European Journal of Sustainable Development Research
2024, 8(1), em0242
e-ISSN: 2542-4742
https://www.ejosdr.com

MODESTUM

Review Article **OPEN ACCESS**

Watershed management in Ethiopia and its effects on soil quality and productivity

Fekede Terefe Gemeda [1*], Bedane Shata Gemeda [2], Teshale Sori [2]

[1] Center of Environment and Development, College of Development Studies, Addis Ababa University, Addis Ababa, ETHIOPIA
[2] Addis Ababa University, Addis Ababa, ETHIOPIA
*Corresponding Author: fekekio@gmail.com

Citation: Gemeda, F. T., Gemeda, B. S., & Sori, T. (2024). Watershed management in Ethiopia and its effects on soil quality and productivity. *European Journal of Sustainable Development Research, 8*(1), em0242. https://doi.org/10.29333/ejosdr/13890

ARTICLE INFO

Received: 24 Jan. 2023

Accepted: 31 Aug. 2023

ABSTRACT

Indigenous peoples have utilized watershed management techniques for ages. It has substantial ramifications for improved productivity and improved soil management. This essay examined Ethiopia's soil quality and production improvements as they relate to watershed management strategies. In particular, the roles of the government and other partners who started soil and water conservation initiatives are described. These initiatives had unsatisfactory or unsuccessful results because the community was not involved, the land was held insecurely, there were disincentives, and the planning units were too large. Ethiopia's Federal Democratic Republic has copied community-based participatory watershed management. It has had a great impact on the restoration of highly damaged areas and provided local populations with a source of income. For instance, Amhara, the Oromia, and Tigray Regional States' well-managed watersheds of the Abraha Atsbaha, Gerebshelela, Bechyti, Goho Cheri, Kereba, and Bedesa Kela rivers have boosted agricultural incomes and food security. Additionally, the environmental soundness, commercial feasibility, and social acceptability of watershed management must be assessed.

Keywords: water shed management, conservation wetlands, environmental management, land, soil quality, productivity

INTRODUCTION

Since the evolution of *homo sapiens*, people have utilized natural resources for economic extraction (Tedla & Lemma, 1998). Since then, natural resources such as water and soil have been crucial for the existence of life on Earth (Tullu, 2011). Archaeological records dating back to the early Mesopotamian, Babylonian, Assyrian, and other cultures revealed a friendly relationship between soil fertility or quality and civilizations. However, due to soil degradation, those early civilizations vanished (Tullu, 2011). It has been shown that developed economies, which make up approximately 20% of the world's population, consume 80% of their own natural resources, while developing countries, which contain 80% of the world's people, use only 20% (Tedla & Lemma, 1998). Thus, it is essential for sustainable development that natural resource conservation, protection, and equitable distribution among countries be practiced.

Almost 80% of Ethiopia's population relies on agriculture and other natural resources to raise their standard of living (Mamo, 2015). With an average annual soil loss due to farmland activities of 42 tons per ha (Hurni, 1993; Tullu, 2011) and the maximum soil loss of 300 tons per ha per year country's highlands that support 88% of the human population, 60% of livestock, and 90% of the area (Hurni, 1993). The 1,493 hectares (45%) and 1%-2% yearly soil loss that result in productivity loss from farmlands, respectively, mean that topsoil may well be overrun within 100-150 years if it continues (Hurni, 1987; Tullu, 2011).

To accomplish this, the Ethiopian government has been instituting sustainable management of natural resources, particularly watersheds, since the 1960s (Chimdesa, 2016; Tedla & Lemma, 1998), and this impetus increased in the 1970s due to development and sustainability initiatives. As a result, watershed management is critical for improving soil quality and agricultural productivity, as well as safeguarding and protecting the environment for the world's long-term development.

This review article used a review methodology that involved a methodical investigation of ideas and strategies for managing watersheds and their effects on Ethiopia's soil quality and agricultural output. Also, the analytical framework concentrated on native expertise of a Borena Oromo culture on integrated resource management, particularly that which was discovered in meticulously researched publications and thesis works. In general, logical justifications and findings from the literature that had undergone critical assessment were included in the critical review. In light of these consequences for Ethiopia's agricultural output and soil quality, the critical evaluation concentrated on the fundamental principles of watershed management.

CONCEPTS OF WATERSHED MANAGEMENT, SOIL QUALITY, AND PRODUCTIVITY

Watershed is the hydrological, social, political, and ecological entity that provides rural dwellers support for various social, economic, and livelihood needs (Wani et al., 2008). Community participation in the form of micro-watershed management is a facet of community-based watershed development or management. It helps to maximize livelihood and human development through the use and conservation of land, water, and vegetation at household and micro-watershed levels (Assefa, 2011; Bewket, 2003). Effective resource conservation and improved rural livelihoods have been accomplished as results of integrated and/or community-based watershed development (Assefa, 2011; Bewket, 2003).

As a corollary, watershed management is vital for the prudent use and conservation of land, water, and vegetation resources. It has developed to ensure that both social and natural capitals are being used efficiently. It gives smallholder farmers a way to achieve food security through sustainable land management and scientific innovations (Darghouth et al., 2008; Gashaw, 2015). Additionally, it promotes the rehabilitation of degraded land and prepares it for development.

Watershed management is the smart use of natural resources to attain higher efficiency with the least amount of ecological degradation. In the past, the concept of watershed management was primarily focused on the control of resources in medium- or large-scale river valleys in order to slow down excessively rapid runoff, inordinate soil erosion, and high rates of reservoir siltation, together with deleterious blast flooding in river courses (Tadesse, 2016). And nowadays, the central goal of watershed development or management seems to be to take action to conserve water and soil in order to enhance ecosystems and satisfy human demands (Tadesse, 2016). Therefore, the effective and efficient management of biodiversity and the improvement of rural people's standard of living are crucial for the success of watershed management. Catchments may be divided up into sub-watersheds (30-50 km^2), mini-watersheds (10-30 km^2), micro-watersheds (5-10 km^2), and implementation areas (500-5000 ha), based on the size of the hydrological unit (Wani et al., 2011). Thus, for efficient resource management and sustainability of environmental services, micro watersheds or limited watershed areas are recommended.

According to Larson and Pierce (1991), and Papendick (1991), soil quality is defined as improved agricultural productivity, which includes both animal and plant production, with the ultimate goal of sustaining human health (Doran & Parkin, 1994; Doran et al., 1996; Larson & Pierce, 1991; Mekonnen, 2014; Papendick, 1991). According to many studies (Regassa, 2007), soil quality is largely defined by its soil organic matter (SOM) and soil organic carbon (SOC), with the latter serving as a source of energy and nutrient for soil biota (FAO, 1984; Regassa, 2007).

Soil quality is defined as the soil's ability to supply nutrients (SOM, SOC, potassium, calcium, phosphorus, and others); maintain optimal physicochemical conditions for plant growth; promote and sustain crop production; provide a suitable habitat for soil organisms; resist degradation; and improve human and animal health. Although it is not everything, productivity ultimately becomes absolutely everything. Productivity, however, is a function both of technological advancement and efficiency advancement (e.g., economies of scale, learning-by-doing, capacity utilization, and spillovers) (Isaksson et al., 2005).

