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Review Article

A Review on Managing Agroecosystems for Improved Water Use Efficiency in the Face of Changing Climate in Tanzania

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Agroecosystems are important for food production and conservation of biodiversity while continuing to provide several ecosystem services within the landscape. Despite their economic and ecological benefits, most agroecosystems in Tanzania are degraded at alarming rates. Rapid increase of human population and unprecedented impacts of climate change have influenced depletion of natural resource base within agroecosystem in recent decades compared to what communities have experienced before. Increased food demands owing to population increase have increased pressure on exploitation of land resources including water. Cultivation area and irrigation water demands have increased steadily in the last six decades. Nevertheless, approaches used for water supply have not been improved; thus, water use efficiency in most irrigation schemes is quite poor. Conversely, climate smart agricultural practices are practiced less in Tanzania. There is poor adoption of recommended adaptation among smallholder farmers due to several socioeconomic reasons. One of the key objectives of climate smart agriculture is to improve bio-geochemical interactions within landscape and decrease competition of natural resources between humans and other component of agroecosystems. This underscores the assumptions that most cropping systems in Tanzania are not managed sustainably. Moreover, comprehensive assessment of hydrological dynamics within smallholder farming in Tanzania is highly lacking. Therefore, actual causes and extent of water resources depletion are largely unknown among stakeholders. In most tropical landscapes, water resources degradation is influenced by interaction of both anthropogenic and biophysical factors operating at different times and space scales. As the capacity of water-supplying sources continues to decline, Tanzania needs profound changes in agricultural production systems in order to nourish the growing human population. This calls for strategic approaches that have wider adaptability. A literature survey study with the following objectives was conducted (i) to assess current state of agricultural water use and irrigation activities in Tanzania and (ii) to determine major constraints for sustainable water management and identify appropriate adaptation measures for their improvement across diverse cropping systems.

1. Introduction

Agroecosystems are vital for sustaining both food production and conservation of biodiversity within landscapes [1, 2]. Such systems are achieved through systematic selection and combination of different levels of productivity, stability, and equitability [3]. In Eastern Africa, agroecosystems are reported to evolve several centuries ago; thus, many local communities have developed experiences of integrating multiple and complementary components within their production units [4, 5]. Engaruka irrigation schemes in northern Tanzania and Sirikwa agropastoral system in Kenya's western highlands are dated back to circa 12th or circa 15th century [6]. Likewise, during the later Iron Age, the Bantu speakers are presumed to practice intensive farming on highlands of Mt. Kilimanjaro and around Mt. Kenya circa 11th to 16th century [7].

Variable scales of interactions, notably, crops to crops, trees to crops, crops to soil, or crops to wildlife, have evolved within traditional cropping systems over time [8, 9]. These interactions range from simple intercropping to complex agroforestry systems [10–12]. Studies have indicated that the

provisioning capacity of ecosystem services within agroecosystem is highly influenced with increasing hierarchy of component interactions [9, 13, 14].

Despite the recognized values of agroecosystems, they have been constantly ruined over time by number of factors, thus threatening their capacity for ecosystem services provisioning and impinging their resilience to multiple stressors [15, 16]. Recent intensification of agriculture and prospects of the future increase of food demands have detrimental impacts to functioning of natural resources base including depletion of water sources [17]. Additionally, loss of diversity and changes in structural composition of agroecosystems are also associated with conversion of nonagricultural terrestrial to cultivation and grazing areas [18, 19].

Conversely, climate change is already a concern in agriculture. As temperature and water stress amplified, cropping systems become more stressed. At its extreme range, temperature influences excessive water loss through evapotranspiration [20]. However, impacts of climate change are reported to be more exposed to tropical developing countries especially sub-Saharan Africa [21–23]. According to Collier et al. and Hertel et al. [24, 25], the region is more vulnerable to this problem because local communities lack capacity to adapt and respond to climate change impacts.

The combined effect of increased climate change and human disturbances on land resources has profound impacts to sustainability of water resources and overall productivity of crop fields [26]. Water resources are highly fragile. They are highly vulnerable to degradation when exposed to diverse environmental stressors. Many sources are being overabstracted following a mismatch between irrigation water demand and the actual capacity of supplying sources [27]. Increased deforestation in catchment areas expose forest wet ground floor to sun radiation; thus, proportion of stored moisture is lost before released as runoff to rivers [28, 29]. Similarly, increased concentration of sedimentation and agrochemical from upper areas affects both quality and quantity of water in streams to downstream users. This calls for appropriate strategies for improving water use efficiency within cropping systems [30, 31].

