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Review

Risks of Climate Change on Future Water Supply in Smallholder Irrigation Schemes in Zimbabwe

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Abstract: Smallholder irrigation schemes (SISs) have been portrayed as a panacea to climate change adaptation. However, there is an emerging discourse that established schemes are becoming vulnerable to increased climate variability and change, particularly increased water stress. This paper reviews the existing knowledge on risks of climate change and variability in water supply in smallholder irrigation farming in Zimbabwe. In addition, this paper highlights adaptation options to climate change in SISs. Data for this review were collected systematically from peer-reviewed and published literature. The literature used for this study showed that SISs in Zimbabwe are beset with water stress, competing water needs and the outbreak of pests and diseases, which have been related with climate change and variability. Climate change is making Zimbabwe more arid through decreasing precipitation and warming. Droughts and floods are increasing in frequency and severity. Damage by floods is increasing exponentially, impacting environments, ecological systems and national economies. Climate change affects SISs' productivity and decimates the livelihoods of scheme farmers. The review suggests that there is a need for increased adsorptive, adoptive and transformational capacity for SISs to obtain a new state of resilience from adverse effects of increased climate variability and change. This review recommends understanding and prioritizing solutions to vulnerability to climate change in SISs.

Keywords: rainfall; drought; temperature; water stress; pests and diseases

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1. Introduction

Globally, the major abrupt influence of a changing climate in the agricultural sector will be through a more variable precipitation pattern, increased temperatures and increases in the frequency and severity of extreme weather events, such as cyclonic activities, droughts and floods [1,2]. The impacts of climate change on water resources, including quantity and quality of water, are a growing concern in smallholder farming systems, particularly in those areas already experiencing water stress [1,3,4]. Some authors have documented the possible impacts of climate change on new and emerging pests and diseases [5–7]. However, addressing the impacts of climate change must be considered in for all socio-economic conditions, including policies, institutions, investments, economies and technical factors which affect the vulnerability of systems to climate change.

The change in climate experienced world-wide already has negative implications for 21st-century agriculture in Zimbabwe [8]. There is mounting evidence that large investments have been made in Zimbabwe's SISs in an attempt to depart from rain-fed agriculture through judicious harnessing of available water resources. However, there is rising concern about the need to build the resilience of these schemes to protect investments in light of a more variable climate. In this article, climate variables and socio-economic factors are reviewed to inform decision-makers on possible actions for resilience-building, with a particular emphasis on SISs in Zimbabwe. Zimbabwe was selected for this study following recent findings that there is increasing aridity across the country, as evaporation may be rising concurrently with the decline in precipitation [9].

Several studies have been recently conducted globally to assess the influences of climate change on water resources and irrigation systems, with the goal of maintaining the long-term viability of irrigation systems and farmers' livelihoods. Some researcher have found climate change to result in decreased annual precipitation and reservoir inflow [10–12], reduced water quality [13], groundwater depletion [14,15], reduced crop productivity [11,16,17], reduced irrigable land [18], changes in cropping area [16–20] and implicated livelihoods [12]. Further, in Zambia, some authors have recommended the use of water-efficient technologies and better management of water resources given increased water stress [21]. Modeling in the Mediterranean region projected an increase in irrigation water demand and a reduction in reserve water levels by the year 2100 [22]. A study in Ecuadorian coast found out that tropical water resource systems could be unsustainable under climate change [23]. A study in Southern Europe showed that the sustainability of irrigated agriculture will be threatened by current planned management scenarios [24], and in Tarim River Basin (TRB), an upward trend of irrigation carrying capacity towards 2050 is anticipated [25]. Some findings show that change from surface to subdroplet irrigation reduces agricultural water use [15] and adoption of suitable adaptive strategies and that measures could mitigate the effects of climate change [26].

The aim of this paper is to contribute to the understanding of the impact of climate change among SISs. A comprehensive intersectoral analysis of climate change risks for smallholder irrigation schemes was the purpose of this analysis. The present review is the first one to summarize the impacts of climate change and variability in Zimbabwe, giving an overview of implications of climate change for SISs and socio-economic conditions. Therefore, the first climate change scenario for Zimbabwe was characterized based on finding from existing literature. Then, climate change's impacts on SISs in Zimbabwe were discussed. Further, the socio-economic and the underlying factors related to SISs were explored. The impacts of climate change on SISs vary extensively with the schemes' ecological, institutional, governance, and socioeconomic characteristics. A review of a wide range of these factors is critical for successful understanding of the impacts of climate change, and for adaptation and resilience building. New work based on countries around the world regarding climate change adaptation is highlighted to present alternatives to improve climate change adaptation.

2. Methodology

For the purpose of this review, a systematic approach was utilized, focusing solely on peer-reviewed primary articles on the effects of climate change and variability on water systems and smallholder irrigation schemes in Zimbabwe, as shown in Figure 1. Such articles were mainly obtained from Google Scholar using Boolean combinations of keywords, including climate change, smallholder irrigation schemes, water resources, adaptation, and Zimbabwe, for the period from 2010 to the present. A total of 2852 articles related to this review were identified, out of which 28 articles were selected finally selected for this review. An RMSE value of 18.52 was obtained, which is below 20 percent of published papers per year.

Mann–Kendall tests were performed using precipitation and temperature trends of Zimbabwe from 1901 based on data extracted from World Bank Group [27]. The Mann–Kendall test was used previously used to assess climate trends [28,29]. As illustrated in Table 1, temperature significantly increased, but the change in precipitation was not significant. The H_0, which suggests that there is no trend, was accepted for precipitation but rejected for temperature. However, the data used show the general trend of climatic conditions in Zimbabwe, and hence may vary from the observations from various metrological stations across the nation.

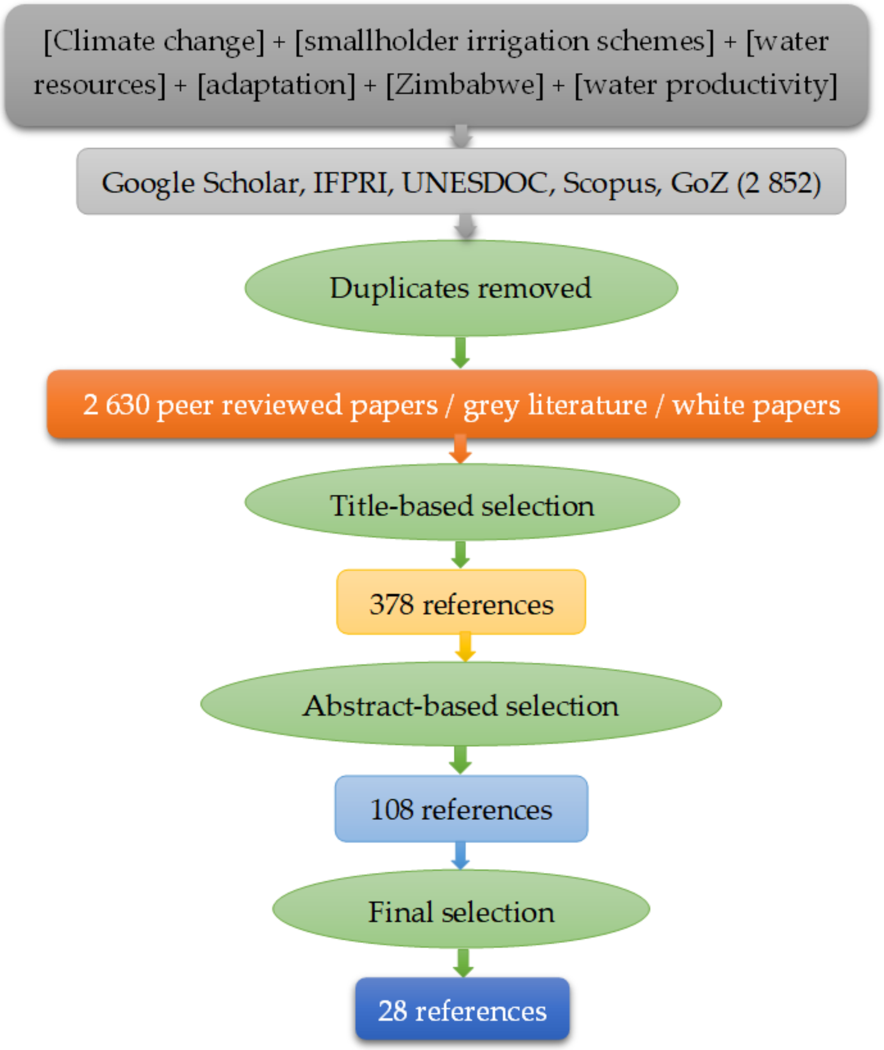

Figure 1. Schematic flowchart of the review process.

