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Intensive Agriculture as Climate Change Adaptation? Economic and Environmental Tradeoffs in Securing Rural Livelihoods in Tanzanian River Basins

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Tanzania is one of the East African countries most vulnerable to climate change impacts. Droughts and floods in 2015–16 had devastating effects on food production, crop failures and livestock deaths reaching record levels. One of the underlying projects of the Tanzanian government to mitigate these impacts is the Southern Agricultural Growth Corridors of Tanzania (SAGCOT), an area spanning the country's largest river basin, the Rufiji, where it collaborates with national and transnational companies to intensify irrigated crop production. Irrigation, drought-tolerant seeds, and employment are three of the key government-advised strategies to help smallholders increase crop yield, adapt to climate change, and alleviate poverty through the corridor. However, little research is available on whether these goals have been achieved. This paper aims to contribute to the literature by assessing harvest and income levels following the 2015–16 drought. Through fieldwork conducted in 2016–17 in Usangu, a key paddy production area in the Great Ruaha Basin within SAGCOT, data is collected from documents and 114 informants. This study finds that irrigation did not significantly contribute to rising paddy production in the case study. Prioritizing the downstream national park and the energy sector, the government periodically cut down the water access of the case-study irrigation scheme, which exacerbated water stress. Moreover, though farmers widely shifted to intensive farming and used hybrid seeds, mainly, the high-income groups ensured and increased the crop yield and profit. The-low income groups encountered crop failure and, due to rising production costs, debt. Many of them left farming, impoverished, and sought to secure subsistence through wage laboring. This study discusses the shortcomings of the transitions from traditional to intensive farming and from farming to employment as climate change adaptation strategies and draws critical policy-relevant conclusions.

Keywords: climate change, adaptation, intensive agriculture, growth corridors, Tanzania

INTRODUCTION

Anthropogenic emissions of greenhouse gases are warming the planet (IPCC Intergovernmental Panel on Climate Change, 2014b; IPCC Intergovernmental Panel on Climate Change, 2019). Temperatures have recently reached new record levels in the Indian Ocean, one of the primary storages of the earth's heat imbalance (Cheng et al., 2020). This change has also risen the frequency of rare cyclones, which was linked to the Australian bushfires of 2019–20 on the ocean's eastern coast and brought about exceptionally wet seasons on the western in East Africa (Cheng et al., 2020; Abram et al., 2021; Australian Meteorological Agency, 2021). As a result, East Africa experienced one of the warmest years in history in 2019; unusually high rainfall and consequent floods adversely affected over 2.8 million people, while more than 280 died (UN United Nations, 2019). This extreme also prompted the desert locus outbreak in Kenya and the Horn of Africa, spreading southward, with swarms of insects destroying croplands within only hours of their arrival (Climate Signals, 2020; National Geographic, 2020; IPP Media, 2021). This situation is about to worsen, with the UN agencies forecasting the continental warming to exceed 2°C by the mid-century and the frequency of rare cyclones, heavy rains, and natural disasters to further increase (IPCC Intergovernmental Panel on Climate Change et al., 2014a; UNFCCC United Nations Framework Convention on Climate Change, 2020; WMO World Meteorological Organization, 2020). These unequivocally devastating climate impacts on the already vulnerable food production and livelihoods in East Africa make adaptation an urgent response.

Climate impacts manifest in various forms and intensities in agriculture, to which farmers have varying capacities to adapt. Some impacts are sudden and extreme, termed shocks by climate researchers, often causing large-scale crop failures and leaving thousands of casualties and displaced people (IPCC Intergovernmental Panel on Climate Change et al., 2014a). Adapting to shocks is challenging; continental and global action is needed to limit greenhouse gas emissions to potentially mitigate warming, and thus, the prevalence of such extremes in the first place (Baarsch et al., 2020). But other climate impacts develop gradually and are not as intense. For instance, across most parts of Africa, temperatures have risen slowly by about 0.5°C in the last 50–100 years (IPCC Intergovernmental Panel on Climate Change et al., 2014a). This slow warming nonetheless put natural resources and crops under stress, the term for the gradually arising and often predictable climate impacts. Examples include groundwaters becoming depleted and rivers, lakes, and dams drying off, subsequently accelerating soil salinization and making croplands inarable, especially in semi-arid and intensively farmed areas (Herbert et al., 2015; Okur and Örçen 2020). Additionally to such stress on land and water resources, rainfall and temperature changes are moving beyond the levels that crops and livestock can tolerate, thus directly impacting agricultural production (Thornton et al., 2009; Thornton et al., 2014; Pereira 2017). As a result, staple food production is predicted to fall by a third by the end of this century and aggravate food insecurity in Africa (Lobell et al., 2008; IFPRI International Food Policy Research Institute, 2009; Schlenker and Lobell 2010; Lobell and Gourdji, 2012). In drought-prone countries, the number of undernourished people has already risen by 45.6 percent since 2012 (UNFCCC United Nations Framework Convention on Climate Change, 2020). Low-income groups are most vulnerable to climate shocks and stresses, as with decreasing food production, their income and wellbeing will also further decline (Boko et al., 2007; Arndt et al., 2012a).

The famine-inducing droughts in East Africa and the Horn since the late 2006 coincided with the global financial crisis of 2007–08, influencing African governments to embark on a "green growth" approach that agricultural growth has to be environmentally sustainable to avert new crises (OECD Organization for Economic Cooperation and Development, 2009; OECD Organization for Economic Cooperation and Development, 2011). One of the core ideas in this approach is that crop intensification with integrated biotechnological and market-based solutions can address environmental problems, and for this, private-sector investment into agriculture is necessary. Though green growth was endorsed globally in 2012 at the UN Conference on Sustainable Development in Rio de Janeiro (Rio+20), African governments and the global private sector decided to implement it in Africa earlier: the 2008 United Nations Private Sector Forum and the 2010 World Economic Forum on Africa influenced the designation of agricultural growth corridors, focused areas of expanded land use, investment, and trade (Nogales, 2014). By improving the management of natural resources and boosting food production, investments are envisioned to pull 50 million people out of poverty until 2022 and feed two billion people until 2050 (NEPAD New Partnership for Africa's Development, 2013; USAID United States Agency for International Development, 2020).

However, research-based evidence supporting the green growth idea is limited and not unambiguous. Since agriculture accounts for as much as 30 percent of the atmospheric CO_2 emissions, efficient input use through crop intensification and advanced waste management can potentially sink this emission and alleviate climate stress in agriculture (Beddington et al., 2012; Lal, 2016). But efficient input use and natural resource management locally do not necessarily lead the growing stress on these resources and food production stemming from a globally changing climate to sink. Also, regardless of how efficient these methods are, land use expansion accompanying crop intensification may even increase emissions instead of decreasing. Besides, the birth of growth corridors during a financial crisis is not coincidental. As critical scholars have argued, by the end of the 2008 crisis, rising food prices made food an attractive business for global corporations, pulling them to Africa for production and export (EU European Union, 2015; Buseth, 2017; Hall et al., 2017; Mdee et al., 2020). In this business-driven context, whether climate adaptation by the low-income groups will materialize pulls this study's attention into exploring one of the leading corridors in the continent.