In Tanzania, about six types of farming systems have been reported across different agroecological zone, namely, maize mixed root crops, highland perennial, agropastoral millet/sorghum, tree crop, and highland temperate mixed [32]. This variation is attributed to different biophysical factors characterizing agroecological zones, such as climatic conditions, topography, and soil properties [33–35]. Additionally, several anthropogenic factors including land tenure, consumers' preferences, and institutional issues have been reported to influence farmers' decisions on land management in Tanzania [36, 37].

However, comprehensive estimates of water demands and supply in different cropping systems in Tanzania are lacking. This often contributes to water management challenges in most agricultural landscapes [38]. We suppose that strategies to cope with increased water scarcity in Tanzania should not focus on attributes of local farms only but also the entire basin. Additionally, good coordination among key institutions is essential for sustainable management of water resources.

Therefore, a review was conducted to assess current knowledge on patterns of agricultural water management under smallholder farming in Tanzania. Both historical and current literatures from various sources, such as journals articles, technical reports, and gray literatures covering water management in different cropping systems and eco-regions of Tanzania, were used to extract information. The main focus of this review is centered on water use practices, major constraints, and various adaptation strategies for improving its use efficiency. Furthermore, it intends to provide updated information on the status of water management, contributing to improvement of water policies and their implementation frameworks. Government officials, policymakers, and local farmers are the key target audience of this review.

2. Water Use in Smallholder Farming in Tanzania

Generally, agricultural production in Tanzania is influenced by the size of cultivation areas rather than improvement of agronomic management. FAO's assessment on the long-term trend of cereals production in Tanzania indicated cereal yields were positively correlated with the size of the field. Nevertheless, a sharp decrease of yields was observed in early 2000s (Figure 1). Several causes are reported behind unimproved cereal production in Tanzania [39–41].

Agriculture consumes the largest proportion of basin discharge in Tanzania [42]. Irrigation consumes 86%, while the municipal sector uses 10% and less than 1% by industry. For nearly six decades, Tanzania has made some progress on irrigation sector including expanding the area under irrigation. According to the National Irrigation Master Plan (NIMP), Tanzania has identified a total irrigation potential of 30.4 million ha. Out of this, 2.3 million ha is classified as high potential; 4.8 million ha as medium potential; and 23.3 million ha as low potential. Nevertheless, only 289,245 ha has been transformed to improved irrigated agriculture [43]. Almost all regions in the country have the promising capacity for food production under different adaptable cropping systems. However, out of 25, only 8 regions indicate the highest potential for irrigation. These include Mwanza, Mara, Kagera, Shinyanga, Arusha, Kilimanjaro, Morogoro, and Iringa regions. Notably, preference to irrigation varies across different crops varieties. Maize, rice, and vegetables are more irrigated than other cultivated crops [38, 44].

Tanzania is endowed with diverse sources of supplying agricultural water. However, the majority of small-scale farmers (more than 80%) depend on rainfall [38]. Rainfall varies significantly across different agroecological zones. While some parts receive, on average, up to 3,000 mm of rain per year, others like the central regions and along rift valley receive relatively lower amount averages 600 mm [45, 46]. We suppose that deficiency of rainfall in central regions such as Dodoma, Singida, and Shinyanga diminishes the opportunities to grow some food crops.