Table 1. Mann–Kendall trend tests for precipitation and temperature in Zimbabwe.

	Precipitation	Temperature
Kendall's tau	−0.07	0.37
S	−522.00	2663.00
Var(S)	194,366.67	194,319.67
p-value (Tw tailed)	0.24	<0.0001
alpha	0.05	0.050

3. Results

Illustrated in Figure 2 is a flow diagram of the proposed interaction of the factors discussed in this study.

3.1. Current Climatic Conditions and Their Variation in Zimbabwe

The current climatic conditions in Zimbabwe were compared to its base season in 1950. Greater parts of the country now experience a late start to the rainy season by up to 18 days, while some regions experience an early start [9]. Additionally, termination of the season occurs early, resulting in contraction of the season [9]. Further, the length of the dry spells has increased, with a number of dry spells during the rainy season stretching to 20 days. Currently, annual rainfall ranges from 450 mm in agro-ecological zone (AEZ) V*b* to 1250 mm in AEZ I [9]. Rainfall decreased in the northern, eastern and southern parts while increasing significantly from the central to western parts of the country [9].

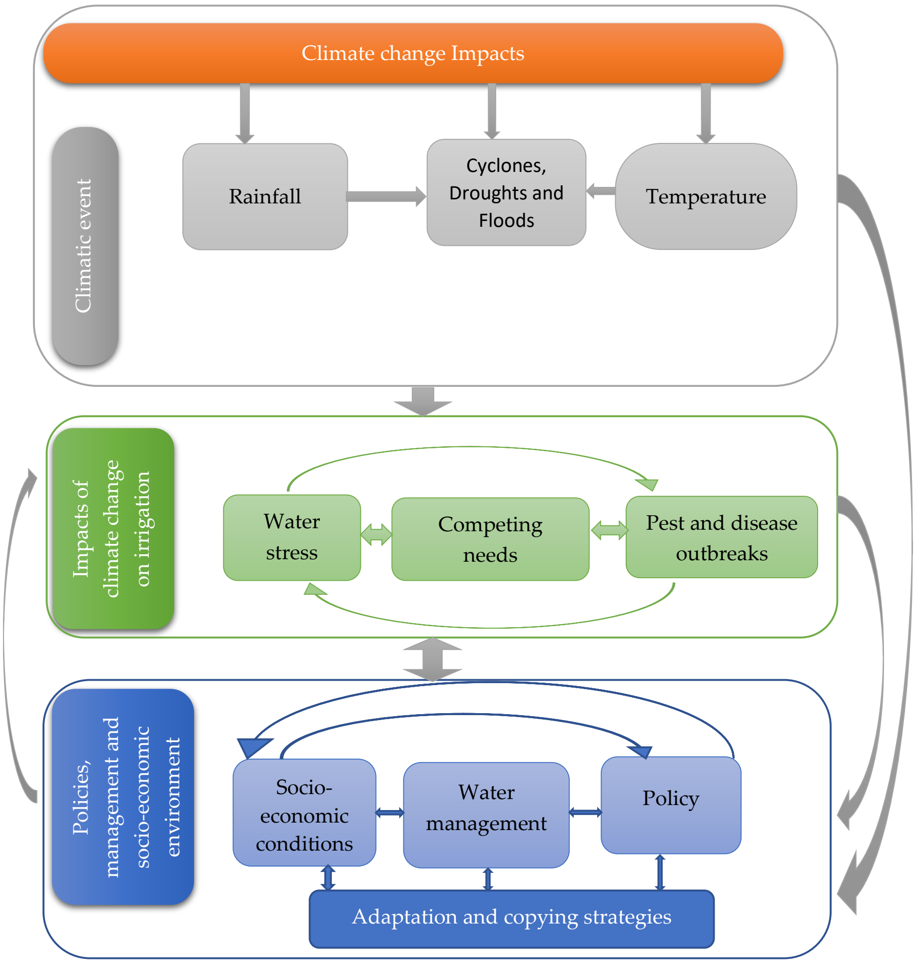

Figure 2. Flowchart of proposed interaction of climatic, ecological and social factors.

Further, there was significant warming in both minimum and maximum temperatures across the country [9]. Currently, the mean annual temperature ranges from 25 °C in AEZ I to a maximum of 32 °C in AEZ V*b* [9]. Maximum monthly temperature significantly increased in February, May and June in the central, eastern and southern parts of the country while decreasing in August in the southern parts of the country [9]. The winter months (May, June and July) are getting colder. An increase in potential evapotranspiration and a decrease in precipitation increase aridity across the country [9]. Arider agroecological zones (AEZs) rose to 8.5% for AEZ V*b* and 29.3% for region V*a* [9].

3.2. Climate Change Impacts in Zimbabwe

The potential impact of climate change on SISs depends on a combination of exposure, sensitivity and resilience of the SISs to potential water supply and demand changes, and hence, it varies considerably from one scheme to another. Agricultural communities are seriously at risk due to reliance of their livelihoods on farming, their little scope of diversification and their high exposure to climate variability [30]. Zimbabwe is evidently experiencing the effects of climate change through notable increases in the frequency and intensity of extreme weather events, making it face chronic food insecurity [31]. These changes will result in water stress, rendering land difficult for agriculture, thereby threatening the nation's economy and livelihoods. Agricultural systems in Zimbabwe have already been identified as the most vulnerable entity to climate change due to their dependence on natural resources [32,33]. The relative dependence of SISs in Zimbabwe on surface water makes the livelihoods of communities more vulnerable to climate change and variability, as the existing resources often dry up [34], leading to water stress. The vulnerability of SISs in Zimbabwe are increased revenue collapse, poor access to credit due to weak tenure security and degradation of irrigation infrastructure [35]. Small scale farmers are subjected to cropping calendars, low-value crops, uncertain markets, climate variability and little food security, challenging their ability to benefit from loans. Although the SISs are touted as a panacea to withstand impact of climate change and variability [31,36,37], they face increasing water stress. Rising temperatures and changes in precipitation patterns, a rise in evaporative demand, increased frequency of floods and greater depletion of water supplies contribute to water stress. On the other hand, outbreaks of pests and diseases, including new and emerging pests, are expected to increase due to changes in rainfall and temperature [38].

The impact is expected to vary across the AEZs of Zimbabwe, since these are divided mainly on the basis of rainfall regimes, soil quality and vegetation [32,39]. The impacts of all the above challenges will not be homogeneous, given the heterogeneity in management and institutions; thus, resilience and adaptive capacity varies across SISs.