Since productivity is crucial for improving living standards or welfare improvements, alleviating poverty, ensuring a safe environment, and stimulating economic growth, United Nations Industry Development Organization (UNIDO) has focused on this facet of growth (Isaksson et al., 2005). Obtaining maximum output (efficiency), substantial cost savings in production, and a change in living standards are now all indicated by the notion of productivity (OECD, 2001). If the resources have been used efficiently through effective watershed management in the ecosystem, productivity appears to be crucial for economic prosperity, welfare gains, poverty reduction, and sound environmental conditions. The social, economic, and institutional factors that seem to be engaged both inside and outside the watershed are symbolized by the two sides of the coin that are utilized to develop or manage the watershed (Adane, 2010). In order to give recommendations for selecting suitable management options within social and economic aspects, watershed management often includes a variety of elements from forestry, agriculture, hydrology, ecology, soils, physical climatology, and other sciences (Achouri, 2002).

COMPONENTS, THEORIES, OR APPROACHES OF MANAGING WATERSHED

Crop diversification and intensification, on-farm and off-farm agricultural activities, integrated pest and nutrient management, in-situ and ex-situ land and water use and conservation practices, and capacity building are the components of watershed management (Wani et al., 2008). It is a combined approach with a consortium architecture that integrates technologies with a focus on institutions, governments, and non-government groups (**Figure 1**).

The primary goal of the watershed management program is soil and water conservation. Ex-situ watershed management and in-situ management can both be decent alternatives for soil and water conservation techniques. Ex situ watershed management deals with the construction of dams, ponds, gully control structures, and pit excavation across the stream channel to reduce peak discharge. In-situ management is concerned with land and water conservation practices,

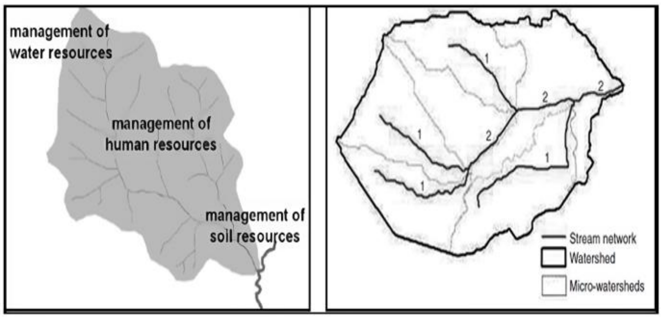

Figure 1. Component of watershed management (Schütt, 2004; Wani et al., 2011)

Figure 2. Contour trash line Arba Minch Jinka, Karat Town (EPA, 2004)

including contour bunds, graded bunds, field bunds, terrace building, broad bed and furrow practice, and other soil-moisture maintenance practices (Bationo et al., 2006). On the other hand, in the vicious and virtuous loops of land degradation and fertility management, the vicious cycle argues that a lack of knowledge causes an absence of resource management, which results in land degradation, but the virtuous cycle asserts that an increase in knowledge leads to an improvement in soil management and improved livelihoods (Bationo et al., 2006).

In Ethiopia, in-situ watershed management is prioritized upon ex-situ watershed management. To improve soil quality, production, and productivity in Ethiopia, integrated uses of in-situ and ex-situ watershed management are required. Furthermore, the county's management of fertility and land degradation is more characterized by a vicious cycle than a virtuous cycle. For improved soil quality, improved productivity, and improved livelihoods for the community in the country, effective and efficient utilization of integrated in-situ and ex-situ watershed management as well as virtuous cycle of land degradation and soil fertility management are important.

EVOLUTION OF WATERSHED MANAGEMENT IN ETHIOPIA

Ethiopian farmers have developed their own conservation efforts at the farm level as a consequence of a lengthy realization of the problem of soil degradation. However, a rigorous assessment of indigenous knowledge in land management by Kruger et al. (1996) showed that policymakers and professionals in soil conservation had a poor track record and a lack of regard for indigenous practices (Taye, 2014). This corroborates with Reij's (1991) research, which revealed that Ethiopian scholars and practitioners had given less attention to indigenous soil and water conservation (Taye, 2014). These emphasize the importance of focusing on soil conservation and farmers' indigenous practices in order to protect ecosystem services for future generations.

A few studies on watershed management showed that this was not a recent occurrence in Ethiopia (Chimdesa, 2016). However, most of this indigenous knowledge has not been given the spotlight it needs, and as a result, it has not been incorporated into methods for managing watersheds. The key indigenous conservation measures used by different ethnic groups in Ethiopia are described in detail in the following sections of the text.

INDIGENOUS CONTOUR MANAGEMENT IN ARBA MINCH

Sorghum is mostly cultivated on the area's typical steep, hilly landform with moderately shallow soils. Straw and sorghum stalks have been cultivated on the contour's lower slope exactly as "contour trash lines" (**Figure 2**). Trash line contour farming has been used across a large area from Arba Minch to Jinka in Karat Town as a popular method of soil and water conservation (EPA, 2004).

BORANA-OROMO INDIGENOUS NATURAL RESOURCES MANAGEMENT

Borana Oromo Gada system laws (Seeraa Gadaa) have specific regulations and rules that regulate how natural resources are managed. The principles concern the appropriate use of communal rangelands, water sources, and forests (**Figure 3**). The typical structures of the Borana laws for managing rangelands and other environmental assets often start at the bottom point of the organogram and are known as Warra, Ollaa, Ardaa, Reera, Madda, and Dheeda (Godana, 2016). Like with the trustee of each well (Abbaa Konfii), the coordinator of water use and maintenance (Abbaa Herregaa), and other members, the wells (Eelaa) are, for illustration, strictly regulated and managed by retired special counselors or individuals called (Hayyuu), a local lineage of clan elders or special messengers (Jallaba), and many others. The rights to diverse water sources, notably wells, ponds, and rivers, are clearly established (Tache & Irwin, 2003).

The council of elders (Jaarsa Deedhaa) is mainly accountable for managing the grazing resources. The general assembly of the Borana political system is carried out in the assemblies of Kora, which could be considered relying on grazing territory (Kora Dheedaa) or the users group right on a well (Kora Eelaa) at Madda, Reera, Olla, and even outside of these areas. Decisions on Kora associated with resource management are enforced once the general agreements are reached. The second level of Gumi Gayo's Pan-Borana General Assembly results every time all of Borana's laws, including those governing resource management, are made public