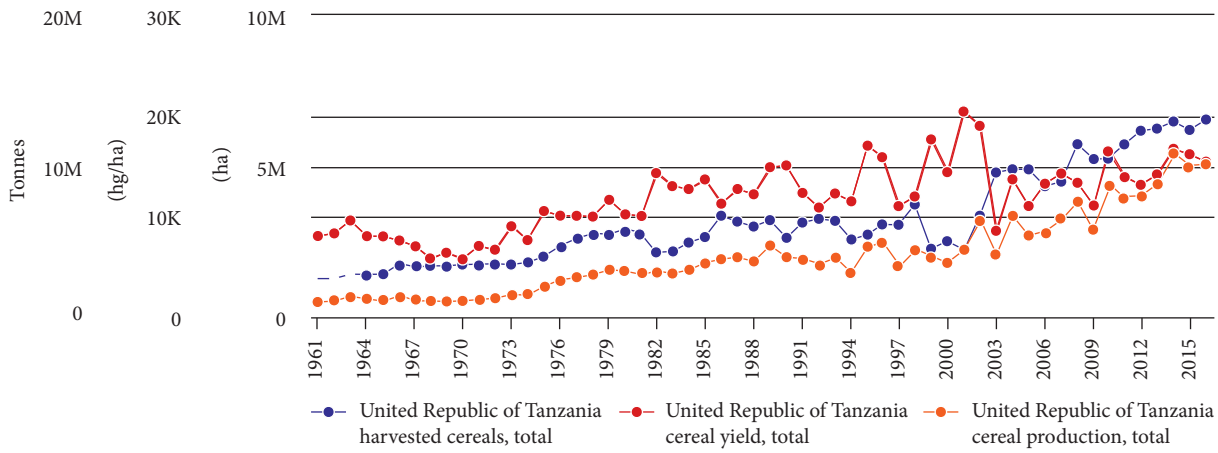

Figure 1: Tanzania total cereal production between 1961 and 2016.

Irrigation relies on the abstraction of rivers runoff through gravity-based flow [38]. Notably, a substantial decline of water in rivers is normally observed during dry seasons, which usually lasts from June to October [47, 48]. Thus, water supply to irrigated fields declines during dry season [42]. Poor efficiency of water supplying infrastructure also aggravates the problem. The main drawback of traditional irrigation methods is the low water conveyance efficiency and excessive water loss en route from sources to crop fields [49–51]. This often limits downstream users to access sufficient water, especially during dry seasons [52].

In contrast, adoption of modern irrigation technologies such as sprinklers and small motorized pump still needs further mobilization and facilitation. In some districts, authorities restrict direct pumping of water from river and lakes for irrigation purpose [44]. Nevertheless, positive responses to crops yield have been realized where modern irrigation approaches have been adopted [53].

The least exploited water resources include groundwater sources and harvested rainwater. The former involves only 0.2% of all irrigated area. Rainwater harvesting technologies only cover 27,200 ha and more confined within the central drier regions such as Dodoma, Tabora, Singida, Manyara, and Shinyanga [38, 44].

3. Constraints to Agricultural Water Management

3.1. Anthropogenic-Induced Causes. Several discourses have pinpointed that human activities are more responsible for water resources depletion within agroecosystems than natural-based causes [54–56]. Where this holds true, the problem could be further aggravated by lack of precautionary measures and eventually affect the hydrological circle [29]. Agricultural fields in most sub-Saharan African countries are characterized with poor storage of soil water due to several losses. For instance, Cooper et al. and Casenave and Valentin [57, 58] reported that between 30 and 50% of rainfall is lost by soil evaporation while surface runoff accounts for 10–25%. Rockstrom [59] observed that productive green water flow as transpiration accounts for a small proportion, notably 10–30% of rainfall. Additionally, other studies have indicated that traditional irrigation systems in Eastern Africa are characterized with water use efficiency below 50% both in supplying canals and storage facilities [42, 60]. Here, we review some selected anthropogenic activities that have been known to cause serious water management problems. However, there are still several managerial and technical issues that limit the development of irrigation sector [37, 61, 62].

3.1.1. Land Degradation. Land degradation affects the quality of landscape and accelerates agricultural water losses [63, 64]. Notably, water erosion is the most serious erosion in Tanzania, especially on highlands and areas with poor vegetation cover due to human action [65, 66]. Uncontrolled runoff leads to loss of water and soil fertility that could be stored in the soil for future use. On the north of Mahale Mountains in Tanzania, Busch et al. [67] noted that anthropogenic alteration of lake hinterland due to cultivation, burning, and deforestation influences fine sediment deposits in shores of Lake Tanganyika. Agronomically, soil permeability could be influenced by inherited factors such as soil texture [68]. However, management practices such as heavy farm machinery can influence soil compaction, especially when operating at poor soil moisture regimes [69]. Given that overall use of mechanization is still low in Tanzania smallholder farming, its influence on total annual soil loss could be very minimal.

Conversely, the efforts for improved soil moisture level are not always rewarding. Salt accumulation and leaching of nutrients often occur in over irrigated fields. Assessment of soil condition in Ndungu rice irrigation schemes in Same District indicated high exchangeable sodium percentage and high bicarbonates on top soils [70]. Salts raise their osmotic pressure and induce ion toxicity or nutrient imbalances which disorder the water and nutrient transport between plant roots and soil [71]. On the basis of limited studies on crops development, this review fails to determine the contribution of the impacts of salinization in other cropping

systems in the country. However, the extent of soil salinity is very dynamic at spatial-temporal scale. Several factors could influence the accumulation of salinity in the soil in the cropping system. These include quality of irrigated water, drainage conditions, evapotranspiration [72].