3.2.1. Impact of Climate Change Change on Rainfall

Rainfall is seasonal in Zimbabwe. The rainy season generally stretches from mid-November to March [32,40]. The country's rainfall patterns are influenced by El Nino–Southern Oscillation events, which have a 30% chance of causing drought [40]. Evidence of desiccation below previous averages and increased rainfall variability has been noted in most parts of the country [9,39]. A decline in rainfall by an average of 10% or 100 mm has been observed in the country [40]. Most parts of Zimbabwe are becoming increasingly drier due to climate change [32,41]. Besides, even AEZ II and III are becoming arid, as noted by remarkable decreases in precipitation of 49% and 14%, respectively [32,39,42]. Rainfall patterns and intensity are highly variable and are projected to be uncertain in the second half of the 21st century [43]. Zimbabwe's monthly precipitation is projected to decrease by 3.3, 5.1, 7.4 and 8.2 mm in the 2030s, 2050s, 2070s and 2090s under Representative Concentration Pathway (RCP) 8.5, respectively [32,44]. According to IPCC, seasonal rainfall characteristics such as onset, duration, dry spell frequencies and intensity have changed significantly in the region [44]. However, the recent decline in agricultural production is linked to more frequent and severe droughts [32,40]. Thus, Mazvimavi [40] advocates for planning and managing water resource systems to adapt to changing climate.

Although the Mann–Kendall test showed an insignificantly trend of precipitation (Table 1), the Sen slope (Figure 3) shows a gradual decrease with a margin of −0.47 mm per year, which may suggest that climate change is negatively impacting rainfall.

3.2.2. Impact of Climate Change on Temperature

There is variation in temperature across AEZs [45]. The average annual temperature varies between 18 and 25 °C in areas with high altitude (approximately 1500 m) in the eastern and highveld and between 22 and 25 °C in lower altitudes (northern and southern regions) [45]. The Metrological Services Department (MSD) of Zimbabwe has reported that the daily minimum temperature rose by approximately 2.6 °C and the daily maximum temperature rose by 2 °C over the last century [46]. The rise in temperature is attributed to the recent increase in the number of hot days and nights and decrease in the number of cold days and nights in recent decades. Temperature across the country is projected to rise in the 21st century and beyond. However, the increase in temperature will depend on greenhouse gas emission scenarios, as Zimbabwe's monthly temperature is projected to rise by 1.2 °C, 2.2 °C, 3.4 °C and 4.5 °C in the 2030s, 2050s, 2070s and 2090s under RCP8.5, respectively [32,44]. The highest temperature increases are projected to occur in June to September [44].

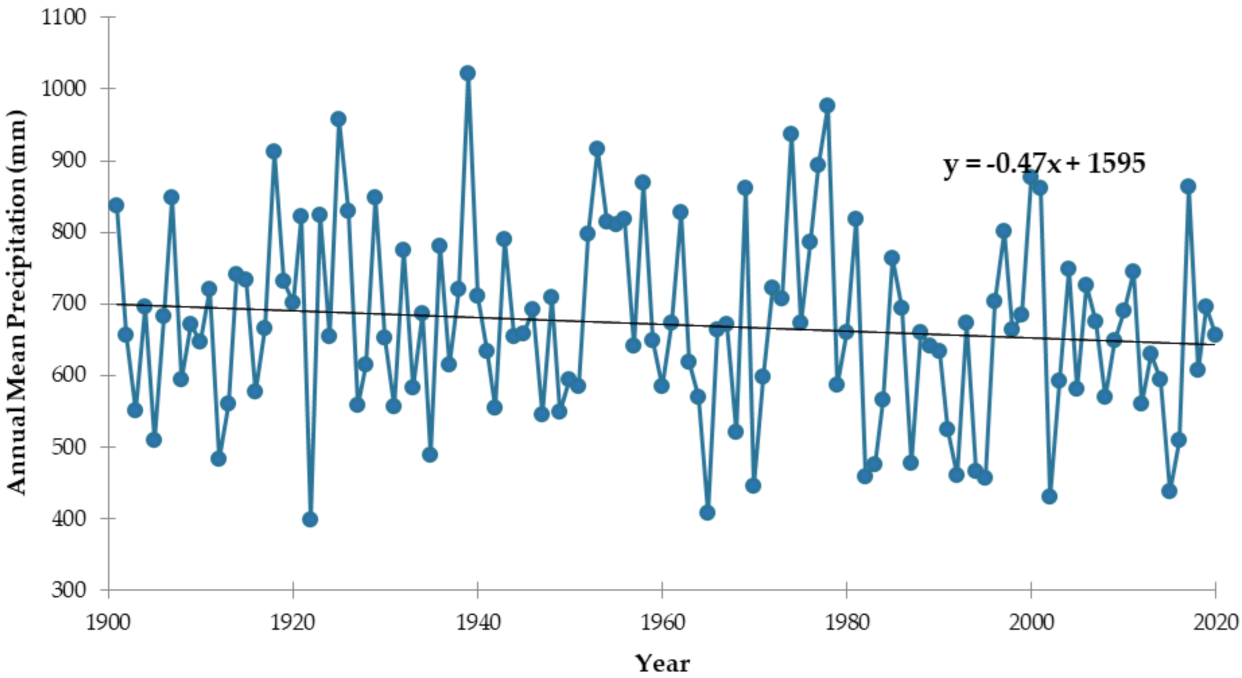

Figure 3. Rainfall trend in Zimbabwe from 1901 to 2020.

The Mann–Kendall test (Table 1) and Sen slope (Figure 4) show a significant increase in warming in Zimbabwe. The increase in warming trend reflects the growing impact of climate change.