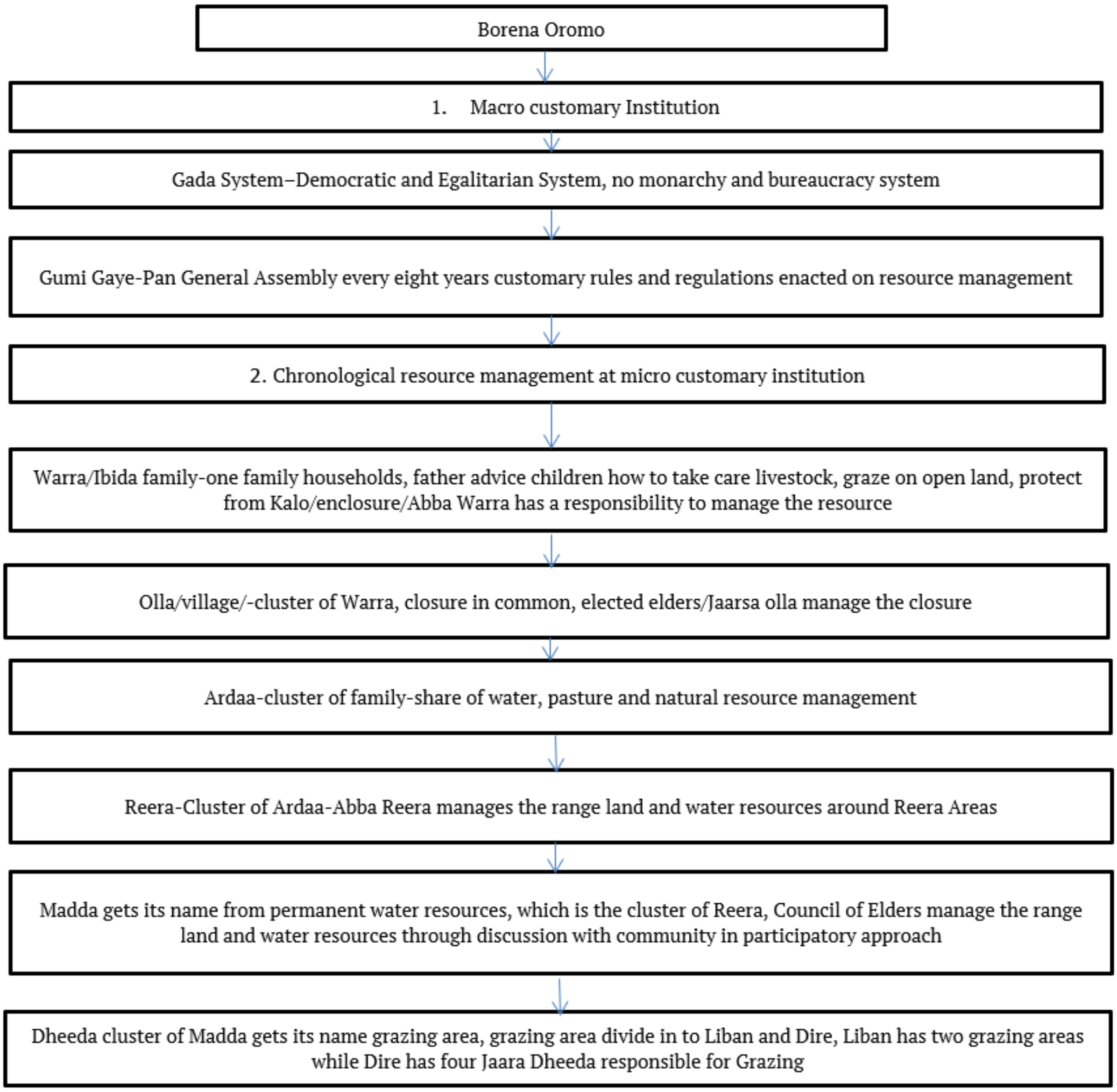

Figure 3. Borena Oromo indigenous knowledge of resource management (Chimdesa, 2016c ; Doyo, 2011)

(Chimdesa, 2016). As a result, the native management of the Borena watershed was long-standing or immoral, and further research is needed to establish if the practice of resource management is beneficial in improving the country's valuable ecosystem services.

Gedeo Zone is a 1,347 km^2 South Nation Nationalities People (SNNP) area with a population of 773,514 people (EPA, 2004). Gedeo people basically live in a home garden land use system on production slopes as steep as 80 degrees. Agroforestry development activities are one of the greatest ways to mitigate the effects of climate change on the zone's drought, with approximately 86% of the total population of the zone residing in rural areas. Numerous different types of vegetation and crops, notably cordia africana, coffee arabica, enset ventricosum, and a variety of root crops, cover particular plots of land.

The findings indicate that the Neolithic, or New Stone Age, around 5000 years ago dates back to when the Gedeo indigenous agro-forestry system first started to evolve naturally (Kippie, 2002). Unexpectedly, Gedeo people had safeguarded and conserved their natural resources and culture through their lengthy Ballee management system (Chimdesa, 2016). Evergreen forests, better environmental gardening, agro-forestry, and biodiversity are the results of well-conserved biological measurements of soil and water resources (**Figure 4**).

Figure 4. Gedeo multistory agro forestry system (Chimdesa, 2016c; Tadesse, 2010)

Figure 5. Konso indigenous hill side bench terrace (Tadesse, 2010)

Furthermore, Gedeo agroforestry system offers a wide range of crops, spanning from short-lived annual herbs to long-lived multipurpose trees (over a century old), such as medium-aged ensete and coffee (EPA, 2004). Thus, this local indigenous knowledge has contributed significantly to the sustainability of the region's environmental services.

KONSO'S INDIGENOUS TERRACE BUILDING

Southern Nations, Nationalities, and People's Region includes the Konso district (SNNPR). Indigenous soil and water conservation (SWC) practices have long been used in the area. It is a special terrace made out of amazing stones that really is 2,354.3 km^2 in size and sustains over 212,235 households, or roughly 80% of a district (EPA, 2004). Konso people's bench terraces' indigenous knowledge goes back more than 400 years (Chimdesa, 2016). As a result, this creative indigenous and noble work culture gained Konso people the UN Prize in 1995, and UNESCO designated their territory as an UNESCO Cultural Heritage Site in 2010 (**Figure 5**).

Ethiopia has a rich historical perspective on the management of natural resources in a watershed setting. The indigenous knowledge and experiences of country's economic communities might offer critical role models for other communities around world. So, it follows that indigenous knowledge of natural resource management from the Borena Oromo range land management, Konso terrace development, Gedio agro-forestry, and other places was applied to develop watershed management practices in Ethiopia.

EVOLUTION OF MODERN WATER SHED MANAGEMENT

Since agriculture first arose 5,000 years ago to benefit from agriculture and manage flooding and droughts, watersheds have evolved (Chimdesa, 2016). However, modern watershed management began with development of irrigation infrastructure in China on banks of Yellow River, in fertile Near East along Nile, Indus, Tigris, and Euphrates rivers (Mesopotamia, Iraq), in Greek and Roman urban centers with urban water systems, and in Mediterranean landscapes with hillside terracing and tree planting on slopes (Darghouth, 2008).

Since the 1992 Rio de Janeiro Earth Summit and the United Nations Conference on Environment and Development (UNCED), the principle of watershed management has gained worldwide recognition (Forch & Schutt, 2004). Watershed management is being addressed more and more in emerging economies as a method for long-term rural development (Alemu & Kidane, 2014). The historical perspective of current watershed management in Ethiopia was then relatively akin to that of other emerging economies (**Figure 6**), since most natural resource legislation has been enacted since the mid-1960s (Dessalegn, 1998). Ethiopia's famine in 1974-1975 served as a catalyst for the country to start safeguarding its natural resources (Alemneh, 2003). Similarly, as a result of the severe drought of 1972-1973, the need to begin land degradation caused by soil erosion was realized (Chimdesa, 2016). Prior to 1974, Ethiopia's government did not have a policy on natural resource management (NRM) or soil and water conservation (SWC) (Berhanu & Simane, 2015).