One of the first corridor showcases in Africa is the Southern Agricultural Growth Corridors of Tanzania (SAGCOT), inaugurated by the Tanzania government in 2011 as its commitment to achieving agricultural green growth (SAGCOT, 2012a). The corridor area spans one-third of Tanzania (300,000 square kilometers), where almost a hundred official "partners" (investors, banks, input suppliers, food processor-traders, and donors) operate (SAGCOT, 2011b; SAGCOT, 2018). Investors acquire lands from the government to set up private farms, while other companies are commodity suppliers and financiers, distributing seeds, agrochemicals, and loans to both corporate and existing small producers. SAGCOT envisions to "sustainably intensify agriculture for smallholder and commercial agriculture alike, while simultaneously conserving the natural resources base that supports agriculture" and fostering climate adaptation (SAGCOT, 2012a: ii). In the center of this vision, the government emphasizes irrigation (bio)technologies, and employment (ESRF Economic and Social Research Foundation, 2018): while irrigation is the chief strategy to address climate stress on water resources, SAGCOT spans Tanzania's largest river basin, the Rufiji (SAGCOT, 2011b; SAGCOT, 2013). It seeks to draw $3 billion investment into irrigation and waste management technologies (SAGCOT, 2012a; SAGCOT, 2012b). In terms of biotechnologies, drought-tolerant (hybrid) seeds are introduced for enabling producers to withstand intensified droughts while increasing crop production; for rice by an additional 2.2 million tons (SAGCOT, 2012a; CGIAR Consultative Group on International Agricultural Research, 2019). Lastly, by employing low-income farmers in private farms and nascent urban industries (after they abandon their lands), SAGCOT seeks to prosper and transition them into the middle-income status ($3 per capita per day and more) while propelling sectoral growth. Overall, by sustainably intensifying production, SAGCOT seeks to decrease CO_2-equivalent net emissions by about three million tons and pull 7–11 million people out of poverty by 2030 (URT United Republic of Tanzania, 2015b; URT United Republic of Tanzania, 2016a; URT United Republic of Tanzania, 2016b).

However, to whether crop intensification helps low-income farmers adapt to adverse climate impact and prosper, the literature provides polarizing answers. Significant research is available on hybrid seeds. Some studies explored their reproductive qualities, stress tolerance, and input dependence under diverse environments (Li et al., 2013; Assefa et al., 2015; Abberton et al., 2016; Ma et al., 2016). Others found that African farmers extensively adopted them to combat extreme droughts (Howden et al., 2007; Mengistu, 2011; Li et al., 2015; Elum et al., 2017; Komba and Muchapondwa, 2018). Still, their costs and whether the low-income farmers most vulnerable to climate stress can afford them are under-researched. This is relevant because certain hybrid varieties promoted in growth corridors, such as rice hybrids in SAGCOT, are bred for intensive farming and need increased investment. However, the low-income farmers in Africa often seek to cope with dry periods by shifting to low-investment and low-return farming instead of sowing seeds requiring high investment for high returns (Rosenzweig and Binswanger, 1993; Lema and Majule, 2009). This strategy protects them from risks, such as debt, since drought tolerance of these seeds has limits; they cannot perform their full productive features and bring high returns under extremes (Howden et al., 2007). In this context, expanded and improved irrigation as the chief adaptation strategy of the Tanzanian government is promising. But findings also show that government investments to expand and modernize irrigation have incited conflicts over land and water, reallocated from some users to others (Harrison and Mdee, 2017; de Bont et al., 2019). Moreover, strict water regulations enacted in river basins to promote efficient water use restricted agricultural water access and favored nonagricultural sectors, such as tourism and energy, aggravating these conflicts (Juma and Maganga, 2004; Mehari et al., 2009; England, 2019). Exploring whether such resource scarcity and conflicts persist and possibly prevent low-income farmers from withstanding droughts while they intensify farming is an interest of this study.

The potential of employment as adaptation is similarly disputed in the literature. Studies showed that farmers often prefer to diversify their income without rural outmigration to adapt: by diversifying land use and crops (Townsend, 1995; Bradshaw et al., 2004; Zonneveld et al., 2020); selling assets and livestock kept as microinsurance (Kazianga and Udry, 2006); and seeking local short-term employment (Paavola, 2004; Eriksen et al., 2005). Only when these strategies are inadequate, they consider temporary and short-distance rural outmigration for employment (Stark and Bloom, 1985; Henry et al., 2004; Black and Collyer, 2014), and permanent migration is a last resort (Banerjee and Duflo, 2011). However, opinions are divided on whether such transitions from farming to employment and migration are adaptation. Some scholars argued that rural and urban employment helps the affected people recover as long as household resettlement capacities and skills allow (Barnett and Webber 2010; Piguet, 2010). Others opposed that household decisions for rural outmigration for jobs are usually radical outcomes of climate impact, rather than decisions made before devastating impacts occur, and indicate worsened livelihoods (Brown et al., 2007; Brown, 2008; Warner and Afifi 2014; Adger et al., 2015). Whether local climatic variabilities are indeed behind the globally rising internal and crossborder migration is also debated (Hunter et al., 2015; Hoffman, 2020; Mueller et al., 2020; New York Times, 2020). The findings show that the drivers of rural labor transition and outmigration are nuanced and contextual, which this study pays attention to.

Overall, this study explores how the transition to irrigated intensive farming influences food and income security and the tendencies of agrarian households to leave farming for wage laboring and migration in Tanzania and whether such transitions can be considered adaptation. The definition of the concept of adaptation draws from the IPCC Intergovernmental Panel on Climate Change et al. (2014a): the process of adjustment to actual or expected climate and its effects. This process entails efforts to "moderate or avoid harm or exploit beneficial opportunities" arising from changing climatic conditions (ibid: 5). Since this definition is broad and allows multiple interpretations, this study selects an agrarian political economy lens to evaluate and interpret adaptation. This lens postulates that the transition to intensive commercial farming heightens rural inequalities, and new classes, such as laborers and migrants, naturally emerge, but farmers start falling into these classes as a result of worsened livelihoods (Bernstein, 1977; Bernstein, 1988; Griffin et al., 2002; Akram-Lodhi et al., 2006; Bernstein, 2010; Vicol et al., 2018). Based on this lens, the central hypothesis of the paper is: if the shift to intensive farming sustained crop yields and prospered livelihoods during erratic weather, farmers would not have to abandon their lands to seek jobs and migrate. To support this hypothesis, this study focuses on whether farmers, especially the low-income ones, justify the outcomes of such livelihood transitions as becoming better off or impoverished. Hence, the success of intensive farming is evaluated based on its ability to benefit the lowest-income groups and sustain their livelihoods.

Methods include empirical research conducted in southern Tanzania during the 2016–17 agricultural season. This season had erratic weather following the 2015–16 drought that prolonged into 2017. The potential of irrigated intensive farming as adaptation must be evaluated during such adverse periods. The case study is the Madibira irrigation scheme, constructed in 1998 in the Great Ruaha River Basin. This scheme is one of the major rice supply areas prioritized by the government for public irrigation investments. Mixed methods are used: document analysis, semi-structured and in-depth interviews, and surveys with 114 farmers. Interview data spans farmers' land sizes, production costs, loan sizes, harvest levels, marketing strategies, income sources, climate adaptation strategies, and livelihood changes over the years to interpret the drivers and outcomes of such change based on their perspectives. Harvest data is available from only 81 farmers. The 2017 harvest data is compared with the pre-intensification average of 4–5 tons per hectare in Madibira. The main level of analysis is the land in the scheme as an income source, and labor to the extent it supplements or substitutes such land-based income.

This paper is structured as follows. Section *Climate Impact in the Context of Staple Food Production in Tanzania* reviews the literature on climate stress and shocks in agriculture and finds that intensive agriculture has not significantly improved livelihoods in Tanzanian river basins. Section *Results: The Economic-Environmental Tradeoffs in the Great Ruaha Basin, 1998–2017* provides the results on irrigation, hybrid seeds, and the transition from farming to employment as potential adaptation strategies, along with the harvest and income data, identifying problems in this context. Finally, Section *Conclusion* discusses the results in the light of the literature, outlines the contribution of this study, and suggests avenues for further research. The findings align with the political economy literature: irrigated intensive farming mainly benefits the land-rich groups who are already able to withstand climate stress. Smallholders and middle-scale farmers leaving farming to work for the wealthier rural classes encounter worsened livelihoods. Hence, as long as intensive farming and employment opportunities arising in this context heighten rural dichotomies, they cannot be considered adaptation.