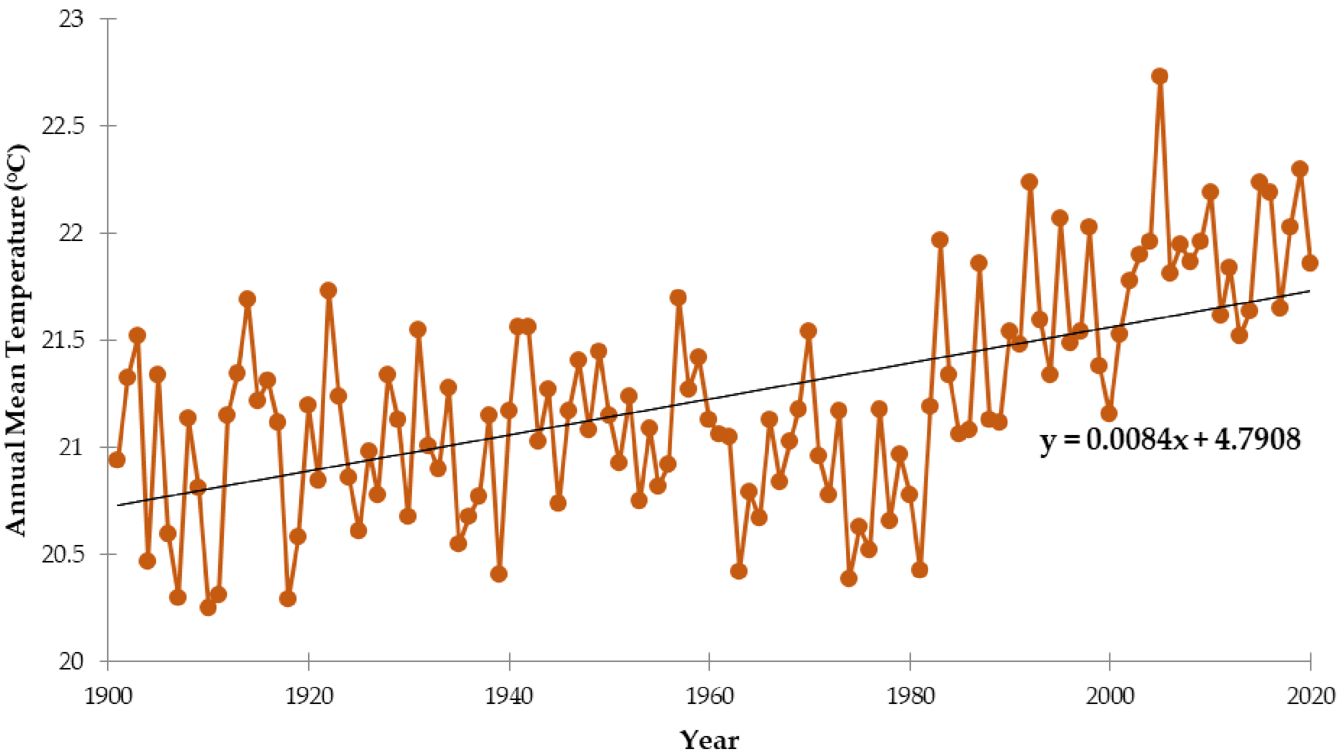

Figure 4. Temperature trend in Zimbabwe from 1901 to 2020.

3.2.3. Impacts of Climate Change on Incidences of Cyclones, Droughts and Floods

Droughts have devastating impacts on the nation's economy and contribute to the terminal vulnerability of the majority of its communities (Figure 5) [38]. The devastating droughts recently affecting Zimbabwe (January to March 2021) are strongly correlated to El Nino [47]. Zimbabwe's agricultural sector, which contributes nearly 12% of the nation's Gross Domestic Product (GDP), is severely affected by droughts (Figure 5) [38]. Approximately 70% of the national population depends directly on agriculture [38]. Climate-induced water stress has crippled agricultural and economic productivity, further resulting in an upward spiral of poverty and insecurities [38]. Since 1990, severe incidences of droughts were recorded: in 1991–1992, 1994–1995, 2002–2003, 2015–2016 and 2018–2019 seasons [38,45]. Isolated droughts patterns varied spatially in 2003–2004, 2006–2007, 2011–2012 and 2017–2018 farming seasons [38,45]. Although droughts are a common feature in all the provinces, they are more severe in southwestern provinces—Matabeleland North and South—and less severe in the eastern provinces—Manicaland and Mashonaland East [42]. The bulk of droughts in the past century occurred in the past two decades, although most of them were mild [45]. Droughts have culminated in the stagnation of rural livelihoods for more than four decades through hunger, decimated crops and livestock production, environmental degradation and declining socio-economic status [45]. In Zimbabwe, ad hoc measures to address drought focus on alleviating its impacts rather than encompassing the full cycle of drought management to ensure adaptation and copying at the individual, national and regional levels in the unforeseeable future [3].

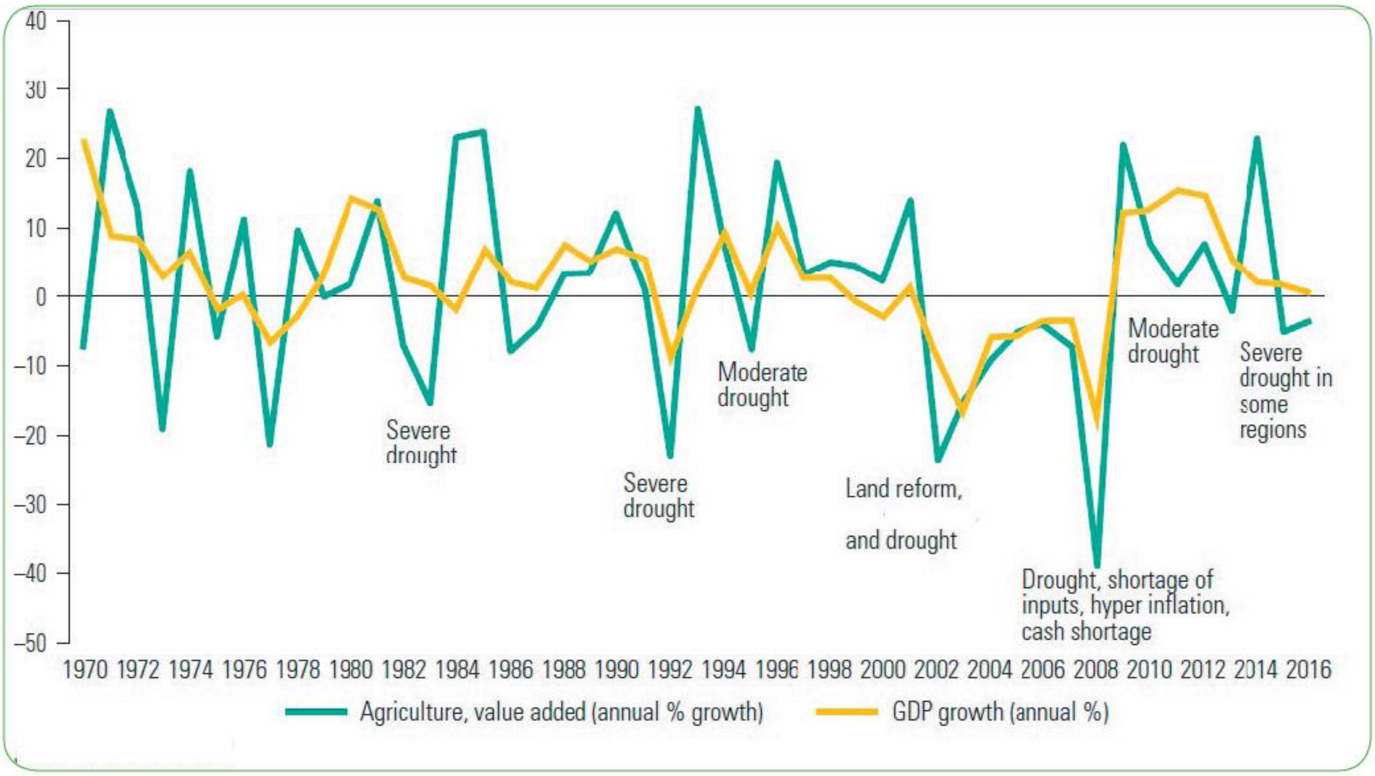

Figure 5. Drought-affected agricultural GDP and overall GDP growth from 1970 to 2016 (source: Green Climate Fund [48]).

Cyclone-related extreme flooding has destroyed pumping facilities, embankments and irrigation and drainage infrastructure in Zimbabwe over the years [37]. Cyclone Eline of 2000, Cyclone Dineo of 2017 and Cyclone Idai of 2019 were the most disastrous and fatal cyclones over the past two decades [49,50]. The communications system, crops ready for the market, dwellings and SIS infrastructure were destroyed by cyclones and floods [49–51]. Cyclone Eline destroyed Mutema Irrigation Scheme infrastructure, including three boreholes, resulting in the scheme operating only at 10% capacity [51]. Cyclone Japhet destroyed a dam in the Chirume communal land in Shurugwi, making the community more sensitive to drought [52]. Cyclone Idai damaged ten SISs in Chimanimani district and eight SISs in Chipinge district [53]. Specifically, 2293.50 ha were damaged, affecting 5041 scheme farmers [53]. In addition to this, other support infrastructures, such as roads, power supply lines and schools, were also damaged; and some crops under irrigation were also lost [53]. According to estimates, a total of US $4,890,000 will be required to rehabilitate the schemes [53].