3.1.2. Complex Land Tenure System. There is a close relationship between the complexity of land tenure and overall management of crop fields. In highly populated agroecosystems, access to arable land is already a problem. For example, around Mt. Kilimanjaro, the average size of land ownership is less than 2 ha per person. This has influenced some households to depend on hired or looking after relatives' land in their absence [73, 74]. Given that tenure period is unguaranteed, tenants fear to invest in improving land quality.

A study by Bayisenge [75] noted that where farmers lack clear land tenure system, it will be impossible for them to implement long-term soil conservation practices since the benefits from such investment take a long time before paying back. Efficient irrigation technologies such as drip irrigation or sprinkles demand higher initial capital investment that many rural villagers cannot afford to pay upfront [76].

On other perspectives, the influence of gender on land possession could indirectly impact on land management. In most parts of East Africa, nearly 60–80% of food is produced by women but only 4% have land with their names [77]. The same problem is observed in Mt. Kilimanjaro whereby the *Kiamba* system involves land passing through sons and thus limits a right of land ownership to women [74]. Comparable findings were reported by Galiè et al. [78] who observed that a lack of gender equality has unnoticed impacts on land management and food security in developing countries.

3.1.3. Weak Institutional Linkages. Donors and government's support to rural irrigation projects in Tanzania started back in the early 1970s. However, less has been achieved compared to the invested effort. Several technical and managerial problems have been limiting the expansion and sustainability of these projects. Notably, project implementers focused more on engineering part, whereas social aspects important for projects sustainability have been overlooked. Local people have accumulated experience of types of crop they grow, seasons of the year, and suitable locations within the village land [79].

Currently, water management in all river basins is under both formal and informal institutions [37]. However, there are fewer success stories in Tanzania about the improvement of agriculture water to benefit smallholder farmers. Notably, conflicting national policies contribute several contradictions on the ground [42, 61]. Given that water is a multisectoral resource, there is a need for harmonizing policies to guide equitable water sharing among users. For example, conflicts between farmers and livestock keepers have already affected agricultural production and water quality in several districts in Tanzania [79, 80].

Management of hill irrigation on the southern slope of Mt. Kilimanjaro provides a good case study of agricultural water management. There is a general concern that cohesion between formal and informal institution for basin water management around Mt. Kilimanjaro is weak [61, 81], thus creating communication barriers between district authorities and Chaggas' water committees. Seemingly, increased water abstraction to gravity-free water pipes has affected the discharge of traditional irrigation canals [50, 82]. We attribute this to the marginalization of local people whose expertise and local experience could be useful input during project planning [79]. In addition to the weakness of district authorities, Chaggas' local institutions have been reported to deteriorate over time, thus dwindling internal arrangements that used to maintain irrigation schemes [61].

3.2. Biophysical-Induced Causes. Despite some interrelationship between anthropogenic and biophysical factors, there is some evidence whereby biophysical factors interact among themselves to cause deleterious impact to the hydrological cycle in agroecosystems. Notably, climate change and variability are the most influential biophysical factors to land resource degradation. This includes extreme temperature range and rainfall with high emissivity. Conversely, the influence of terrain slope and soil properties on water resource depletion is more influenced by management practices.

3.2.1. Climatic Factors. Climate change has become a serious environmental concern in tropical agroecosystems with unprecedented impacts which are reported to increase in the future [83, 84]. Extreme weather events and changing of seasonal patterns have already impacted the hydrological cycle [85]. Temperature and rainfall are the major climate variables speculated to influence the dynamics of crop water use efficiency; however, this is understood only theoretically among farmers and extension workers. Each crop has its threshold temperature and moisture range, yet farmers have indicated fewer efforts to modify crops arrangement or agronomic practices in order to overcome the effects of heat or water scarcity [23, 86]. Despite the facts that mixed cropping has been perceived as a potential strategy for climate change, the strategy could as well affect overall yield if complementarity between crops is lacking [87]. Currently, tree planting and adoption of hybrid crop varieties campaigns are highly promoted in agricultural landscape. Due to several socioeconomical factors, communities could develop interest to hybrid crops or exotic trees species at the expense of local or indigenous ones [1, 36]. However, introduction of some exotic tree species within agricultural fields has already caused negative impacts to nutrient and water cycles [88, 89].