In Ethiopia, the consciousness of land degradation, particularly soil erosion, and the commencement of its conservation date back to 4000 BCE (Gedeno, 1990). Other researchers observed in **Figure 7** that watershed management started in 1971 and has offered a wide range of advantages, like boosting production and productivity, restoring natural land, and improving local community livelihoods in drought-prone areas (Gebregziabher et al., 2016). Hence, there is still contention that different scholars were not able to agree on the exact time when Ethiopia started implementing the first soil and water conservation efforts.

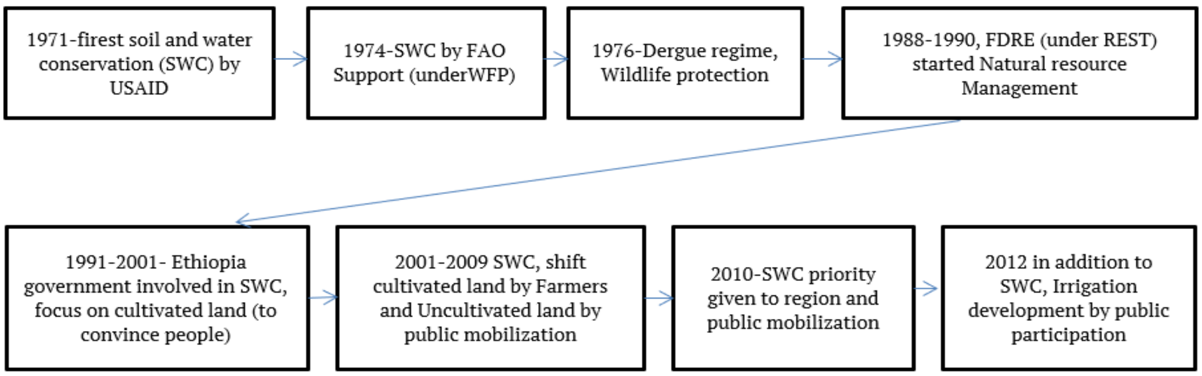

Figure 6. History of watershed management in Ethiopia (Woldearegay, 2012)

1976-1988	Area constructed	1976-1990	Area constructed	1971-1993	Area constructed	1980-1994	Area constructed	PASDEP(2004-2010	Area constructed	GTP 2011/2012	Area Constructed
Soil and stone bonds on cultivated land	800,000 ha	Soil and stone bonds on cultivated land	71,000 ha	Soil and stone bonds on cultivated land	700,000 ha	Soil bonds and hill side terrace	1,045,130 ha	2004/05 plantation of multipurpose trees	0.82 million ha	Rehabilitated degraded land through community participation (EPA, 2012)	About 6.8 million ha
Hill side terrace	600,000 ha	Hill side terrace	233,000 ha	Hill side terrace	289,504 ha	Check dams and cut off drains covered by afforestation and closures	17,880 ha	2009/10 plantation of multipurpose trees	3.77 million ha		
Closure for steep slope regeneration & reforestation	80,000 ha	Bench terrace	526,425 ha	Pant seedlings	955.98 ha	Small earth dam	1,259,760 ha				
-		Plantation of different tree species	448,000 ha	Closed off for recovery vegetation	1,105,939 ha						
-		Construction of check dams in gullied lands	12,000 ha								
-		Closure area for natural regeneration	390,000 ha								

Figure 7. Watershed management practices in Ethiopia (1971 to 2011/12) (Compiled by researcher, information acquired from Abelieneh, 2011 about SWC from 1976-1990; Constable & Belshaw, 1989 about SWC of 1976-1988; about SWC of 1971-1993 & Asnake, 2016 about SWC of 1980-1994 and EPA, 2012 about WSM in GTP I)

EMPIRICAL STUDIES ON WATERSHED MANAGEMENT, SOIL QUALITY, AND PRODUCTIVITY

Under the auspices of the Ministry of Agriculture, a watershed development and conservation program began in the 1970s with an emphasis on soil and water conservation (Desta et al., 2005; Hurni, 1988). It then gained attention during the drought-related starvation and malnutrition catastrophes of 1984-1985. Since then, 116 watersheds have indeed been formed on almost 1.5 million hectares using various techniques in soil and water conservation (Chimdesa, 2016). Watershed management was therefore viewed as a method for increasing the productivity of the land by restoring natural resources (Desta et al., 2005; Gete, 2006). The debate over watershed management, which was first intended to reduce soil and water degradation, has since developed into a sustainable method of increasing production via cost-effective and ecologically friendly ways (Alemu & Kidane, 2014). To increase the efficiency of farmland, the Ethiopian government was using a variety of mechanical and biological soil and water conservation measures in cooperation with foreign contributors (Alemu & Kidane, 2014).

Soil erosion has been reduced to a maximum tolerable value of 10 t ha^{-1} $year^{-1}$, compared to estimates of 36.6 to 165.6 t ha^{-1} $year^{-1}$ in the United States (Mitchell, 1978) and 6 to 12 t ha^{-1} $year^{-1}$ in Argentina (Buck,1993). Hurni (1993) assessed the soil loss from Ethiopia's cultivated areas as a result of erosion to be approximately 42 t ha^{-1} yr^{-1}. However, other studies showed that soil erosion occurred frequently, spanning from 17 t ha^{-1} yr^{-1} to 176 t ha^{-1} yr^{-1} (Herweg & Stillhardt, 1999). The mean rate of soil loss globally is 15 t ha^{-1} yr^{-1}, while in Africa it really is 9 t ha^{-1} yr^{-1} (Beyene, 2010). Furthermore, it is crucial for Ethiopia to work very hard on watershed management for soil security, soil quality, and soil productivity for the country's environmental sustainability. Food security, biodiversity protection, ecosystem service delivery, energy sustainability, mitigation of climate change, and other variables all rely on the security and quality of the soil (McBratney et al., 2012).

The famine of 1973-74, exacerbated by work with the Relief and Rehabilitation Commission on food-for-work (FFW) conservation measures supported by the European Economic Commission, UNDP, and FAO in the sovereign country, was the catalyst for the beginning of the environmental movement (Getachew, 2005). FFW-based conservation activities in the 1984-1985 famine bolstered environmental activities (Slegers et al., 2004) (**Figure 1**).

Incentives in the form of compensation for labor as direct economic incentives, either FFW or, in some cases, cash-for-work, were offered by international donors of FFW program in Ethiopia between 1976 and 1988 and 1976 and 1990, etc. Moreover, the bulk of conservation measures in rural areas were physical measures applied to both communal holdings and farmer plots (Demeke, 2003). Additionally, the Fanya-juu terrace's structural measures, which were augmented with vetiver and elephant grass, showed that Fanya-juu with elephant grass produced a higher yield than Fanya-juu with vetiver grass (309.6 g/m^3) and unconserved (207.9 g/m^3) land (Debie, 2014). Nevertheless, compared to land without those structures, research findings showed that grass strips, bench terraces, and fanya juu all dramatically decreased soil loss by 40%, 76%, and 88%, respectively (Asnake, 2016). Therefore, the country's soil quality has improved, and its productivity has expanded as a result of the soil and water conservation measures.