3.2.4. Impact of Climate Change on Water Resources

Zimbabwe's water resources, which amount to 20,000 million m^3 per year, or 1413 m^3 per capita, are mostly surface water resources, since there are limited groundwater resources [47]. The country has 2200 dams, including 260 large dams with a total capacity of 99,930 m^3 [47]. The water resources in the country vary across five AEZs [7]. The impact of climate change is projected to severely reduce Zimbabwe's water resources [7]. Rainfall simulations in the Odzi, Gwayi and Sebakwe catchment areas has shown a decrease in precipitation by 15–18% and an increase in evaporation by 7.5–13% [54]. This was projected to result in a 50% decrease in runoff by 2075 [54]. Runde and Mzingwane catchments, where average rainfall could decrease by between 12% and 16% by 2050, are anticipated to face the largest decline [7]. Additionally, the recharge rates of wetland and aquifers are expected to be reduced, impacting water availability for irrigation farming [7]. Additionally, water demand for domestic purposes, irrigation, livestock, industry and energy generation is expected to grow, as the population, number of cities and industries and evaporation are projected to rise gradually [54]. The WorldBank [32] stated that climate change will result in a 38% decline in national per capita water availability by 2050 in the best-case scenario, pushing inhabitants of Zimbabwe to depend on groundwater sources.

The estimation by Yu et al. [55] that Africa could irrigate over 40 million ha is based on land resources. However, such figures might be inaccurate, as they do not consider available water resources, irrigation technology in use, diverse uses of water and the possible impact of climate change. The surface and groundwater resources are challenged by climate change and variability due to unpredictable seasonal rainfall and losses from evaporation, low runoff and sedimentation in reservoirs [56,57]. Water resources are gradually moving towards the level where current irrigation technology will not sustain them. Therefore, the ministry responsible for water resources has a responsibility to formulate water resource utilization policies [47].

3.3. Climate Change and Its Impact on Irrigation in Zimbabwe

3.3.1. Water Stress

The relationship between climate change and water stress could be the main contributing factor to vulnerability among SISs. The projected reduction in rainfall translates to reductions in runoff and the refilling of water bodies [7]. Dams, rivers and catchment areas are susceptible to drying, resulting in inadequate water supply for irrigation purposes. Additionally, groundwater recharge is predicted to be more severe in arid and semi-arid regions due to a decline in runoff [30]. Therefore, a rise in temperature and a decrease in rainfall are predicted to worsen water stress among SISs [31,58]. Increased warming will increase irrigation water demand by triggering a rise in evapotranspiration [59].

Water stress among SISs in Zimbabwe is associated with a combined effect of a rising water deficit in catchment areas, an increase in population, rapid urbanization and industrialization [43,60]. For example, a fall in Ruti dam's water level in mid-2013 resulted in the diversion of water from the Ruti Irrigation Scheme and allocating it to sugar estates, making the problem of the SIS farmers more acute [58]. This was followed by the dam's total drying up in September 2013, resulting in the loss of the entire cropping season [58]. Additionally, Hanusch et al. [35] anticipate SIS performance to decline in the face of climate change and variability, coupled with depleted sources of resilience in the country. In the Mkoba Irrigation Scheme, only 20% of irrigated land was utilized in 2015, as the dam could not meet irrigation water requirements [41]. The absence of an accessible and reliable water source following the destruction of a dam in the Chirume community in 2008 has resulted in crop loss due to water stress during prolonged mid-season droughts [52]. Low rainfall experienced in Zimbabwe due to climate change leads to poor crop yields, resulting in massive economic, environmental and social costs [45]. The 1991/1992, drought resulted in water stress, reducing Zimbabwe's agriculture production and GDP by 45% and 11%, respectively [61]. The increasing trend and severity of similar events resulting from climate change cripples the national economy and livelihoods of rural people [45].

Several studies have shown excessive water stress-related yield decline in most SISs in the western parts of the country, particularly Matabeleland South and North [43,45,60]. The water stress is projected to particularly affect schemes in AEZ IV and V [9,39]. Climate change is likely to worsen evaporation in Zimbabwe, especially in the Lowveld, where it is higher (<2200 mm), and where precipitation is a paltry (<300 mm) [47]. However, there is a scarcity of data and accurate simulations of the potential effects of climate change on water sources and catchment areas in Zimbabwe [62]. The projected rise in irrigation water demand of 7% to 21% by the 2080s due to a surge in evapotranspiration water demand [30] will worsen water stress in SISs. Some studies suggest that increased temperature and low rainfall are altering the water available for irrigation purposes [58,62]; therefore, the decline in water availability for irrigation diminishes productivity and livelihoods of scheme farmers.

3.3.2. Competing Needs

Irrigation water has multiple uses among rural communities, where most schemes are located. Water, an essential element in biological, social and economic systems [41,63], has competing uses that affect water discharge to SISs. Competing water needs vary from one AEZ to another, and are likely to intensify with climate change. High-level pressure on water resources due to the combined demands of agriculture and other sectors has resulted in water scarcity in Zimbabwe's rivers, impacting water users and the environment [60]. In rural Zimbabwe, water is needed for livelihood needs, including domestic uses, gardening, fishing, irrigation, recreation, reeds, dip tanks and livestock watering [64]. However, in Mkoba and Silalatshani irrigation schemes in the Midlands and Matabeleland South provinces, water is diverted from irrigation canals to home gardens [41]. Increases in average irrigation water requirements of 33%, 66% and 99% are expected in the 2020s, 2050s and 2090s, respectively, from a baseline of 67 mm, for maize production in Zimbabwe [65].

Water, energy and food (WEF) are closely linked. Water use for energy generation, representing 15% of global water withdrawal, competes with water demands for food production [66]. Energy is essential for making water available for irrigation, food processing and wastewater treatment [66]. Electrification is lacking in rural areas in Zimbabwe, and those connected to the grid suffer frequent power cuts [60], making pumping of water for irrigation purposes challenging. Moreover, there are limited prospects of expanding the national grid to rural areas, as it will be more costly than in dense urban settlements [60]. As most SISs are located in rural regions, poor rural electricity has an impact on smallholder irrigation. The challenge of simultaneously addressing potentially conflicting objectives of WEF while maintaining resources for other sectors needs an integrated approach of the system as a whole [67].

Meaningful development opportunities are missed when there is no clear link between water use, energy supply and mainstream agricultural livelihood in Zimbabwe [68]. The nexus' effectiveness among SISs in Zimbabwe can be determined by community institutions' strength, ownership and management structure [68]. The variable climate and recurrent droughts in the country make the water supply sporadic, affecting hydropower's potential in Zimbabwe. Competing community needs around water use have been seen in the development and use of SISs and hydropower stations. The sophisticated and organized community structure at a scheme in Chipendeke in Manicaland province has integrated an 80 KW hydropower plant and irrigation [68]. Multiple uses of available water resources can result in conflicts and lead to the possibility of multiple but independent failures in the water supply system in the face of climate change [63]. According to Palombi and Sessa [30], climate change exacerbates tensions and increases competition for water.