Plants growth responds positively to temperature increase, but the benefit is overwhelmed with extreme temperature levels and frequent droughts [90, 91]. Given phenotypic difference across different crop varieties [92, 93], they could be characterized with different transpiration rates. Most semiarid areas, such as central Tanzania, experience high evapotranspiration and receive less amount of rainfall per year compared to highlands [94]. Therefore,

farmers need to implement different adaptation strategies for water management in order to reduce risks of crop loss caused by drought.

3.2.2. Soil Properties. Soils' inherent characteristics are highly heterogeneous at spatial scale [95]. Information about soil permeability properties, such as water infiltration and hydraulic conductivity, can be useful to predict water gain and losses within irrigation fields [96]. Additionally, they can be used for developing crop water stress maps within the field in order to optimize irrigation water use [97, 98].

Soil texture is very static but highly heterogeneous at spatial scale [99, 100]. The difference in the amount of water retained in the plant root zone is mainly influenced by its soil texture. Under the same amount of irrigation water, loamy soils store more water followed by clay whereas sand is the least [101]. In Tanzania, most soils around the coastline of Indian Ocean are arenosol [102]. Such soil is mainly consisting of sand with little humus and clay [103]. Being coarser in texture, such soil is highly drained, thus not suitable for establishing furrow irrigation schemes, unless lined. In contrary, most highland areas such as Kilimanjaro, Arusha, Mbeya, and some parts of Mara region are characterized with Andosol [102, 104]. These soils are young and originate from the volcanic deposit. Hydrologically, Andisols exhibit good properties for water holding capacity [103]. Extensive unlined irrigation canals have been operating on slopes of Mt. Kilimanjaro and Mt. Meru for decades because the soil is less drained and stable [50, 73].

3.2.3. Topographical Factors. Topography has an influence on the hydrological process within the landscape [105]. Slope increases the flow velocity of surface discharge linearly. However, slope curvature is responsible for certain degree of variability along the hillslope transect [106]. In the Uluguru Mountains, east southern Tanzania, Nishigaki et al. [107] reported a higher rate of runoff and sediment loss on upper steeper compared to foothill sites. Additionally, inherent microtopography induces variability of soil moisture accumulation at the end of irrigation or rainfall event. Depressed and converged landscapes tend to accumulate higher moisture content compared to hilly areas [108]. The same effect is suspected to influence nutrient availability to plant. Sufficient evidence about the influence of terrain curvature on surface hydrology is lacking in Tanzania. However, a study in southwest Niger by Brouwer and Powell [109] noted that manure applied on the wettest concave part of the farm indicated more nutrient leaching compared to those on drier convex areas. This implies that farmers need to trade-off between cost spent on acquiring manure and benefits gained on soil moisture storage.

It is asserted that crop fields on the steep slopes could be more vulnerable to soil moisture deficit if control measures are lacking. Areas indicating highest risk include northern highlands such as Mt. Kilimanjaro, Mt. Meru, the South Pare Mountains, and the Usambara Mountains. In southern highlands, it includes Matengo hills and Makambako hills. The semiarid areas such as Dodoma and Singida are characterized by flat terrain; therefore, the overall risk of water loss due to topography could be minimal.

4. Adaptation Strategies for Agricultural Water Management

Addressing water problems in crop fields demands a range of management interventions starting from the crop field up to catchment level. There are a number of possibilities that water supply to agricultural fields can be improved without increasing abstraction rates of their sources. The concerted efforts are needed among key water users to minimize wastage and reduce unnecessary water uses.

Given that water and soil are the main resources in agricultural production, any agricultural project should address pillars of millennium sustainable development goals [110, 111] and national strategies for improving food security. Several frameworks have been established in Tanzania, which also address transformation of agricultural productivity. These include Tanzania Development Vision 2025 (TDV 2025); National Strategy for Growth and Reduction of Poverty (NSGRP/MKUKUTA); and Agricultural Sector Development Program (ASDP), just to mention a few [30, 112, 113].

In order to advice farmers and policymakers on better water management options, a strong empirical evidence embedded with evidence-based interventions are needed. Several mechanisms addressing water management challenges have been advocated, yet some indicate narrow applicability [61, 62].

