribution towards sustainable development. For these challenges in the water and agriculture sectors, there is an urgent need to provide pathways that lead towards sustainable food systems and other transformative systems. For Southern Africa, the challenge is multi-pronged, affecting mainly the water and agriculture sectors through reduced rainfall and increased temperatures. These changes are threatening water availability in Southern Africa and the ability of agricultural systems to meet the increasing demand of food from a growing population and to contribute towards sustainable development. The impacts are differential across the region with the western drier parts expected to suffer the most. Although investments in irrigation technologies offer an important adaptation measure for agriculture, the reduced availability of water resources calls for more efficient irrigation systems to sustainably use limited water and produce enough to meet the demand for food and fibre. Improving resilience of water resources and agriculture systems remains a priority to both avoid slowing and reducing progress in the agriculture sector performance and contribution to achieving regional developmental goals. The discussion acknowledges that impacts of climate change on agriculture transcends beyond effects on water resources and irrigation. In addition, the performance of the agriculture sector is determined by various climatic and non-climatic factors beyond what has been considered in this paper. Vulnerability of water resources and agricultural production systems to climate change and other multiple stresses should be integrated in adaptation investments to ensure more comprehensive responses for building resilient farming systems and communities. Given the role and importance of water and agriculture sectors in the region, investments in adaptation and building resilience should consider a much broader sustainable development approach in both the countries and the region. Future research should consider interaction effects of both climate and non-climate factors in affecting water resources and the agriculture sector. It is also important to increase awareness and access to sustainable use and conservation of water resources and sustainable agricultural production systems.

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