The failure of large-scale watershed planning for 30 to 40 thousand hectares and the lack of local social inclusion in the management of the projects have been the roots of watershed management failures in Ethiopia (Berhanu & Simane, 2015). Due to inadequate funding for monitoring and evaluation and an absence of institutional systems that facilitate watershed management project monitoring and evaluation, the effectiveness of watershed management in Ethiopia was really only weakly assessed (Wassie, 2000). Extensive soil and water conservation programs implemented by Dergu regime were ineffective due to poor planning, poor building design, a lack of community engagement, ineffective conservation measures, poor interconnection to the poor's subsistence methods, and a lack of an integral approach that goes beyond soil conservation to address intertwined productivity (Menale et al., 2009).

In line with this, FAO carried out a pilot study on nationwide watershed management from 1988 to 1991. The study's findings underscore the shortfalls of large-scale waterways from the 1970s and 1980s and the lack of community engagement in project management in the past. As a result, FAO initiated a bottom-up approach to watershed management, participatory planning methods, and the use of smaller area units for watershed management (Berhanu & Simane, 2015). As a corollary, in South Gonder, North and West Shoa of Oromia, and some areas of Tigray, North Wello, and Wolaita, participatory land use planning has indeed been started by the Ministry of Agriculture, GTZ, FAO, and SOS Sahel. Furthermore, Ethiopia started releasing community-based watershed development guidelines in 2005 for environmentally friendly watershed development and maintenance (Berhanu & Simane, 2015; Desta et al., 2005). As a consequence, watershed management is effective since it improves local communities' level of living in drought-prone areas, improves degraded land, and improves production and productivity (Gebregziabher et al., 2016).

Broad studies conducted in recent times (mainly in the years 1975 and 1995) also indicated that 28 % of Ethiopia's highlands (14.5 million ha) are severely degraded land, 24% of them (13 million ha) are moderately degraded land, estimates of deforestation range from 150,000 to 200,000 hectares per year, approximately 550,000 tons of dung are set on fire as fuel, and estimates of progressive losses in grain and livestock production due to accelerated soil erosion are expected at 170,000 ha (Abelieneh, 2011). As a result, the country will need substantial watershed management to minimize environmental degradation and consequently improve soil productivity and quality.

In Ethiopia, studies on watershed management for reversing land degradation displayed increased soil erosion and associated downstream siltation, increased vegetation cover and surface roughness, increased soil depth, increased groundwater table recharge, increased production area and green environment, increased crop production and productivity, and enhanced fodder availability (Gashaw, 2015). Conversely, the results of other studies on watershed management in the Ethiopian highlands indicate that watershed management led to ecological sustainability and conservation, sustainable agricultural sector development, and overall economic improvement in the area (Meshesha & Tripathi, 2015).

Higher elevations in Ethiopia have better soil because quasisoils predominate. About seven million ha of the 12 million ha of vertisols in the country are in the highlands, despite the fact that water logging has decreased their productivity (Mamo, 2015). Additionally, 28.1% of the entire country has been affected by severe soil acidities. Furthermore, the Amhara, Oromia, and SNNP regions' 43% of agricultural land is plagued by soil acidity, according to the soil health and fertility for increased agricultural productivity study. Due attention must thus be given to mitigating acidic soils and waterlogging vertisol soils in order to boost national production and productivity in favor of efforts at sustainable development.

Genale watershed's ideal blend of ecological management practices was applied afor soil and water conservation (Negewo & Sarma, 2023). In the highland watershed of Lake Tana Sub Basin of Ethiopia, there is greater erosion during times of heavy rainfall and less erosion during times of light rainfall (Leul et al., 2023). In contrast to forest soils in a tropical sub-humid habitat in western Ethiopia, soil quality indices such as SOM, total nitrogen, calcium, and magnesium were considerably reduced (Leul et al., 2023).

The average soil loss from the government's cultivated land ranges from 21 to 42 t/ha/year (Hurni, 1988; Meshesha & Tripathi, 2015). Additionally, it is estimated that Ethiopia loses 1.5 billion tons of soil per year to erosion (Berhanu & Simane, 2015; FAO, 1984). About 90% of this vast soil loss is discharged in a valley, with the remaining 10% of water flowing to Egypt. Ethiopia's capacity to produce food is severely jeopardized by the deteriorating quality of its agricultural land in the high mountains (Hurni, 1988; Meshesha & Tripathi, 2015). Food insecurity in Ethiopia is thus directly linked to problems with the destruction of natural resources (Meshesha & Tripathi, 2015). To rehabilitate the country's environmental services, watershed development is required.

In the Ethiopian highlands, soil erosion-related land degradation is a major problem. In Ethiopia, it is estimated that 1.5 billion tons of soil erode annually, costing the nation between US$1 billion and US$2 billion (Berhanu & Simane, 2000; FAO, 1984). Various studies have revealed that Ethiopia's highlands are deteriorating in a variety of ways. Around 4% (2 mha) of the country's highlands were considered to be severely eroded and possibly unsuitable for cultivation in the mid-1980s, while 52% of the highlands had moderate to severe degradation (Kassie et al., 2009; Meshesha & Tripathi, 2015). Furthermore, of the estimated 60 million hectares of agriculturally productive land, 27 million hectares had experienced significant loss, 14 million hectares had experienced substantial deterioration, and two million hectares had reached the point of irrevocable loss of resources (Bishaw, 2001; Berhanu & Simane, 2015). Consequently, watershed management is critical for safeguarding our environment and sustaining the standard of living for the vast majority of people.

The country's low agricultural growth is caused by a number of aspects, including severe land degradation, traditional farming methods, farmers' slow adoption of modern technology, low inherent soil fertility, limitations on the use of fertilizers, a lack of comprehensive and available soil fertility information, a lack of human capital, and many others (Mamo, 2015). As a result, the average soil loss in the area was significant, amounting to about 42 t/ha/yr (Hurni, 1993). The quality and productivity of the soil have deteriorated as a result. On the other hand, the findings of various studies show that the use of natural resources exceeds the ecosystem's carrying capacity. The large wetlands drainage of up to 150 springs in Illubabor Metu Woreda, for example, was dried up as a result of vast irrigation development projects that precipitated the conversion of pastoral lands into cotton production in the Awash valley (Abebe & Geheb, 2003; Berhanu & Simane, 2015). Therefore, it's indeed necessary to apply watershed management measures to balance the unprecedented population growth, which has surpassed the carrying capacity of ecosystem services.

In East Gojjam of Ethiopia, according to Abelieneh's (2011) study on community-based watershed development for climate change adaptation in Choke Mountain of the Upper Muga Watershed, the status of livelihood resources including biophysical and financial resources like income, soil fertility, land productivity, forest, water, and food supply improved after the intervention of watershed development in the area. As a consequence, after the intervention of watershed development, the reconstruction and rehabilitation of the livelihoods of the inhabitants of the region were improved.