CLIMATE IMPACT IN THE CONTEXT OF STAPLE FOOD PRODUCTION IN TANZANIA

Tanzania is one of the fastest-growing least developed countries and transitioned from low- to lower-middle-income status in 2020 (World Bank, 2020), though its economy remains highly vulnerable to climate impacts. Temperatures have been variably increasing and changing precipitation across the country: in northeastern highlands, the mean, maximum, and minimum temperatures increased, leading to longer-than-average rainfall seasons with an earlier onset and late cessation of rains (Lema and Majule, 2009); in eastern Tanzania, rains increased by up to 50 percent, leading to higher frequency and severity of floods (Paavola, 2008; Kijazi and Reason, 2009); and southwestern highlands area (where this study is conducted) experienced decreasing rainfall and prolonged dry seasons (Kahimba et al., 2015). Studies associated the increasing frequency and severity of droughts and floods with climate change and agreed on the paralyzing and poverty-inducing effect of this change on livelihoods (Kijazi and Reason, 2009; Shemsanga et al., 2010; Kahimba et al., 2015; Irish Aid, 2018). Model projections revealed that if the temperature increase reaches 2°C by 2050, staple food yields (maize, sorghum, and rice) will further substantially decrease, leading to chronic food insecurity, especially in the southern highlands regions (Mbeya and Dodoma) affected by droughts (Rowhani et al., 2011; Arndt et al., 2012a; Kahimba et al., 2015).

Recurrent extreme droughts and rains since 1993 have influenced the present policymaking in Tanzania. First, the El Niño Southern Oscillation of 1993, followed by the 1997–98 La Niña, caused heavy droughts in some regions (Kahimba et al., 2015). A prolonged drought returning in 2005–06 impaired growth in agriculture and the overall economy, as the government reported (URT United Republic of Tanzania, 2007). Then, in 2010–11, heavy rains associated with El Niño prompted flooding in Morogoro and Dodoma, destroying infrastructure and human settlements. The 2015–16 drought, which this study covers, was "the worst El-Niño" until that year, as the Tanzania Meteorological Agency advertised (FAO Food and Agricultural Organization of the United Nations, 2016: 1). It resulted in massive crop losses, especially for staple crops, such as rice and maize, and livestock deaths, while food prices spiked, driving food insecurity across the country (FAO Food and Agricultural Organization of the United Nations, 2016). As the delayed onset of rainfall and early cessation of below-average rainfall continued in 2017, food shortages persisted: only from January 2016 to January 2017, maize prices doubled in Arusha, increased by 25 percent in Dar es Salaam, and generally reached high levels across the country (FAO Food and Agricultural Organization of the United Nations, 2017). This situation led the Economist Intelligence Unit to forecast the annual inflation rate to rise from 5.2 to 7.2 percent from 2016 to 2017 (Irish Aid, 2018).

The Tanzanian government acknowledges recurrent heavy floods and droughts as threats to food and income security and took four steps to mainstream climate change adaptation into its economic and agricultural policies. First, it designated the National Adaptation Program of Action of 2007, adhering to the United Nations Framework Convention on Climate Change guidelines of 2001, and prioritized agriculture as the most climate-sensitive sector (URT United Republic of Tanzania, 2007; Majule et al., 2014). Second, the National Climate Change Strategy of 2012 and the related sector-specific

Nationally Appropriate Mitigation Actions emphasized the necessity to mitigate climate impacts. Three, climate change is mainstreamed into the National Strategy for Growth and Reduction of Poverty, a cross-sectoral policy focused on poverty alleviation. Four, the Agricultural Environmental Action Plan (2011–17) prepared by the Ministry of Agriculture, Food Security, and Cooperatives emphasized environmental protection in the agriculture sector development planning (Majule et al., 2014). These four principal policy actions advised irrigation (and water harvesting), drought-tolerant seeds, and crop and income diversification as the leading adaptation strategies (ESRF Economic and Social Research Foundation, 2018), though significant problems arose in implementation.

Irrigation in river basins as the priority adaptation strategy of Tanzania has been on the top of the policy agenda since the 1970s, without succeeding in the desired expansion and efficiency outcomes. Tanzania has abundant water bodies, feeding its world-known rich ecosystems and wildlife, though only five percent of the potentially irrigable lands are under use (Majule et al., 2014). Such underuse influenced the government since the early 1970s to aim to unleash the full potential of its river basins by expanding irrigation in order to transform production from smallholder to highly productive commercial farming. The National Irrigation Master Plan of 2002 sought to expand irrigation to 29.4 million hectares, but until 2013, only 450,392 hectares were realized (URT United Republic of Tanzania, 2002; URT United Republic of Tanzania and JICA Japanese International Cooperation Agency, 2013). During the 2015 elections, expansion to one million hectares by 2025 was again on the top of the lead party's (Chama cha Mapinduzi, CCM) election agenda (URT United Republic of Tanzania, 2016a; URT United Republic of Tanzania, 2016b; JICA Japan International Cooperation Agency, 2018). Recently, the National Rice Development Strategy Phase II (2019–30) endorsed irrigation expansion for rice from 1.1 to 2.2 million hectares and emphasized its importance for climate adaptation in this subsector (URT United Republic of Tanzania, 2019), though the progress has been slow (USDA United States Department of Agriculture, 2021). Low public investment and lack of administrative capacities played significant roles in such slow progress (JICA Japan International Cooperation Agency, 2018).

In the lack of systematic irrigation expansion, common adaptation strategies among farmers had limited success during dry spells and adverse environmental ramifications in the past. Encroaching on wetlands to cope with water stress has been prevalent, depleting water resources and degrading ecologically rich river basins (Kikula, et al., 1996; Paavola, 2008; Kangalawe and Lyimo, 2013; Munishi and Jewitt, 2019). To fight water stress and increased land infertility, farmers switched to hybrid seeds and intensified fertilizer use, but harvest losses remained as high as 50 percent during dry spells (AATF African Agriculture Technology Foundation and COSTECH Tanzania Commission for Science and Techology, 2010; Shikuku et al., 2017; Komba and Muchapondwa, 2018). Government officials and extension agents lacked the budget and skills to improve land use management (Shemdoe et al., 2015; Pardoe et al., 2018) and passed on short-term solutions that did not foster long-term adaptation (England et al., 2018). The consequent failure to turn intensive farming sustainable came at the cost of the government expanding conservation areas (instead of irrigation) and expelling smallholder agrarian groups from river basins to give their land to companies that could invest in irrigation (Bergius, 2016; Buseth, 2017; Bergius et al., 2020).

Lastly, crop and income diversification helped farmers only to the extent they had recourse to them in supportive capacities instead of abandoning farming for employment and migration. In a case study in Kilombero, about half of the farmer population had such additional local income sources (Herrmann, 2017). After harvesting and selling crops, temporary migration for jobs in charcoal, timber, and brick production in nearby urban and rural areas has been common (Paavola, 2004; Paavola, 2008; Eriksen et al., 2005). The rising intensity and recurrence of climate stress turned such seasonal migration permanent, which did not significantly improve livelihoods (Warner and Afifi, 2014). Some low-income farmers failed to survive devastating crop and income losses after being exposed to climate extremes only once (Lema and Majule, 2009; Kahimba et al., 2015). Moreover, they found only low-income jobs, while mainly the existing better-off farmers diversified their incomes into profitable nonagricultural businesses, further prospering (Kahimba et al., 2015). These findings from the literature thus far support this paper's central hypothesis that if intensive farming stabilized and prospered livelihoods during erratic weather, farmers would not abandon their lands and migrate to seek jobs. The following sections dive into empirical insights to assess this argument.