4.1. Mulching Application. Mulching is among the simplest and widely used technique for soil water conservation in agricultural lands. It involves covering soil surface with a layer of organic materials for purpose of reducing soil moisture loss through evaporation [114, 115]. Additionally, mulching has a number of cobenefits in crop fields, such as the addition of organic matter and suppression of weeds [116, 117].

In the Usambara Mountains, the traditional mulching system (*Miraba*) has been used for decades for controlling soil erosion and improving soil fertility and crops yield [118]. Moreover, a study by Kaihura et al. [119] noted that farmyard manure (FYM) can effectively be used as mulch material and better input for soil nutrient in diverse agroecosystems compared to N and P mineral fertilizers. To benefit more from mulching, other soil management practices such as reduced tillage or addition of animal manure can be integrated easily [120].

4.2. Contour Farming. The terrace is a leveled surface normally established on the steeply sloped area to overcome the effect of the slope to soil erosion. The technology could be one of the oldest approaches for land conservation [121]. Sloped areas are highly susceptible to degradation that may affect soil quality of crop fields. Modifying sloped terrain into contour terraces prevents runoff during rainfall or irrigation [122, 123]. In Tanzania, like other East African

countries, *Fanya juu* terraces have been used to control soil erosion in steep gradient. Construction of *Fanya juu* involved lifting the lower soil upslope by using hand hoe to create trench and ridge that follow along contours lines. The ridge controls runoff overflow whereas the trench acts as a depression that collects runoff and transported sediments [124, 125].

Notably, construction of terraces demands careful approaches. Where soil is unstable, like Makanya watershed in eastern northern Kilimanjaro, stone terraces might be used to stabilize terrace wall. Conversely, at gently undulating slopes (2–5°), borders have been widely used [126]. In most cases, however, plant roots are used to stabilize terrace edge. In the Usambara Mountains, Guatemala grass is grown for dual purpose, to control soil erosion and as a source of livestock fodder [127].

Besides multiple benefits of terraces, their regular maintenance is reported to be challenging. We relate this with decreasing population of youth in rural areas in most regions of Tanzania [128]. Construction and maintenance of terraces are very laborious; thus, increased population of elderly and children in rural areas is translated as a silent dearth of terraces [129].

4.3. Change of Crop Varieties. Meeting food supply for a growing population will require other innovative strategies rather than increasing cultivation areas or abstraction of sources. In drier areas, growing drought-resistant crops such as sorghum, lablab beans, or millet will save a substantial amount of water and also ensure high crop yield. Similarly, more acreage of rice would be grown in water-rich areas at lower water supplying cost and less pollution [59, 130]. However, it is envisaged that specialized farming demands efficient crop marketing between regional borders. Therefore cross-sector collaboration between agriculture, trade, communication, and transport is emphasized [131, 132].

Impacts of climate change are now unequivocal, particularly in terms of increasing temperature and carbon dioxide concentration. Thanks to ongoing efforts on crop breeding programs, whereby advanced bio-technology have achieved several milestones in improving crop capacity to withstand biotic and abiotic stress caused by extreme climatic conditions [133, 134]. Notably, several options of improving water use efficiency have been investigated; these include (i) reducing nontranspirational uses of water; (ii) reducing transpiration without reducing production; (iii) increasing production without increasing transpiration; and (iv) enhancing tolerance of water-related stresses. For example, sorghum (*Sorghum bicolor* L. Moench) is a very adaptable crop in arid areas because of its ability to withstand severe climatic conditions, suppressing weeds and demanding less agronomic inputs compared to most cereal crops [135, 136]. As a C4 plant species, it has the higher photosynthetic ability and greater efficiency of nitrogen and water use.

Despite these merits, some improved varieties of sorghum, such as var. Tegemeo from Tanzania, are still not widely adopted. Some key reasons include low protein content and the presence of tannins [137].

4.4. Water Harvesting. Developing supplementary sources of irrigation water could be one way of sustaining agricultural water supply during the dry season. Indeed, this technology is not quite new in Tanzania. Small to medium size dams (*Madibwi* in Kiswahili dialect) have been used to collect rainfall in semiarid areas [138, 139]. However, in northern highlands like Mt. Kilimanjaro, water harvesting in the agricultural area involves establishment of microdams (*Nduwa* in Chagga dialect) along the small stream routes (Figure 2). The overnight storage is released in the next day to fields through irrigation canals [50, 140]. Elsewhere in Tanzania, small circular pit holes, microcatchment about 30 cm in diameter and 20 cm deep, are used as a crop irrigation technique. For example, *Vinyungu* have been used in Iringa rural areas, southern Tanzania highlands, for growing food crops [141]. Other comparable techniques of using micropit systems include Zai, Tassa, and Chololo [20, 142]. The advantage of these techniques includes water storage, improving soil fertility around the crop root zone, and improving groundwater recharge.