3.3.3. Climate Change Impacts on Pest and Disease Outbreaks

Climate change will lead to new and emerging pests, whose effects vary with AEZs. Crop loss will be increased by a myriad of climate change-related factors that include: decrease in host plant resistance, reduction in the efficacy of pesticides and the arrival of alien pest species [5,69]. Changes in both precipitation and temperature will lead to increased infestations of pests and disease outbreaks, reducing crop and animal productivity and driving up expenditure of pesticides, herbicides and veterinary drugs [6,7]. A change in pest distribution is among the most commonly reported abiotic responses to climate change [5,6]. A study in Mutare district shows that coffee white stem borers respond more to precipitation factors [6]. Mafongoya et al. [5] postulate that incidences of pests in Zimbabwe respond to changes in seasonality, temperature and rainfall patterns. Projected climate change-related temperature and precipitation changes will likely result in crop losses due to increased abiotic stress from weeds, insects, fungi, viruses, nematodes and rodents. Pests cause yield loss at all stages of the production cycle, from planting to postharvest [69]. It is projected that theyield loss of major staple crops due to increased pests alone will expand by 10 to 25% for each degree of global mean surface warming [7]. Temperature enhances the development rates of pests, shifts pests' species composition and increases the spread of invasive pests into new zones as suitable climatic conditions expand [5].

Zimbabwe's smallholder farmers are projected to face a wave of new pests spreading to Southern Africa, including the fall armyworm, tomato leaf miner and cotton mealy bug [32]. Mid-season and prolonged dry spells may promote the occurrence of insect pests, such as armyworms [70]. Fall armyworms destroyed 20% of the nation's maize crops during the 2016–2017 farming season, worsening the nation's food status. Over 4 million people were dependent on food aid [32]. New and emerging pests that are suited to the changes in conditions make farming difficult in Zimbabwe [5,32]. However, characteristically, poor smallholder farmers have no options to deal with new pests. A countrywide survey by Mafongoya et al. [5] in Zimbabwe found out that smallholder farmers perceived increases in the abundance of aphids, whiteflies, stem borers, ball worms, red spider mites, termites and diamondback moths; and the emergence of new pests due to the shortening winter, increasing temperature and lengthy dry spells.

3.4. Policies and Issues Related to Irrigation Water Management and Irrigation Schemes

Since the pre-independence era of Zimbabwe, the development of SISs has been spearheaded using different management models [71]. During the post-colonial era (1980 to date), the government intensified the development of SISs. In 1980, about 4400 ha were under SISs [72,73]. At the same time, 81 SISs were operational [72]. In 2000, the total area under SIS was 11,860 ha and the number of SISs was 187 [74]. The area under SIS farming as a percentage of the total irrigated area rose from 3.4% in 1980 [72] to 9.8% in 2000 [74]. Between 2000 and 2020, the area under SIS rose by about 119% to 26,000 ha [71]. The land distribution program resulted in an increase in land under SIS farming, as the land was acquired from large-scale commercial farmers and divided into smallholder irrigation plots [46]. According to [75], Zimbabwe has a potential irrigable area of approximately 600,000 ha. As indicated in Table 2, the government proposed to develop 29,000 ha of SISs, increasing the area under SISs by 112% to 55,000 ha by 2025 [71].

Table 2. Proposed smallholder irrigation development from 2021 to 2025.

Year	Area (ha)	Percentage	Total Area under SISs (ha)
Base year (2020)			26,000
2021	4000	15.38	30,000
2022	5000	34.62	35,000
2023	5000	53.85	40,000
2024	5000	73.08	45,000
2025	10,000	111.54	55,000

Adapted from [71].

Meanwhile, the Government of Zimbabwe (GoZ) has managed to mobilize funds for development and revitalization of SIS annually after independence [76].

Among its initiatives, the GoZ has bilateral agreements with Brazilian, Chinese and Indian governments towards the development of SISs. The Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement (MLAWCRR) mobilized a loan of US$ 98 million from the Brazilian government for SIS development [31]. The Government of China is focusing on transferring technology to SISs [31]. The International Fund for Agriculture Development (IFAD) initiated the Smallholder Irrigation Revitalization Programme (SIRP) and Smallholder Irrigation Support Programme (SISP) to rehabilitate existing schemes and facilitate the development of new SISs [33].

In order to improve operational efficiency and guide the operation of SISs, Zimbabwe has developed strategies and policies since 1980. Currently, the SISs are mainly guided by the Zimbabwe Agricultural Policy Framework (ZAPF) (1995–2020) [76]. The National Water Act of 1998 is the basis for financing the management of water resources under the Zimbabwe National Water Authority (ZINWA) [76]. At the same time, several national policies have sections devoted to SISs.

These policies are effective instruments for implementing and managing activities in SISs in Zimbabwe [77]. Policies are among the pathways of SIS development, considering the need for improved water utilization management across scales and sectors. Policies which evolved over the years have shaped the practices and performance of SISs in Zimbabwe [31]. Despite the prominence of irrigation development in the governmental development agenda, little attention has been paid to scheme management [41]. Recently, Zimbabwe has unveiled the irrigation policy (Accelerated Irrigation Rehabilitation and Development Plan 2021–2025) [71] after years of relying on other policies/sector strategies shown in Table 3.

Table 3. Policies, programs and strategies relevant for SIS in Zimbabwe.

Policy/Strategy	Relevance in the Context of SISs
1998 Water Act	Gives authority to catchment council to allocate water to SISs [78].
2000 Zimbabwe National Water Authority Act	Establishes the ZINWA as a parastatal agency—in charge of water permits and water allocations, including for SIS use [79].
2002 Environmental Management Act and 2003 Environmental Agency Act	Introduces mandatory environmental impact assessments for SIS development [80].
2000 Land Acquisition Act	Empowers the government to compulsorily acquire land for SIS development purposes [81].
Zimbabwe's Agenda for Sustainable Socio-Economic Transformation (Zim-Asset) 2013–2018	Sets the objective of increasing the area under SIS through rehabilitation and modernization of irrigation schemes and increase in power available and affordable for irrigation [82].
Zimbabwe's National Climate Change Response Strategy 2015	Mainstreaming climate change in all key sectors of the economy; calls for integrated management and development of agricultural water resources [75].

Table 3. *Cont.*

Policy/Strategy	Relevance in the Context of SISs
Comprehensive Agricultural Policy Framework 2012–2032	Includes provisions for rehabilitating and modernizing SIS infrastructure, developing new irrigation infrastructure and strengthening research on irrigation development and new technologies (objective 7.3) [83].
Zimbabwe's Agricultural Investment Plan 2013–2017	Aims to redesign and rehabilitate SIS infrastructure [84].
Medium-Term Plan 2011–2015	Focuses on rehabilitation of existing SIS infrastructures and completion of irrigation projects to increase agricultural production [85].
National Development Strategy 1 2021–2025	Intensification of construction and rehabilitation of SIS infrastructure including dams and funding of irrigation development [86].
National Agricultural Framework (2018–2030)	Development of low-cost technology investment in SIS, capacitation and enhancing skills for irrigation technicians and promotion of low-cost finance for irrigation development, investment in irrigation development and water harvesting technologies [87].
Accelerated Irrigation Rehabilitation and Development 2021–2025	Rehabilitation and revitalization of over 450 SISs in communal areas, on 26,000 ha and a concomitant farmer capacitation, governance overhaul and business model transformation to ensure viability and sustainability of these schemes. Development of various SISs in the Lowveld Green Zone Irrigation Development and projects linked to dams in communal and resettlement areas. To improve access to finance, inputs, markets and overcome governance and business systems at irrigation schemes. Reliable market arrangements for produce from SISs [71].