RESULTS: THE ECONOMIC-ENVIRONMENTAL TRADEOFFS IN THE GREAT RUAHA BASIN, 1998–2017

Irrigation as Adaptation

In the Great Ruaha River Basin of Tanzania, climate stress in agriculture is significantly about water, which the government seeks to address through irrigation. However, a neglected tradeoff in this context is that the extreme weather episodes in the last decades have adversely affected not only rainfed farming but also irrigation due to recurrent and intensified river droughts in this basin. The years of droughts coincide with the years of below-average rainfall driven by El Niño and La Niña weather events. Based on the Tanzania Meteorological Agency (TMA) data (2016), the basin region (the Mbeya Region) has experienced new rainfall extremes in 1986, 1993, 1998, 2005, 2011, and 2015 as **Figure 1** shows (TMA Tanzania Meteorological Agency, 2021). The El Niño Southern Oscillation prompted prolonged droughts in 1992–93 and 1997–98 (Kijazi and Reason, 2009). From 1998 until 2005, most parts of the country, including the Great Ruaha Basin, experienced at least two consecutive droughts, with delayed rainfall onsets and unevenly distributed and below-

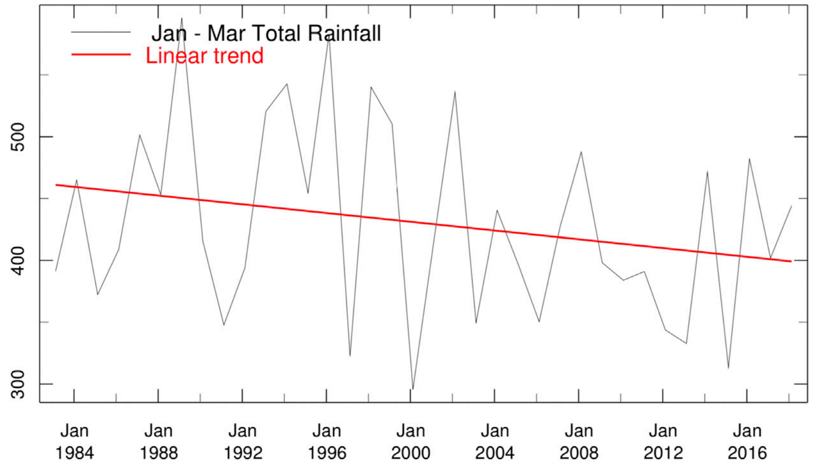

FIGURE 1 | Historical rainfall averages and anomalies in the Mbeya Region.

average rains (Kijazi and Reason, 2009). In 2014–15, another drought was caused by "the worst El-Niño" until then, as the FAO (2016: 1) reported, which extended into late 2016, with devastating consequences for livelihoods.

The climate data excerpted from the TMA database is consistent with farmers' perceptions of historical rainfall changes. The interviewed farmers argued that since the first paddy irrigation in 1998 (when the irrigation scheme was constructed), rains have been falling with more extended delays, with less precipitation, and ceasing earlier than usual. Especially the 2015–16 drought was felt strongly: as the annual report compiled by the scheme authorities confirmed, "the 2015–16 rainfall crisis severely affected farmers in the village and caused crop failures" (Annual Report 2016/17). Farmers contended that many of them had encountered crop failures this year, some already at the beginning of this season, due to the delayed rainfall begin; the seedlings had desiccated before sprouting and yielding crops. Consequently, they could not generate sufficient income to afford basic livelihoods needs, such as food and travel. These dramatic outcomes influenced the National Food Reserve Agency and the World Food Program to plan emergency food purchases in the region to secure rural income and store rice (staple food) in national warehouses to prepare for potential food shortages.

Despite the insights pointing to a strong connection between climate events and local rainfall extremes, Tanzanian policies have mainly focused on the potential role of the growing agriculturalist population in exacerbating water stress in river basins and sought to address this. This misplaced focus was to some extent driven by increasing water competition between water users, leading them to lobby for expulsion of smallholders out of the Great Ruaha Basin. Two decisive events that escalated this discourse were, first, the river's disappearing water flow for the first time in 1993 and then, the Mtera and Kidatu dams (meet for more than half of the country's power demand) entirely drying out in 1998, which caused days-long blackouts and paralyzing impacts on the economy (SMUWC, 2001). Scholars found that the local farming, hunting, and tourism businesses alleged small farmers as the main cause of the recurrent droughts in 1998–2005 (Lankford et al., 2009; Walsh, 2007; Walsh, 2012). Hydrological studies did not confirm the veracity of these allegations: the UK-funded project called Sustainable Management of the Usangu Wetland and its Catchment (SMUWC), one of the few and the most informative accounts on the hydrological change in this basin, listed agricultural water use as one of the potential drivers of the sporadically receding river flows, without making a firm statement (SMUWC, 2001). Nevertheless, in 2005, upon his election, president Kikwete acknowledged these claims, ordering "immediate urgent action" to revert the water crisis, as Walsh (2012) quoted, which included conservation area expansions to repel smallholders off the basin. Neither this decision nor studies examining this political discourse paid attention to the potential impact of the 1998–2005 climate events on this hydrological change.

The case study (the Madibira irrigation scheme) as a large-scale smallholder irrigation project played a critical role at the heart of this basin water debate, pulling hostility from the local business circles. The scheme construction was approved in the early 1990s when the government embarked on irrigation expansions to foster rural food and income security (SMUWC, 2001). The scheme abstracts water from the Ndembera River, one of the three major tributaries of the Great Ruaha (along with the Kimbi River and the main branch of the Great Ruaha River) before it flows into the Ruaha National Park (**Figure 2**). Its construction started in 1993 and ended in 1998, coinciding with the years of the two most dramatic river droughts, inevitably accentuating its potential role on the river droughts. At the end of the 1998–2005 droughts, a paper drafted by a local tourism company addressed this scheme as one of the causes of the droughts and accused the African Development Bank of funding this scheme without an environmental impact assessment and bringing "huge number of migrant people associated with rice farming" to this area (Fox, 2004: 4).

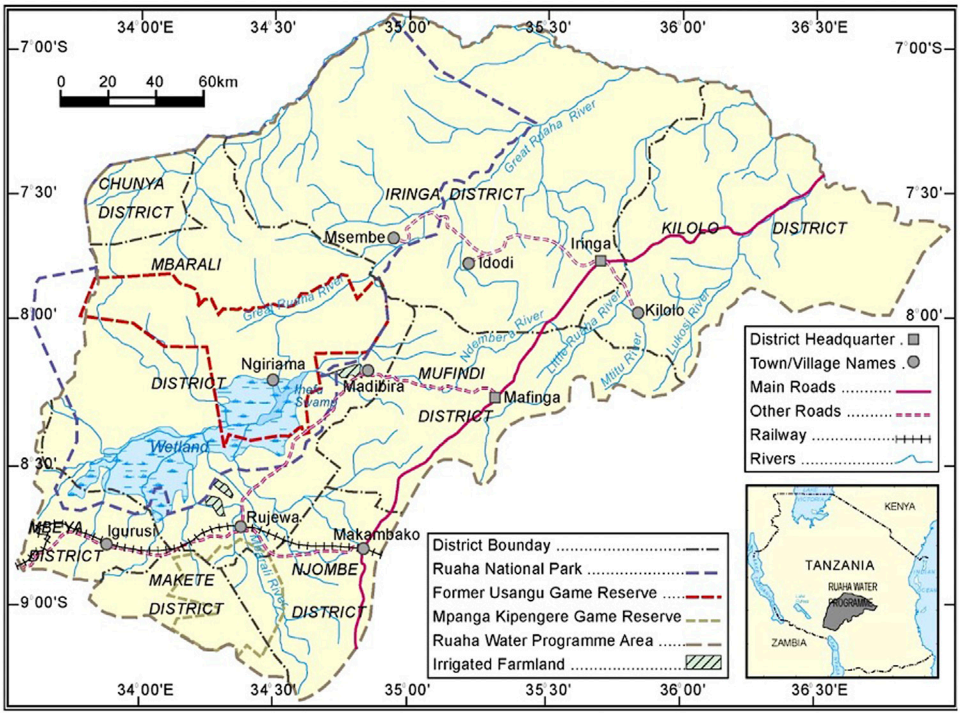

FIGURE 2 | Case study area (Madibira) within the Great Ruaha Basin Source: Mwakalila (2011).