The practices used to manage the watershed are key to limiting runoff and reviving dried springs. Due to this, a pilot watershed management project was implemented in 2006 in Ethiopia over 297 km of degraded hillside area, 27,783 trenches, 446 m^3 of gabion, 3167 m^3 of stone check dam, 854 m^3 of sediment storage, 586 m^3 of gully rehabilitation or re-vegetation, 80 ha of bund stabilization, and 25 km of recharge pits (AMAREW, 2006; Mekonen & Tesfahunegn, 2011). In 2006, pigeon pea (edible seed), sesbania, and over 77,945 tree lucerne forage seedlings were planted on about 35 ha of closed hillside and 2.5 ha of gullies for the same pilot watershed management practices (AMAREW, 2006).

Additionally, 255,906 multipurpose tree species saplings were planted in Lenche Dima, Yeku, and Gumet in 2006 as part of a watershed conservation practice (AMAREW, 2006). Since then, community livelihood in the community has improved, and degraded areas have been restored owing to watershed management measures. Therefore, effective watershed management is crucial for restoring degraded resources and improving the standard of living in areas of the country that are prone to food insecurity.

Manuring (kosii fi dikee naquu), fallowing (Lafa baasuu), and traditional water ways (Bo'oo baasuu) practices are effects of traditional ways of soil fertility maintenance techniques, according to Damtew's (2011) study on the benefits and challenges of adopting soil conservation techniques in the Goromti watershed of Central Ethiopia. Soil quality and productivity in the area have increased as a result of the rehabilitation of this soil.

A local community's acknowledgement of land degradation can be controlled by using SWC in on-farm and off-farm activity through active community participation and good community participation, according to Dawit's (2014) study on the impacts and impediments of community participation on soil and water conservation to sustainable land resource management in Laelay Machew Woreda of Tigray Region. However, the impact of soil and water conservation on their economic progress is still limited. Even though the farmers have some food stocks for subsistence, this indicates they do not have sustainable food security. Therefore, it is vital for concerned government bodies to examine alternate ways to ensure long-term food security and improved livelihoods for agricultural producers in order to promote local adoption of watershed management practices.

Asnake (2016) showed that a study of the effect of soil and water conservation measures on soil macronutrient and moisture status in Guba-Lafto Woreda of North Wollo in the Amhara Region demonstrates that SWC measures continued to improve the availability of soil macronutrients and moisture status; nevertheless, there is still a lack of awareness on SWC, a land and labor shortage, in addition to the wealth of the farmers, which made it difficult for the households to implement SWC practices on their farmlands. As a result, more research is needed to balance the ecosystem's carrying capacity with the region's unprecedented population growth and to develop rural farmers' SWC capabilities.

According to Mekonnen (2014), studies on the effects of climate-smart agricultural practices on soil quality and crop production in Ambo Woreda, West Shewa, in Oromia Region showed that small-scale farmers experience an improvement in crop productivity in addition to an improvement in soil quality. The study's findings also indicated that the difference found between the intervened farmlands of the CSA (Weli) watershed and the non-intervened farmlands in contexts of soil pH ($p=0.314$), SOC ($p=0.211$), total nitrogen (N) ($P=0.902$), EC ($P=0.211$), Av.K ($P=0.832$), and Av.P ($P=0.096$) was not statistically significant (Mekonnen, 2014). To improve the soil quality in the region, watershed management intervention is therefore needed.

According to Assefa's (2015) study, the factors (e.g., with soil samples for agricultural productivity in the Central Highlands of Oromia Region (in areas of Bako-Tibe, Becho, Gimbichu, Girar Jarso, and Munessa Woredas) for agricultural productivity in Bako-Tibe woreda are low nitrogen thresholds, soil acidity, poor drainage, flooding concerns, and water logging difficulties; low nitrogen and potassium, poor drainage, and soil erosion Therefore, watershed management should be put into action in order to protect the area's soil quality and boost productivity.

According to Gebregziabher et al.'s (2016) study on the impact of watershed management in six watershed areas of Oromia, Amhara, and Tigray, farm incomes and food security were improved by an average of 50% and 56%, respectively; the risk of crop failure due to moisture stress and climate shocks was reduced by up to 30%; and vegetation restoration and land cover were improved by an average of 40% (Gebregziabher et al., 2016). Abraha-Atsbaha and Kereba watersheds are experiencing the most improvement in food security as a result of watershed management, and the risk of crop failure has been reduced by more than 50%, while it has been reduced only by about 10% in the less efficient watersheds (Gebregziabher et al., 2016). Thus, by minimizing the chance of crop failure and enhancing soil quality, watershed management is essential for improving food security in areas that are really prone to poverty.

The results of the study illustrate that efficient upstream-downstream hydrological linkage, the presence of supporting institutional structures, and active community participation in watershed management practices were the driving factors of significant improvement in rural people's livelihoods and the rehabilitation of natural resources (Gebregziabher et al., 2016). Thus, watershed management has a positive impact on increasing productivity and improving soil quality across the country.

CONCLUSIONS

In Ethiopia, knowledge of the benefits of managing the water shed for improving soil production and quality has expanded. However, there really are substantial spatio-temporal variations in the level of awareness and application. Furthermore, native methods for conserving soil and providing shade over water have been effectively integrated into contemporary techniques. Although the concepts of water shed and soil management have indeed been practiced since the beginning of time, there are still a number of issues that need more research and development. Large-scale soil and water conservation programs have historically been largely ineffective due to poor planning, poor structure design, a lack of community participation, inappropriate conservation techniques, poor connections with the poor's livelihoods, and a lack of an integrated approach that went beyond soil conservation to address interrelated productivity.

Watershed management, however, has recently been linked to increased livelihood and the conservation of natural resources. Also, there seem to be strong upstream and downstream hydrological linkages, institutional support, and active community participation in watershed management practices. The country's productivity will increase as a result of better soil quality and watershed management.

Author contributions: All co-authors have been involved in all stages of this study while preparing the final version. They all agree with the results and conclusions.

Funding: No funding source is reported for this study.

Declaration of interest: No conflict of interest is declared by the authors.

Ethical statement: Authors stated that the study was approved by the Addis Ababa University graduate studies with approval code: 2021/22. Authors further stated that they have abided by the institutional and regional laws, rules, and regulations and conducted the research with integrity, fidelity, and honesty.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

REFERENCES

Abebe, Y. D., & Geheb, K. (2003). Wetlands of Ethiopia. In *Proceedings of seminar on the resources and status of Ethiopia's wetlands*. IUCN.

Abelieneh, A. (2011). *Community based watershed development for climate change adaptation in Choke Mountain: The case of Upper Muga Watershed in East Gojjam of Ethiopia* [MSc thesis, Addis Ababa University].

Demeke, A. B. (2003). *Factors influencing the adoption of soil conservation practices in Northwestern Ethiopia*. Institute of Rural Development.

Achouri, M. (2002). Preparing the next generation of watershed management programmes. In *Proceedings of the Asian Regional Workshop on Watershed Management*. ICIMOD.