Investment in expanding SISs needs to be coupled with measures to allocate water effectively and equitably. The MLAWCRR is responsible for the development and implementation of agriculture and irrigation policies. The department of Water Resources Planning and Irrigation Development (WRPID) of MLAWCRR is responsible for planning, identifying, designing, constructing, operating and managing SISs at the national, provincial and district levels [31]. The MLAWCRR formulates policies for the utilization of water resources. The Water Law of 1998 emphasizes water management through decentralization and stakeholder participation in line with International Water Resources Management (IWRM) [76]. ZINWA manages water permits in seven catchment councils which are subdivided into sub-catchment councils. Governance structures of an SISs vary with scheme type. The GoZ partly operates and maintains jointly managed schemes. Farmer-managed schemes were developed by GoZ but are owned and managed by farmers through irrigation management committees (IMCs) [76]. However, the effectiveness of IMCs varies from one scheme to another. Traditional chiefs allocate land for scheme development. Multilateral and bilateral donors exclusively support SISs in communal areas by rehabilitating decaying scheme infrastructures. The Food and Agriculture Organization (FAO) supports MLAWCRR in policy formulation and coordinates efforts by donors and GoZ to partner in the irrigation sector [31].

Both GoZ and donor communities have introduced some initiatives to improve the production of SISs. They have financed the maintenance of SISs to enhance their productivity. Moreover, GoZ injects input subsidies to enhance crop productivity [41]. The GoZ prescribes a cropping program which aim to sustain production [31]. The cropping calendar focuses on low-value staple crops, which are the cheapest on the market, which is a big stumbling block for resilience. Surprisingly, there is minimal critical reflection in the literature on limitations of SISs as a climate change adaptation strategy in different contexts [31].

3.4.1. Socio-Economic Conditions

There are limited statistics on the contribution of SISs to the national GDP; however, the evidence that SISs contribute to food security, income and general well-being better than rainfed farms is overwhelming [35,64]. In addition, SISs provide rural people with an alternative source of employment and income [33]. However, gendered plot ownership exists in SISs in Zimbabwe, as males own approximately 67.9% of plots, despite that most scheme labor is provided by women [33]. The majority of farmers are women, as many men work in towns because farming is not profitable enough to support a family.

Climate change's impact on SISs is worsened by non-climatic factors, including population growth, urbanization, global economic growth, rising competition for natural resources, agronomic management, technological innovations, trade and food prices [30]. These factors have immediate impacts on water resources, hence the need to be understood and incorporated into climate change adaptation discourse in SISs [30]. The population of Zimbabwe of 16.6 million people. It is rising at the rate of 2.3% per annum and is projected to reach 22.2 million and 33.2 million by 2030 and 2050, respectively [47,88]. The population rise relates to the reduction in HIV-related deaths, improved health services, expanding educational levels, rising income and urbanization [88]. However, the majority (66%) of the population resides in rural areas [88].

Zimbabwe has experienced a deteriorating socio-economic environment following the Economic Structural Adjustment Program (ESAP) of the 1980s and the downwards macroeconomic trends in the 2000s, which impact the supply of basic agricultural inputs (fertilizers, seeds, crop chemicals and electricity) [31,33,89]. In the 2000s, a decline in the country's GDP was noted [33]. The economic downturn perpetuated widespread poverty and loss of livelihood opportunities, particularly in rural areas, mostly in semi-arid and arid regions, where 76% of people live below the national poverty datum line [46]. The turn of events has decapacitated the schemes' ability to cope and transform to match temporal and permanent changes in climatic conditions.

Additionally, Zimbabwe has endured HIV/AIDS, which remains in above 15% of the population, decimating the labor force and diverting income and labor from scheme farming [3]. The current outbreak of COVID-19 and its associated control measures, such as lockdowns, negatively affect small and medium enterprises in Zimbabwe, which are mainly agro-based [90].

Conflict and insecurity, inequitable land distribution, low education, poor infrastructure, gender inequality, dependence on natural resources and low health status perpetuate vulnerability at the household level in Zimbabwe [3]. Zimbabwe's drought and food insecurity situation was projected to result in 1.5 million people (16%) being food insecure by 2050 [32].

3.4.2. Water Management

Zimbabwe has seen limited conceptual and practical analysis of the management of SISs, as much of the recent studies focused on the quantitative performance of SISs. Water management in SISs in Zimbabwe is coupled with inefficient and inflexible scheduling, making it challenging to maximize yield and profit [36]. Poor water management; low input use; relatively small, irrigated plots; and complex group dynamics have been implicated in the low crop yields in SISs in Zimbabwe [71]. However, the recent development of the Accelerated Irrigation Rehabilitation and Development Plan 2021–2025 has brought to an end the challenges of adopting other policies to address scheme challenges. In addition, SISs in Zimbabwe's primary focus on food security at the expense of economic growth has resulted in farmers' failure to meet the schemes' maintenance and development demands [31].

Water pricing is among the tools used to manage water scarcities and competing demands to protect the resource and its quality [66]. Therefore, water pricing policies can incentivize water conservation, construction, operation and maintenance of the systems [91]. However, use of water pricing impacts availability of water for agricultural uses especially for marginalized populations [66]. A case study in irrigation projects in

Nyanyadzi, Zimbabwe, noted that communities view irrigation as a development expenditure for the government and donors in their pursuit to ensure food security among rural communities [92]. This, in turn, diminishes the proportion of cost recovery, threatening the viability and sustainability of SISs [92].

Given that the country's agricultural system is heavily subsidized, cost recovery of water delivery is arduous and complicated [92]. Fundamental planning, designing and maintaining of the water delivery system is constrained by stakeholders' inability to address the budget deficit challenge in SISs [92]. Mutambara et al. [60] suggest that low productivity, dependency syndrome, poor services and political interference in water governance in SISs in Zimbabwe affect farmers' contributions towards water bills. Failure to pay water bills directly affects water access, water resource planning and infrastructure maintenance, hampering the system's ability to adapt and mitigate climate change's impacts [60,91].

SISs in Zimbabwe can exploit short- and long-term adaptation and management practices. Conservation agriculture, crop rotation and mulching are common adaptation practices implemented in Zimbabwe [7,93]. However, the usefulness of agriculture and irrigation policies is limited by a lack of appropriate mechanization, making them labor-intensive [93]. Conservation agriculture is mostly implemented among rain-fed farmers, and its consideration for scheme farming is minimal [93].

3.4.3. Policy Influences on Adapting to Climate Change in SISs

Policy interventions affect the adoption of smart technology, institutions and value-chain networks that are required for successful irrigation timing; the number of farmers; and the size of irrigated land for profitable, equitable and economically sustainable schemes [36]. Collective social network interventions transform irrigation schemes into sustainable irrigation communities. These require policy interventions and institutional commitment. The failure of SISs is caused by weak institutions which perpetuate a lack of agronomic and irrigation knowledge, a limited financial capacity to fully maintain scheme infrastructure and the dilapidated state of irrigation infrastructure, in addition to existing water challenges [36]. New and existing policies must have the potential to reduce water-related conflicts between irrigators and multiple water consumers within SISs. However, the success of majority of irrigation policies hinges on irrigation management committees' (IMCs) strategies.

Land tenure in Zimbabwe is not well defined or understood by irrigators, leading to confusion over management and challenging individual loan acquisition for investing in schemes [36,41]. Perceived tenure security by farmers and potential investors and lenders influence long-term investment. Furthermore, small plot sizes limit scheme faming's ability to be financially sustainable for loan payback. Market access, which can potentially incentivize the production of irrigators, is extremely limited [41]. Water pricing in Zimbabwean policy is dependent on geography, allowing for local payment arrangements that could jeopardize the irrigation system's long-term viability [41]. IMCs lacks the capacity to enforce critical rules, resulting in limited maintenance and reduced production. Irrigators in Zimbabwe were recognized for a lack of knowledge of critical statutory bodies, such as the Agricultural Marketing Authority of Zimbabwe, which is responsible for regulating participation in the production, buying and processing of agricultural products in Zimbabwe [41].