Scholars claimed that this paper was backed by the state-owned Tanzania Electric Supply Company, which manages the dams, accusing the scheme and farmers of the desiccated river and the countrywide electricity crisis, allegedly attempting to veil its own water mismanagement of the dams (Machibya et al., 2003; Yawson et al., 2003; McCartney et al., 2007). This paper was influential upon the president's approval of a game reserve expansion in 2006, followed by the national park expansion encircling the reserve area in 2008 and the banning of agriculture therein (Walsh, 2012). The military pitched camps to evict agrarian groups and burned homes and sheds to ensure that farmers left and herders with their 300,000 cattle moved to the coastal region designated for them (IWGIA International Work Group for Indigenous Affairs, 2016). Two of the six dismantled villages (Mapogoro and Ikoga) were relocated to Madibira, folding its farmer population.

Interviews with farmers and the village chairpeople showed that the increasing farmer population due to this inter-district migration led the land and water demand in the Madibira irrigation scheme to rise instantly. But at the same time, with the Water Resources Management Act of 2009, the government enacted a formal water rights system to restrict water access in irrigation schemes, not only uncontrolled small-scale water use outside them. Water rights were first introduced in 1993 following the river drought this year to promote wise water use. Rights as statutory titles indicated the water volumes that water users are authorized to abstract from rivers, while fees, calculated based on these authorized volumes, had to be paid by them (Koppen et al., 2004). However, scholars found that the outcome of this experiment was unsatisfactory: basin officials lacked administrative capacities to monitor and sanction abstractions according to rights, and the system did not prevent the Great Ruaha from periodically drying and causing water scarcity (Koppen et al., 2004; Maganga et al., 2004). Still, with the 2009 act, the government renamed water rights as water permits and permanently passed them to restrict irrigation within irrigation schemes, in addition to scaling down agricultural land and water use outside them, and prioritized the Great Ruaha's flows into other sectors, though irrigation has also been a policy priority for decades.

Though the permits are not updated frequently, interviews showed that basin authorities periodically cut off or decreased irrigation water access during dry spells (when farmers need water the most) and continually increased the permit fees. The Madibira irrigation scheme received its final permit in 2013, allowing water abstraction from the Ndembera River from November to October every year. As the scheme's irrigation officer reported, the permit fee gradually increased from TSH7 to 11 million until 2016, and further changes followed the drought this year (Key informant 1, December 12, 2016). On the one hand, in 2016, basin authorities ordered him to halve the scheme's water abstraction from 7.5 to 4 cubic meters per second to retain water in the riverbed, although the permit fees would further rise in the same year. The Annual Report 2016/17 supports this statement that decreasing the scheme's water abstraction is necessary "to restore the perennial water flow of the Great Ruaha River, which will be prioritized." On the other hand, additionally to halving water abstractions, from 2017 onward, the scheme received water only from January to July, with a five-month cut in the irrigation period. However, as farmers indicated, paddy cultivation traditionally requires a longer time, from December to July, from seedling preparation until harvesting. The late cultivation by one month in January means potential harvesting delays into August, when farmers needed but lacked water due to the end of irrigation and cessation of rainfall, both in June. Together with the increased permit fee, water restrictions heightened the risk of crop loss and strained many livelihoods.

These findings show that irrigation as a climate adaptation strategy has limits in practice. Though the Tanzanian government has hailed irrigation for improved food and income security since the 1990s, it also took contradictory steps to restrict it, bringing about land and livelihood losses. This threat retains its significance since the government neither recognizes climate impact on natural resources nor the agricultural and nonagricultural sector interests standing in conflict in the context of the ongoing basin debate that is political in nature. This omission countervails the prospect of expanded irrigation to foster adaptation for small farmers. Another contradiction in this context is that while the water stress has been blamed on farmers, a narrative which drove conservation area expansions and strict water regulations, in another context promoting the shift to intensive farming, this stress has been considered a consequence of climate change. Though they themselves cut down the Madibira irrigation scheme's water access, backing the claims that farmers used too much water, two authorities argued that the rising water stress resulted from "global warming" but would be "compensated through efficient commercial agriculture," with the use of the drought-tolerant hybrid seeds (Key informants 2 and 3, December 13, 2016). Various potential reasons for water stress being reworked in different contexts is another political insight that points to limits of irrigation as adaptation. The next section explores whether the shift to intensive paddy farming has indeed been rewarding in this context.

Intensive Paddy Farming With Hybrid Seeds as Adaptation

In SAGCOT, intensive paddy farming with drought-tolerant seeds is promoted as a way to foster climate adaptation and food security. Though some multinational SAGCOT partners, such as Monsanto and Syngenta, sell genetically modified seeds across the corridor, specifically in the rice subsector in the Mbarali cluster, most drought-tolerant rice seeds are bred by the national agricultural research institutes that have received donor support since the 1980s. These seeds are hybrid varieties, combining productive and morphological qualities of traditional and genetically modified seeds, and advertised by the government and partners to sustain and increase crop yield with less water and in a shorter time than usual. In addition to their productivity features, some offer an enhanced taste, which contributed to the widespread acceptance of some varieties by Mbarali farmers since 2013. The most successful hybrid rice seed combining high yield with semi-aromatic flavor is SARO5 (termed TXD306), bred by the Agricultural Research Institute Chollima-Dakawa, with TXD (Tanzania Cross Dakawa) indicating its origins. Other hybrids, such as Katrin (IR54 and IR64), bred by the Kilombero Agricultural Research Institute (KATRIN) in Morogoro, are more productive than SARO5 but did not succeed due to their lack of aroma (most farmers produce rice for both cash and household consumption). Still, farmers locally call SARO5 "the export variety" since it is highly demanded in export markets and brings cash through mass production. Meanwhile, the traditional variety is preferred mostly when taste and domestic market supply are farmers' priorities.

In Madibira, SARO5 has succeeded, with an above 90 percent acceptance rate by commercial farmers. Various informants (farmers, local authorities, and companies) confirmed that this variety indeed yields more paddy. Moreover, though it requires irrigation for such high-yielding performance, SARO5 crops mature faster, enabling adaptation to shortened irrigation and rainfall periods, for which they are considered drought-resistant. The government extension officers argued that SARO5 seeds can multiply the average paddy production under irrigation from the country average of 4–5 tons per hectare with traditional seeds to 8–9 under intensive farming and 12 under systematic rice intensification (SRI) (*kilimo shadidi*) (USDA United States Department of Agriculture, 2018). SRI is an intensive rice farming technique developed in Madagascar in the 1980s, which, under some conditions, can provide two times the yield with half of the amount of water required by some traditional seeds (Cornell University, 2020). Spreading the SRI practice along with expanded irrigation to increase paddy production from the countrywide traditional rainfed average of 1–2 tons per hectare is one of SAGCOT's subsectoral goals (SAGCOT, 2011a). Though progress has been slow: in Madibira, in 2017, only ten farmers practiced SRI, as confirmed by the extension agents. The interviewed farmers considered it a labor-intensive technique needing to count seeds and sow according to a linear pattern (instead of randomly planting in the field) and flatten the soil for which they lacked capital. Still, without SRI, SARO5 has fulfilled its increased production and decreased water requirement promises to some extent, which contributed to their widespread acceptance in a short time. As a farmer put it, "after seeing their neighbors harvest a lot and prosper, even those skeptical of this seed at first only cultivate it today" (Farmer 1, December 04, 2016).