Adane, Y. (2010). *Integrated watershed development from sustainable livelihood perspective: The case of Terri Watershed in Delanta Woreda, Ethiopia* [MA thesis, Addis Ababa University].

Alemneh, D. (2003). *Integrated natural resources management to enhance food security: The case for community-based approaches in Ethiopia*. FAO, Rome.

Alemu, B., & Kidane, D. (2014). The implication of integrated watershed management for rehabilitation of degraded lands: Case study of Ethiopian highlands. *Journal of Agriculture and Biodiversity Research, 3*(6), 78-90.

AMAREW. (2006). *Amhara micro-enterprise development, agricultural research, extension and watershed management*.

Asnake, B. (2016). *Effect of soil and water conservation measures on soil macro nutrient and moisture status in Guba-Lafto Woreda, North Wollo, Ethiopia* [MSc thesis, Addis Ababa University].

Assefa, E. (2015). *Characterization and classification of the major agricultural soils in CASCAPE intervention woredas in the central highlands of Oromia Region*. Addis Ababa University.

Assefa, S., Kessler, A., & Fleskens, L. (2018). Assessing farmers' willingness to participate in campaign-based watershed management: Experiences from Boset District, Ethiopia. *Sustainability, 10*(12), 4460. https://doi.org/10.3390/su10124460

Bationo, A., Hartemink, A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., & Thiombiano, L. (2006). African soils: Their productivity and profitability of fertilizer use background [Paper presentation]. The African Fertilizer Summit June 9-13, 2006, Abuja, Nigeria.

Berhanu, Y., & Simane, B. (2015). Assessment of the effectiveness of watershed management intervention in Checha Woreda, Kaffa Zone, Southwestern Ethiopia. *Journal of Environment and Earth Science, 5*, 17.

Bewket, W. (2003). *Towards integrated watershed management in highland Ethiopia: The Chemoga watershed case study* [PhD thesis, Wageningen University].

Beyene, A. (2010). *GIS and remote sensing based assessment of causes and risk analysis of flood hazard in Iresha Watershed, Meskan Wereda, SNNPR, Ethiopia* [MSc thesis, Addis Ababa University].

Bishaw, B. (2009). Deforestation and land degradation in the Ethiopian highlands: A strategy for physical recovery. *Ethiopian E-Journal for Research and Innovation Foresight, 1*(1), 5-18.

Buck, L. E. (1995). Agroforestry policy issues and research directions in the US and less developed countries: Insights and from recent experience. *Agroforestry Systems, 30*, 57-73.

Chimdesa, G. (2014). *The impacts of land certification on adoption of long-term soil and water conservation measures: The case of Dadaba Watershed, West Arsi Zone, Oromiya Regional State, Ethiopia* [MSc thesis, Addis Ababa University].

Chimdesa, G. (2016a). Climate change impacts and adaptation actions in Central Rift Valley of Ethiopia: A review. *Journal of Natural Sciences Research, 6*, 3.

Chimdesa, G. (2016b). Ecosystem approach for sustainable natural resources management: A review. *Journal of Resources Development and Management, 19*, 17-22.

Chimdesa, G. (2016c). Historical perspectives and present scenarios of watershed management in Ethiopia. *Review Article. International Journal of Natural Resource Ecology and Management, 1*(3), 115-127. https://doi.org/10.11648/j.ijnrem.20160103.17

Constable, M., & Belshaw, D. (1989). The Ethiopian Highlands Reclamation study: Major findings and Recommendations. In *ONCCP Towards a Food and Nutrition strategy for Ethiopia; The Proceedings of the National Workshop on Food Strategies for Ethiopia, 812 Dec. 1986*. Addis Abeba.

Damtew, A. (2011). *Benefits and challenges of adopting soil conservation techniques in Goromti Watershed, Central Ethiopia* [MSc thesis, Addis Ababa University].

Darghouth, S., Ward, C., Gambarelli, G., Styger. E., & Roux, J. (2008). Watershed management approaches, policies, and operations: Lessons for scaling up. *World Bank*. http://hdl.handle.net/10986/ 17240

Dawit, T. (2014). *Impacts and impedments of commiunity participation on soil and water conservation to sustainable land resource management in Laeley Maichew Woreda, Tigray, Ethiopia'* [Masters thesis, Department of Geography and Environmental Studies, Addis Ababa University, Ethiopia].

Debie, E. (2014). *Integrated soil and water management approach and its socio-ecological implications in Goncha-Siso-Enese Woreda, North-Western Highlands of Ethiopia* [PhD dissertation, Addis Ababa University].

Dessalegn, R. (2001). Environmental change and state policy in Ethiopia: Lessons from past experience. In *Forum for social studies monograph Series 2* (pp. 10-108). Addis Ababa. Ethiopia.

Desta, L., Carucci, V., Wendem-Ageňehu, A., & Abebe, Y. (2005). *Community based participatory watershed development: A guideline*. Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia.

Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. In J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 3-22). Soil Science Society of America. https://doi.org/10.2136/sssaspecpub35

Doran, J. W., Sarrantonio, M., & Liebig, M. A. (1996). Soil health and sustainability. *Advances in Agronomy, 56*, 1-54. https://doi.org/10.1016/S0065-2113(08)60178-9

Doyo, J. (2011). *Indigenous practices of rangeland management: Constraints and prospects in Borana Pastoralists of Southern Ethiopia, Oromia Regional State* [MA thesis, Addis Ababa University].

EPA. (2004). The 3rd national report on the implementation of the UNCCD/NAP in Ethiopia. *EPA*. http://www.epa.gov.et

EPA. (2012). United Nations Conference on Sustainable Development (Rio+20) national report of Ethiopia. *EPA*. http://www.epa.gov.et

FAO. (1984). *Ethiopian highlands reclamation study*. https://www.fao.org/3/ar863e/ar863e.pdf

Forch, G., & Schutt, B. (2004). An introduction to water shed management. In *Lake Abaya Research Symposium Preecedings* (Vol. 4).

Gashaw, T. (2015). The implications of watershed management for reversing land degradation in Ethiopia. *Research Journal of Agriculture and Environmental Management, 4*(1), 5-12.

Gebregziabher, G., Abera, D. A., Gebresamuel, G., Giordano, M., & Langan, S. (2016). *An assessment of integrated watershed management in Ethiopia*. International Water. https://doi.org/10.5337/2016.214

Gedeno, M. (1990). *Sustainability of soil and water conservation practice in Konso Woreda, Southern Nations, Nationalities and People's Region* [Unpublished masters' thesis, Addis Ababa University, Addis Ababa, Ethiopia].

Getachew, A. (2005). *Determinants of land degradation in the Lake Tana Basin and its implications for sustainable land management: The case of Angereb and Gish Abbay Watersheds* [MSc thesis, Alemaya University].

Gete, Z. (2006). Integrated management of watershed experiences in Eastern and Central Africa: Lessons from Ethiopia. In B. Shiferaw & K. P. C. Rao (Eds.), *Integrated management of watersheds for agricultural diversification and sustainable livelihoods in Eastern and Central Africa: Lessons and experiences from semi arid South Asia*.