3.4.4. Recommendations to Adapt to Climate Change in SISs

Moyo et al. [41] recommend transformation of the agricultural landscape in Zimbabwe through the adoption of pluralistic extensions to enable diversification of sources of information and skills. The participation of private-sector players (sellers and buyers) was recommended for the provision of extension advice. Existing policies and institutions must ensure that input and output markets, and associated information flows between these markets and farmers, function properly [36]. To ensure the effectiveness of this intervention, a critical mentality shift is required to go from subsistence to market-oriented production by creating economic incentives. Governance actors, NGOs and private-sector players anchor their perceptions of the goals of the system food security paradigm on the economic-development paradigm [63]. Devolution of the central control to a lower-level was recommended by van Rooyen et al. [63]. This would provide farmers with the opportunity to experiment, learn and organize in response to actual irrigation demands. Improving interaction between actors and the central government would boost the ability to respond to changing conditions. The presence of the Agricultural Marketing Authority within the scheme communities needs to be substantially improved to foster their mandate. Ownership of implements such as tractors, ploughs and wheelbarrows was implored for poverty reduction, securing livelihoods and climate change adaptation [41]. Coordinating efforts to integrate missing value chain players through stakeholder dialogue and utilization of mobile phone technologies is a goal. Policies and institutions need to support irrigators in innovation and development [41]. In addition, examining the organizational structure of schemes institutions (IMCs, ZINWA, the Department of Irrigation and AGRITEX) would help to clarify their roles and responsibilities [41].

A study in Zambia recommends use of water-efficient technologies and improved management of water resources [21]. Additionally, subsidizing agricultural production was recommended to ensure sustainable groundwater withdrawal and food security in arid and semi-arid regions [67]. In contrast, water resource planning and management were recommended for mitigation and development in water systems [10]. The adverse effects of climate change on water resource availability can be mitigated by expanding storage capacity (or rainwater storage), fair policies for water supply and distribution, river health and watershed management [94]. Further, completion and modernization of the sewage treatment and wastewater treatment was recommended as the best alternative to improve water quality before channeling it back into rivers [95]. Optimal operation of the reservoirs through irrigation management could address water stress challenges, although decreasing agricultural income. The transformation from traditional surface irrigation to subdroplet irrigation substantially reduces agricultural water use [15]. Lv et al. [96]. Schilling et al. [12] highly emphasized the possibility of water resource policy contributing to effective water allocation in the face of climate change [90], as users would respond by changing their patterns of water use and allocation [10]. Smallholder irrigation schemes can adopt crops with lower water footprints [97], improved irrigation water management and climate-smart irrigation, to sustainably improve food security [94]. At the same time, technical interventions through technological integration, nutrient and water management, temperature measuring instruments and soil health analysis are key for climate change adaptation [94]. Farmers, local communities, universities, scientists, policymakers, NGOs and others can use a holistic strategy to decrease the risks and improve the adaptation to climate change of agriculture and water resources [94].

The literature remains unclear about the future patterns and impact of climate change on water availability for SSI farming in Zimbabwe. All models might not point to the same scenario, as there are large variations in the assessment of runoff and recharge. Several studies projected a general decline in rainfall and rise in temperature across the country [4,7,9,40,44], whereas others suggest a redistribution of the AEZs [9,39]. Some studies suggest shrinkage of more productive regions, while others suggest a shift in AEZs, making existing zones obsolete and misleading [98]. There is a dearth of literature on combined insights from quantitative predictive models with quantitative explanatory models, especially for rural areas where data availability is limited. A multidimensional risk analysis is needed to assess climate change's impact on water availability for SIS farming. However, the bottom-up approach gives opportunities to build resilience and develop vulnerable communities.

3.5. Limitations of the Study

This study could have been limited by restricted search terms (climate change, smallholder irrigation schemes, water resources) that could have led to some critical literature being left behind. There is a possibility that different authors used diverse terms based on their studies' purposes, and climate change is a multidisciplinary field. Additionally, this study was limited to the country level, with little focus on regional and global levels, possibly limiting understanding of the study at a broader scale, although lessons from global scale have been drawn. Further, the articles mainly focused on the negative attributes of climate change, with little focus on the potential benefits of climate change in smallholder irrigation, suggesting bias. In addition, the articles used for these studies used varying methods of study, sample sizes and analytical frameworks.

3.6. Area of Future Research

SISs has the potential to provide employment and fight hunger and "hidden hunger" in rural communities [33,64], which affects 66% of Zimbabwe's population [88]. However, there is a broad literature on the underperforming of schemes in SSA, and in Zimbabwe, there are limited studies proving a link between climate change and underperforming schemes. A study by Moyo et al. [41] provides insight on the factors that affect yields, food security and farm income in irrigation schemes in Zimbabwe, including poor infrastructure, soil infertility, limited access to farm inputs, farm implements, functioning markets and agricultural knowledge. Furthermore, as advised by Moyo et al. [41] it is necessary to investigate potential technologies and institutions in which to invest in order to deal with climate change. Their relationship with climate change must be taken into account. To better understand vulnerability to climate change in SISs for future adaptation policy formulation, development and funding, there is a need to assess their vulnerability. This will enable stakeholders to be advised on how to develop local strategies to adapt to climate change. Investigating vulnerability in SISs is important for more vulnerable schemes to be identified and to provide a database for the nature of support needed in each area. Current problems are linked with water management and associated policies in SISs in Zimbabwe making farmers vulnerable to the predicted impacts of climate change. Additionally, investigating the institutions and governance aspects that affect smallholder irrigation adaptation to climate change is key to addressing climate change vulnerability in SISs. How farmers could be better able to deal with predicted climate changes need to be understood.

4. Conclusions

This article has reviewed the impacts of climate change on Zimbabwe's SISs and identified associated adaptation options implemented based on the available literature. In Zimbabwe, climate change has resulted in a rise in temperature and a decrease in rainfall. Studies showed the sensitivity of SISs to climate change, as the recharging of surface and underground water bodies is deteriorating, impacting water access. Climate change results in greater severity of crop pests and disease, their resistance to pesticides and the emergence of new pests and diseases, resulting in crops losing quality and quantity. The crop growing area was reported to shift as climatic conditions become harsher in primary production zones. Therefore, climate change results in a decline in the productivity of schemes and increases production costs beyond the reach of scheme farmers. Literature has shown that existing adaptation strategies fail to catch up with climate change effects, as schemes are reported as having collapsed, especially in drier regions. However, local institutional actors play a key role in the adaptation of SISs to climate change. They formulate policies and offer critical support by maintaining existing schemes, providing subsidies and establishing new schemes. For the successful adaptation of SISs to climate change, there is a need to assess vulnerabilities further and advise stakeholders based on policy and investment options needed at local and national levels. Engaging with scheme farmers and stakeholders at the local level is required to understand vulnerabilities based on their lived experience. Yet, this issue is not documented in Zimbabwe. Climate change risks in SISs are driven by rising temperature, variation in precipitation, rising aridity, the socio-economics environment and limited adoption of irrigation technology. However, adoption of relevant technological, institutional, management and holistic strategies is key to reducing the risk of climate change among the SISs.

The population in need of agricultural transformation is the one that is most vulnerable to climate change due to water scarcity and increased pests and diseases. Farmers are struggling to cope with the impacts of climate change, which is projected to alter the magnitude, timing and distribution of pests, resulting in crop loss. Smallholder farming in Zimbabwe experiences greater vulnerability to climate change hazards due to endemic poverty, restricted access to capital and technology and substandard infrastructure, impacting food and nutrition security. The projected increases in rainfall variability, temperature and extreme events exacerbate the predominantly rainfed farming system's vulnerability, affecting its response to national food needs.

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