The problem about the SARO5 seeds little mentioned in the scholarly and gray literature is that despite their attractive features such as reasonable price, less crop water requirement, and higher productivity than the local seeds, they need intensive fertilizer use. Tanzania does not have a strong fertilizer industry and imports fertilizers, making their intensive use expensive for smallholders. Therefore, fertilizer use across Tanzania has been low, only one to two bags per hectare to none (Majule et al., 2014). In comparison, Madibira farmers used three-four bags per hectare before shifting to hybrid seeds and seven and more after. Moreover, they used YARA fertilizers only. YARA is a Norwegian fertilizer company; it built a fertilizer terminal at the Port of Dar es Salaam shortly after becoming an executive SAGCOT partner and monopolized the fertilizer market by opening retail stores in rural areas. In Madibira, YARA salespeople were more active than the government-hired local extension agents; they frequently visited villages, organized farming workshops, and staged games with free fertilizers for the winners, successfully promoting own products. Also, the extension agents advised farmers to use only YARA fertilizers due to their "higher quality" (Key informant 4, July 13, 2017) and promoted the need to use at least seven bags of this brand fertilizers in the extension curriculum. Though farmers agreed to increase fertilizer use to sow SARO5 for increased production, production costs climbed as well: in the 2016–17 season, one bag cost TSH55,000 ($24) at the village salespoint, TSH40,000 ($17) directly from YARA, and TSH65–67,000 ($28–30) from intermediaries, all of which farmers considered expensive[1].

The shift to intensive farming with SARO5 seeds and increased fertilizer use increased production costs by 50 percent from TSH1.5 to TSH2.5 million ($1,100) per hectare on average, which was beyond the capacity of the most low-income smallholders to afford. This gave rise to loan dependence in Madibira: 60 percent of my informants were smallholders (with one-hectare landholding), and all of them had to rely on loans to engage in paddy cultivation. Though national banks, such as the National Microfinance Bank and Cooperative Rural Development Bank, have joined SAGCOT as partners to give out loans to smallholders, in the widespread lack of collateral to put up for the loan, smallholders in Madibira lacked access to them. The increased production costs thus worsened their dependence on local microfinance institutes and moneylenders (usually, the wealthy local settlers) who charged high interest rates, often exceeding 30 percent. Moreover, some moneylenders used strong-arm tactics to collect loan payments from debtors with low harvest and crop failure by seizing their crops, lands, and small properties at the end of cultivation seasons. Hence, by encouraging the smallholders, particularly the low-income ones, to intensify paddy farming and bear increased costs before establishing a robust microfinancing system, SAGCOT put smallholders at debt risk.

Interviews also cast light on an economic-environmental tradeoff in the shift to intensive paddy farming: farmers stated that they felt "forced to use fertilizers intensively" since the soil fertility steeply declined and soil salinization became a serious problem due to monocropping (Farmer 2, December 05, 2016). They argued that in the first years of irrigation in the scheme in the early 2000s, they harvested 4–5 tons per hectare of paddy without any inorganic fertilizers, which is allegedly nowadays impossible to obtain without multiple bags of fertilizers. Farmers added that intensified droughts accelerated soil salinization, exacerbating the impact of erratic weather on food production. Some findings in the literature align with this suggestion that droughts worsen soil salinity, while salt, in turn, prohibits water uptake by plants (Paul et al., 2019; Corwin, 2020). To address this problem, Tanzanian research institutes developed a salt-tolerant version of the SARO variety, called SATO, which is becoming a necessity for farmers to be able to sustain food production. These findings show that while attempting to nurture food and income security through a shift to intensive farming, the government and SAGCOT partners neglect the rising environmental and economic disadvantages that consequently put greater stress on livelihoods instead of alleviating it.

Harvest and Income Data

Whether intensified irrigated paddy farming is a rewarding adaptation strategy for smallholders to sustain and improve their livelihoods requires examining the changing harvest and income levels. This section sheds light on this change following the shifts to irrigated paddy farming in 1998 and to intensified irrigated paddy farming in 2013 in Madibira, focusing on the 2016–17 season, the fieldwork period.

In Madibira, paddy irrigation began with equitably allocated landholding to local subsistence-oriented farmers, one hectare per capita, to commercialize the existing paddy farming. With this size of land, the government sought to put smallholders, who in the region typically held only a few acres (one hectare is about 2.5 acres) (Franks et al., 2013), at the threshold of transition to middle-scale farming and raise their incomes. Interviews showed that though most landholders initially lacked capital and labor to farm such a scale without loans, their incomes and cultivation capacities gradually improved. The scheme office recorded that the scheme-level harvest average was 4–5 tons per hectare in 2004, increased from 1 to 2 tons per hectare before irrigation begun in 1998, the last year of the official harvest records kept by this office. During these years, an assessment study conducted by the government showed that average income rose from TSH145,000 to TSH360–400,000 per hectare in the same period (AFD African Development Fund, 2004). This study also pointed to livelihood improvements associated with harvest and income increases, measured by increased ownership of burnt brick houses, power generators, motorcycles, farming and milling machines, and village shops. Moreover, school enrollment rates rose, and farmers began hiring laborers, prospering, and creating jobs simultaneously (AFD African Development Fund, 2004). The scheme office argued that this scheme-level harvest average of 4–5 tons was maintained until the transition to intensive paddy farming in 2013. However, interviews revealed that some farmers prospered more than others; the low-income farmers that SAGCOT sought to benefit struggled and often failed to achieve and sustain this harvest level. This finding builds on another one that scheme farmers in practice held lands of diverse sizes—small, middle, and large-scale lands—despite the formal landholding rule requiring them to hold a maximum of one hectare per capita. And mainly, the middle- and large-scale farmers harvested a lot, thus pulling the scheme-wide paddy harvest average above the average of the smallholder subgroup, which this study focuses on.

Despite holding one hectare per capita on paper, prospered farmers have accumulated multiple hectares informally from others who succeeded less in irrigated paddy farming. Among 114 farmer informants, only 66, about 60 percent, were smallholders who held only one hectare. Middle-scale farmers

[1]The conversion rate on 14 January 2017: 1,000 Tanzanian shilling (TSH) = 0.44 United States dollar ($).

with 2 and 3 hectares were 19 and 6 percent of the population, respectively, while 3 percent held lands larger than 3 hectares. The largest-scale farmer held more than 20 hectares and the second-largest 7 hectares; such few very large lands pulled the landholding average among informants up to about 2 hectares. Surveys provided further data showing that farmers with larger landholdings also had higher amounts of additional income, drew more on household-external labor, and owned more properties and livestock, pointing to class division among farmers. Income-generating assets were unequally distributed: all land-rich farmers with 4–5 hectares and more owned big farm machines (tractors and combine harvesters), which they rented out to other farmers for income. In addition, they owned additional businesses, such as the few restaurants, bars, guest houses in the village, and rice milling facilities, engaging in food trade. Middle-scale farmers with 2 and 3 hectares had smaller properties, such as power tillers and village huts, selling food and household goods, hired laborers to relieve household labor shortages, and only occasionally drew on cultivation loans. In comparison, all smallholder informants (with one hectare) took loans; they sometimes hired day laborers to complete difficult tasks during harvesting and sometimes worked as laborers for extra cash. Their property ownership was limited to a few hens and cattle, small maize plots in the drylands, and home vegetable gardens. These assets secured food and income to some degree but did not ensure farming investments when the harvest levels were low following drought periods. Smallholders depended on the harvest from season to season to subsist and reinvest in farming, and low harvest triggered land loss and redistribution to the wealthier classes.

To provide a systematic understanding of how harvest translated into income and potentially improved livelihoods in 2016–17, together with informants, I coined four income thresholds based on the average market prices (**Table 1**). That year, prices were lower than usual due to the grain export ban introduced by the government. This ban led wholesale paddy prices for SARO5 to halve from TSH1.1 million per ton ($484) to TSH0.55–0.6 million per ton ($242–264) in 2015. In 2016–17, prices slightly increased but remained low at TSH0.75 million per ton ($330). Based on this average price, the profit threshold, at which the income barely covered the production costs (TSH2.5 million), was 3 tons per hectare. Farmers defined a harvest at and below this level as crop failure because based on the early marketing season price of TSH75,000 per sack, 3 tons generated only TSH2.25 million per year and zero to minus profit after average production costs were withdrawn. This harvest used to be the subsistence threshold in 2014–15 based on higher prices (TSH1.1 million per ton) and used to create TSH0.8 million profit per year ($352) and TSH2,000 per day ($0.9 per day). However, it generated only $0.3 per day in 2016–17. Decreasing prices caused this harvest level to become insufficient for subsistence.