4.5. Promotion of Agroforestry. Agroforestry can offer a promising solution for improving water use productivity [13, 143]. Establishing agroforestry is possible in most agroecological zones of Tanzania provided that introduced trees or shrubs will improve overall performance of the system [144]. Tree roots enable infiltration of precipitation to the aquifer and control its release down the slope during the drought period. Similarly, tree roots can influence soil moisture through hydraulic redistribution (HR) and therefore enable crops to access sufficient moisture even during the drier period of the year. A study by Bayala et al. [145] indicated the existence of HR leads to high soil water potential in the plant rhizosphere, hence important for crop field hydrodynamics and nutrient circulation. The concept of HR can be beneficial to arid and semiarid areas such as Dodoma and Singida where rainfall is very erratic and deficient [146, 147].

In monocropping systems, field crops suffer from excessive evapotranspiration losses. This is caused by direct solar radiation to crop canopies and soil surfaces. Where trees are integrated, they act like an umbrella to crops. A study by Lin [14] noted that the presence of shade in coffee farms reduced evapotranspiration losses in both crops and soil.

Nevertheless, some tree species could cause some negative impacts within agroecosystems due to lack of complementarity with crops. For example, *Eucalyptus* spp. trees have been widely criticized to affect landscape hydrology and deplete soil fertility [89, 148]. However, they can be useful in controlling raising water table in marginal lands [88]. From a socioeconomic point of view, *Eucalyptus* spp. trees produce high-quality timber whereas their branches are used as poles and firewood [149, 150].

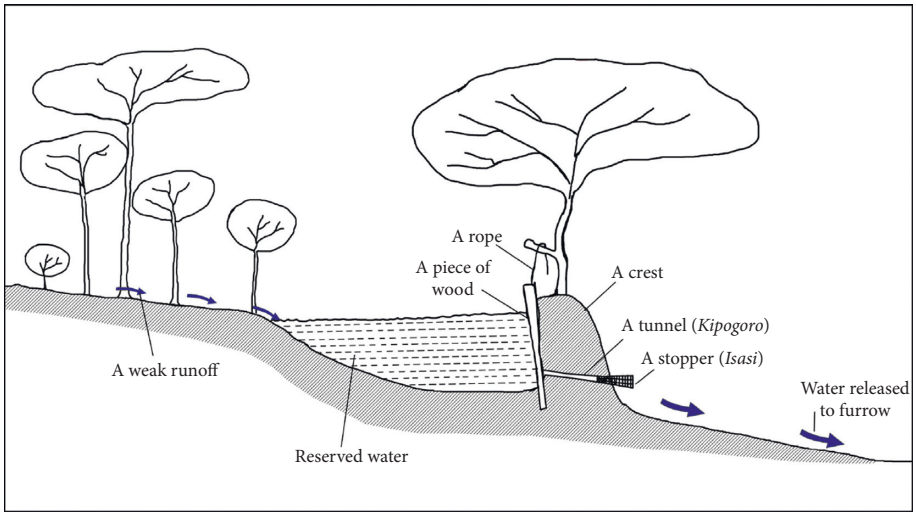

Figure 2: A hand sketch showing traditional reservoir (*Nduwas*) around Mt. Kilimanjaro.

5. Conclusion

Improving agricultural water use efficiency requires diagnosing threats over a broad range of scales. Irrigation sector in Tanzania still needs dramatic changes in order to meet current and future food demand targets. Continued water losses in agriculture production limit equitable distribution of water to other key users and could significantly affect natural functioning of ecological processes. Diverse approaches to reduce anthropogenic and biophysical losses are already familiar to farmers. However, there is a need to investigate how diverse options for agricultural water management can be matched with farmers' local conditions. We suggest that development of these options should be conducted in a participatory way between farmers and other stakeholders. Improving water supply in cropping field is possible without significant increase of abstraction rates. Nevertheless, there is a need for water managers and local farmers in Tanzania to improve coordination of adaptation measures that are based on sound science.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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