The new subsistence threshold, at which the profit made a (minor) contribution to subsistence, became 4 tons per hectare in 2016–17. This harvest generated only TSH1.25 million per year ($550) and TSH3,000 per day ($1.3) in the subsistence range, allowing farmers to access a limited range of food and cover only the basic livelihood needs. The stabilization threshold, which enabled farmers to make a sufficient profit to sustain their livelihoods and replenish their farm investment capacities for the next season (2017–18), was 6 tons per hectare. This harvest generated TSH2 million profit per year ($880) and TSH5,000 per day ($2.4), enabling farmers to afford the children's education costs, access a broader range of food, undertake basic household renovations, and occasionally buy clothes and travel based on the local commodity prices. In addition, loan-dependent farmers could save some cash, thus needing to take smaller loans in the subsequent season.

The wealth threshold, only achieved through intensive farming (requires hybrid seeds, more than seven bags of fertilizers, and mechanized monocropping), was 8 tons per hectare. This is also the harvest level targeted by the government (i.e., 8–9 tons and above). A harvest in this range of 8–9 tons per hectare could indeed bring a profit of TSH3.5–4.25 million per year ($1,540–1,870) and TSH9.6–11.6 per day ($4.2–5.1), enabling farmers to generate farming investment for the subsequent season, overcome loan dependence, meet the household needs, save cash, and access a greater variety of food and some luxury goods. Smallholders sustaining this harvest level for a few years could potentially transform into large-scale farmers and diversify incomes into wealth-generating nonagricultural businesses rapidly, which have been SAGCOT's vision. However, smallholders did not achieve these harvest levels.

Despite the shift to intensive farming, the mean harvest was 5.6 tons per hectare for the informants with harvest data (n = 81)—much below the 8–9 tons goal and not significantly above the pre-intensification range of 4–5 tons per hectare. The difference between the highest and lowest harvest was significant; the highest was above 9 tons per hectare and the lowest below 1 ton, significantly deviating from the mean. Based on the increased production costs (TSH2.5 million per hectare) and below-average market prices, farmers would have to harvest much above the usual levels to be able to sustain their livelihoods; harvesting the same amount of paddy as in the previous year put them into a lower-income group.

TABLE 1 | Harvest-income thresholds for income generation in the case study, 2016–17.

Income threshold	Harvest (tons per hectare)	Annual income
Profit/Crop failure	3	0–TSH250,000 ($0–110 per annum) ($0.3 per day)
Subsistence	4	TSH500,000 ($220 per annum) ($0.6 per day)
Stabilization	6	TSH2 million ($880 per annum) ($2.4 per day)
Wealth	8	TSH3.5 million ($1,540 per annum) ($4.2 per day and above)

TABLE 2 | Landholding size of farmers according to their harvest levels, 2016–17.

	Crop failure (0–3 tons/ha)	Subsistence (4–6 tons/ha)	Stabilization (6–8 tons/ha)	Wealth (8–9 tons/ha)	Above 9 tons/ha
n = 81	9 farmers	34 farmers	30 farmers	6 farmers	2 farmers
Mean land size	2.2 ha	1.6 ha	2.5 ha	4.8 ha	2 ha
Minimum land	1 ha	0.6 ha	1 ha	2 ha	2 ha
Maximum land	4 ha	6 ha	7 ha	15 ha	2 ha
Landholders	1 ha (33%)	1 ha (53%)	1 ha (43%)	2 ha (50%)	2 ha (50%)
	3 ha (33%)	2 ha (29%)	4 ha (20%)	4 ha (33%)	4 ha (50%)
	2 ha (22%)	3 ha (9%)	2 ha (13%)	15 ha (17%)	—

*Percentages show the three largest subpopulation in each group. Smallholders hold only one hectare (italic). Among smallholders (*n *= 34), three are at the crop failure, 18 at the subsistence, and 13 at the stabilization range.*

A comparison of the harvest and land data shows that smallholders harvested less paddy and generated less income than large-scale farmers (**Table 2**). All large-scale farmers harvested above the mean of 5.6 tons per hectare: 6–10 tons per hectare, which enabled them to maintain their high-income status. Only two farmers harvested above 9 tons. One of them was a large-scale farmer who used fertilizers intensively: nine bags above the standard of seven. The other held middle-scale lands, one of the few people that invested in land leveling and external labor to practice SRI, as confirmed by the local extension agent. Thus, the highest income group generating $4.2 and more per day were middle- and large-scale farmers only. Farmers with larger landholdings than smallholders invested more in intensive paddy farming and better coped with erratic weather. Middle-scale farmers fell into both high- and low-income groups. For example, one middle-scale farmer rented three hectares and cultivated middle-scale for the first time and fully on loans in 2016–17, aiming to fold his income over a single season despite hitherto being a smallholder. Harvesting as little as 4 tons per hectare of paddy on average due to the erratic weather, his debt multiplied by several hectares instead, leading him to consider renting out his plot and seek employment in 2018. This case shows that the confidence in the drought-tolerant seeds put some farmers at a disadvantage by encouraging them to neglect the weather risks.

Among smallholders with harvest data (*n* = 34), the main group of interest in this study, corresponding to 42 percent of farmer informants, no one harvested above 6 tons per hectare. The majority, 53 percent, harvested 4–6 tons per hectare and stayed in the lower-middle-income group ($0.6–2.4 per day). Though they survived erratic rains, a few of them struggled to subsist because of paying back loans with high interest rates. Because of submitting a large portion of their harvest to local financiers for loan payments, they also could not add value to crops by warehousing paddy (to sell at higher prices at the end of the season) or milling it to rice that increase income per unit of harvest as land-rich farmers usually do. The second-largest smallholder population with 38 percent harvested 6–7 tons per hectare at the stabilization range, joining the upper-middle-income group ($2.4–3.3 per day). They generated sufficient cash to repay their loans and invest in farming in the subsequent season, thus decreasing their loan dependence, which should be considered a livelihood improvement. Only to a limited extent, intensive farming succeeded in moving smallholders into the government-defined middle-income status of $3 per day. Because only the middle- and large-scale farmers harvested above 7 tons per hectare, earning $3.3 and more per day, intensive farming mainly benefitted the already better-off farmers.

A minority of the informant population (9 percent) had crop failures with 3 tons per hectare and less, putting them into the lowest income group ($0–0.6 per day). Farmers who harvested below the average argued that this was due to erratic weather. For example, the smallholder with the lowest harvest anticipated a harvesting delay to September 2017 (the usual harvest time is July) and collected only 3 tons of paddy with zero profit (Farmer 3, July 09, 2017). She held low precipitation responsible for the crop failure: when the rains ceased and most people harvested in July, her crops were still not ripe and partially died. Another smallholder who collected a low harvest of 3.6 tons also pointed to insufficient rainfall, which he had anticipated before cultivation started (Farmer 4, July 14, 2017).

Narratives from all informants (*N* = 114) on livelihood transitions spanning a longer period since 1998 show that leaving farming to become laborers is impoverishment rather than adaptation. This is because all accounts explaining such transition involved poor harvest and debt, impelling people to abandon the scheme, liquidate their assets, farms, and livestock to pay for debt and look for jobs. For instance, an informant claimed "a life-ruining debt" had driven her family to give away their one-hectare plot in the scheme: she had harvested 4 tons of paddy and submitted all of this to a moneylender to pay her YARA fertilizer debt, and she and her husband started working as day laborers for the wealthier scheme farmers (Farmer 5, December 10, 2016). The village chairperson reported that the 2015–16 drought similarly affected many other livelihoods, leading hundreds of farmers to lease out their lands; "they did not migrate from Madibira but stayed and looked for work at the irrigation scheme" (Key informant 5, December 23, 2016).

The most common and available types of work were day and seasonal wage labor in the scheme, which could not compensate for farming in terms of income generation. Wages for day labor varied depending on the task (e.g., canal cleaning TSH2,000, harvesting TSH50,000). Seasonal wages covered multiple tasks, including land preparation, seedling transplantation, and harvesting, and ranged at TSH500–750,000 ($220–330) per hectare per season, below the subsistence threshold in 2016–17. Only farmers who additionally rented out their formal one-hectare landholding in the scheme at the average lease rate of TSH750,000 generated income equivalent to TSH1.25–1.5 million ($550–660) in the subsistence range. Despite such income established some livelihood security, paddy farming could bring much more cash, up to "multiple millions of shillings," as a local authority claimed (Key informant 6, June 11, 2017). Hence, farmers strived toward this goal even in the sight of weather adversity.

Once farmers became laborers, they found financial recovery difficult. The transition to employment was irreversible for many of them, even when they kept their landholding on paper. For instance, one laborer stated that she hoped to take cultivation loans "some time" again, but for the near future, she wanted to continue engaging in seasonal employment and petty commodity trading, considering these as securer income generation options (Farmer 6, December 10, 2016). Nevertheless, these options did not allow them to generate sufficient income to return to farming. Another laborer, a former farmer, asserted "a constant risk of collapsing" in his family and that he "constantly sought ways to escape this (poverty) cycle" but failed (Farmer 7, December 09, 2016).

CONCLUSION

This paper examined the livelihood effects of three key strategies that policymakers advise farmers for climate change adaptation in Tanzania: irrigation, drought-tolerant seeds, and employment in the context of intensive paddy farming in SAGCOT. Interviews were conducted in the Great Ruaha Basin shortly after the 2015–16 drought prompted by El Niño adversely affected this area but covered a longer period since the beginning of irrigation at the case study in 1998 to understand whether these strategies enabled smallholders to withstand droughts. The findings are to a significant extent consistent with the outcomes of the literature review: climate impact on natural resources and food production has been worsening in Tanzania (e.g., Lema and Majule, 2009; Arndt et al., 2012b; Warner and Afifi, 2014; Komba and Muchapondwa, 2015; Komba and Muchapondwa, 2018). Farmers indicated that the drought that year was more intense than in the past, with decreased rainfall starting later and ceasing earlier than usual. They also pointed to the potential impact of recurrent droughts on exacerbated soil salinity, a common type of land degradation in intensive farming. In this context, expectedly, irrigated intensive farming had limited benefits for the low-income farmers to cope with climate stress and sustain their livelihoods.

Irrigation can offer opportunities for dryland farmers affected by the rainfall decrease to adapt to water stress, thus contributing to food and income security, as the Tanzanian government depicted (SAGCOT, 2011b; URT United Republic of Tanzania, 2011; URT United Republic of Tanzania and JICA Japanese International Cooperation Agency, 2013; URT United Republic of Tanzania, 2015a; JICA Japan International Cooperation Agency, 2018). Documents collected and interviews showed that the transition from dryland to irrigated paddy farming with the construction of the irrigation scheme in the case study area in 1998 indeed increased the average paddy harvest from 1–2 to 4–5 tons per hectare. After that, asset ownership and living standards improved, which the government interpreted as progress toward poverty alleviation in the area, which the government interpreted as progress toward poverty alleviation in the area (AFD African Development Fund, 2004). However, this study also revealed that since then, despite intensified farming with SARO5 seeds with drought-tolerance features, the average harvest in 2016–17 following the drought remained 5.6 tons per hectare, only a little above the 4–5 tons per hectare average. This finding shows that the drought tolerance and productivity of the hybrid seeds are limited: adequate water still has to be available for irrigation to ease water stress and for these seeds to yield the expected high harvest (i.e., 8–9 tons per hectare).

In the water-energy-food nexus in river basins, unless water for food and rural income is a priority, the potential of irrigation as an adaptation strategy for farmers has limits. This is the case in the Great Ruaha River Basin: the existing literature already established that the government holds the upstream farmer population responsible for the drying river and compromises food production while seeking to enhance the water flows into downstream national park and energy sectors—an ongoing debate with significant political dimensions such as powerful interest groups competing for water (Maganga et al., 2004; Walsh, 2007; Walsh, 2012; England, 2019). The findings in this study provide relevant insights for this literature: while releasing abundant water during heavy rains, authorities planned to cut water abstractions of the case-study irrigation scheme by half and the irrigation season by 5 months following the drought when farmers needed water the most. The same authorities, denying the role of inequitable water allocation in exacerbating water stress, also used climate change as a buzzword to explain this situation. This shows that though climate impact on natural resources is an existing problem, this narrative sometimes eludes the nuanced and political drivers of water stress in river basins, pointing to further shortcomings of irrigation as adaptation where water is a conflict substance.

Limited water security leaves farmers no choice but to switch to the hybrid seeds to adapt to water stress and bear increasing costs by taking loans despite the risks associated with this move. Limited drought tolerance of the seeds aside, their fertilizer demand soaring production costs is a problem. The literature argued that hybrid seeds are one of the most common climate adaptation strategies among Tanzanian farmers (CIMMYT International Wheat and Maize Improvement Center, 2016; Komba and Muchapondwa, 2018; Lybbert and Paul, 2018; CGIAR Consultative Group on International Agricultural Research, 2019), but this does not tell much about their success in securing livelihoods, especially for the most vulnerable low-income groups. By showing that the low-income farmers could only engage in intensive farming with hybrid seeds through loans, which perpetuated debt and took a toll on livelihoods, this study adds to the existing but scant literature in this context. Attention is needed on the affordability of other hybrid seeds by the poorest farmers and how their livelihoods improve due to this seed choice to be able to draw conclusions on poverty alleviation. Further research avenues include assessing the environmental impacts of the hybrid seeds where land fertility is already low due to intensive farming.

One of the most significant findings that align with the theoretical agrarian political economy literature is that the transition to intensive commercial farming does not make all farmers better off (e.g., Griffin et al., 2002; Akram-Lodhi et al., 2006; Bernstein, 2010; Bernstein and Oya, 2014; Bernstein, 2016; White, 2018). This study found that farmers who prospered through irrigation gradually accumulated landholding informally and invested in profitable nonagricultural businesses. Only such land-rich farmers survived the 2015–16 drought and the reportedly low precipitation in the subsequent season, reaching the highest and above-the-average harvest levels. Meanwhile, the erratic weather only adversely influenced the small- and middle-scale farmers. In the best examples, small- and middle-scale farmers subsisted and stabilized their livelihoods while depending on cultivation loans in the next season again; in the worst, devastating debt impelled them to rent out their lands immediately after harvesting to pay up the debt. Hence, the shift to intensive farming heightened the rural inequalities as expected. Moreover, most such affected farmers remained settled in the case study area and looked for wage labor instead of migrating. Farmers left their plots involuntarily and found it difficult to create adequate capital to return to farming because the local wages hardly sufficed for subsistence. Hence, the transition from farming to employment, in this case, should be interpreted as worsening livelihoods.

Based on the findings, policymakers are recommended to consider alternatives to intensive farming, such as environmentally sustainable methods improving the soil fertility naturally. Seed varieties aimed at strengthening climate adaptation capacities should not perpetuate input and loan dependence. Also, attention to equitable land and water allocation in river basins is overdue. Finally, SAGCOT maintains a negative reputation in the scholarly literature due to malpractices in land-based investments (Exner et al., 2015; Greco, 2015; Bergius et al., 2020). However, in the staple food subsector, adjusting its focus to enable smallholders to hold land equitably, promote environmentally sustainable climate adaptation and cultivation strategies, and strengthen rural-urban trade for improved food distribution from surplus to deficit areas may help elevate its contribution to the national food and income security.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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