Godana, D. (2016). The role of indigenous knowledge in rangeland management in Yabello Woreda, Southern Oromia, Ethiopia. *Arts Social Science Journal, 7*, 172. https://doi.org/10.4172/2151-6200.1000172

Herweg, K., & Stillhardt, B. (1999). *The variability of soil erosion in the highlands of Ethiopia and Eritrea: Average and extreme erosion patterns*. Ministry of Agriculture and University of Bern.

Hurni, H. (1987). Erosion-productivity-conservation systems in Ethiopia. In P. Sentis I (Ed.), *Proceedings of the 4th International Soil Conservation Conference* (pp. 654-674). Instituto de Edafologia, Universidad Central de Venezuela.

Hurni, H. (1988) Degradation and Conservation of the Resources in the Ethiopian Highlands. *Mountain Research and Development, 8*, 123-130. https://doi.org/10.2307/3673438

Hurni, H. (1993). Land degradation, famine, and land resource scenarios in Ethiopia. In D. Pimentel (Ed.), *World soil erosion and conservation* (pp. 27-61). Cambridge University Press. https://doi.org/10.1017/CBO9780511735394.004

Hurni, H. (2005). *Decentralized development in remote areas of the Simen Mountains, Ethiopia*.

Isaksson, A., Hee Ng, T., & Robyn, G. (2005). *Productivity in developing countries: Trends and policies*. UNIDO.

Kassie, M., Holden, S., Köhlin, G., & Bluffstone, R. (2009). Economics of soil conservation adoption in high-rainfall areas of the Ethiopian Highlands.

Kippie, T. (2002). *Five thousand years of sustainability? A case study on Gedeo land use (Southern Ethiopia)*. Treemail Publishers.

Kruger, H. J., Berhanu, F., Gebere Michael, Y., & Kejela, K. (1996). *Inventory of indigenous soil and water conservation measures on selected sites in Ethiopian highlands*. Center for Development and Environment.

Larson, W. E., & Pierce, F. J. (1991). Conservation and enhancement of soil quality. In *Proceedings of the International Workshop on Evaluation for Sustainable Land Management in the Developing World* (pp. 175-203).

Leenaars, J. G. B., Eyasu, E., Wösten, H., Ruiperez González, M., Kempen, B., Ashenafi, A., & Brouwer, F. (2016). Major soil-landscape resources of the cascape intervention woredas, Ethiopia: Soil information in support to scaling up of evidence-based best practices in agricultural production (with dataset). *Wageningen*. https://research.wur.nl/en/publications/major-soil-landscape-resources-of-the-cascape-intervention-woreda

Leul, Y., Assen, M., Damene, S., & Legass, A. (2023). Effects of land use types on soil quality dynamics in a tropical sub-humid ecosystem, western Ethiopia. *Ecological Indicators 147*, 110024. https://doi.org/10.1016/j.ecolind.2023.110024

Mamo, T. (2015). Transforming soil health and fertility for increased agricultural productivity: Experience from Ethiopia. *Ministry of Agriculture of the Federal Democratic Republic of Ethiopia*.

McBratney, A. B., Minasny, B., Wheeler, I., & Malone, B. P. (2012). Frameworks for digital soil assessment. In B. Minasny, B. P. Malone, & A. B. McBratney (Eds.), *Digital soil assessment and beyond: Proceedings of the 5th Global Workshop on Digital Soil Mapping 2012, Sydney, Australia*. CRC Press. https://doi.org/10.1201/b12728

Mekonen, K., & Tesfahunegn, G. B. (2011). Impact assessment of soil and water conservation measures at Medego Watershed in Tigray, Northern Ethiopia. *Maejo International Journal of Science and Technology*.

Mekonnen, S. (2014). *The role of climate smart agricultural practices for soil quality and crop production: A case study in Ambo Woreda, West Shewa, Oromia Region* [MA thesis, Addis Ababa University].

Menale, K., Mahmud, Y., & Gunnar, K. (2009). *The role of production risk in sustainable land-management technology adoption in the Ethiopian highlands*. University of Gothenburg.

Meshesha, T. W., & Tripathi, K. (2015). An evaluation of watershed management practice in Ethiopia: A preliminary Review. *International Journal of Environmental Sciences, 4*(1), 24-301.

Mitchell, A. (1978). Development of soil conservation in Victoria. *The Journal of the Soil Conservation Service of N.S.W., 34*(2), 117-123.

OECD. (2001). *OECD manual: Measuring productivity measurement of aggregate and industry level productivity growth*. OECD Publishing.

Papendick, R. I. (1991). *International Conference on the Assessment and Monitoring of Soil Quality: Conference Reports and Abstracts*. Rodale Institute.

Regassa, F. (2007). *Assessment of soil quality in Fantale District, East Shewa, as influenced by land use* [MSc thesis, Addis Ababa University].

Reij, C. (1991). *Indigenous soil and water conservation in Africa*. Gatekeeper Series No. SA27.

Schütt, B. (2004). *Watershed management in the Abaya-Chamo Basin, South Ethiopia*. Geographie Heft.

Slegers, M., Selamyihun, K., Hospes, O., & Stroosnijdeg, L. (2004). Land tenure and soil and water conservation adoption in Ethiopia. In S. Kidanu (Ed.), *Using eucalyptus for soil and water conservation on the highland Vertisols of Ethiopia* (pp. 57-68).

Tache, B., & Irwin, B. (2003). *Traditional institutions, multiple stakeholders and modern perspectives in common property: Accompanying change within Borana pastoral systems; securing the commons*. https://pubs.iied.org/sites/default/files/pdfs/migrate/9238IIED.pdf

Tadesse, L. (2016). *Assessing the impact of watershed development programs on soil erosion and biomass production using remote sensing and GIS: The case of Yezat Watershed, West Gojam Zone of Amhara Region, Ethiopia* [Msc thesis, Addis Ababa University].

Tadesse, M. (2010). *Living with adversity and vulnerability: Adaptive strategy and role of trees in Konso, southern Ethiopia* [Doctorial thesis, Swedish University of Agricultural Science].

Taye, A. (2014). *The role of indigenous knowledge and practice on water and soil conservation management in Albuko Woreda, South Wollo, Ethiopia* [MA thesis, Addis Ababa University].

Tedla, S., & Lemma, K. (1998). Environmental management in Ethiopia: Have the national conservation plans worked? *Organization for Social Science Research in Eastern Africa*. http://www.ossrea.net/publications/images/stories/ossrea/part-1-env-1.pdf

Negewo, T. F., & Sarma, A. K. (2023). Sustainable and Cost-Effective Management of Degraded Sub-Watersheds using Ecological Management Practices (EMPs) for Genale Basin, Ethiopia. *Journal of Hydrology, 619*, 129289. https://doi.org/10.1016/j.jhydrol.2023.129289

Tullu, T. (2011). *Soil and water conservation for sustinable agriculture*. Mega Publishing and Distribution Plc.

Wani, S. P., Joshi, P. K., Raju, K. V., Sreedevi, T. K., Wilson, M., Shah, A., Diwakar, P. G., Palanisami, K., Marimuthu, S., Ramakrishna, Y. S., Meenakshi Sundaram, S. S., & D'Souza, M. (2008). *Community watershed as growth engine for development of dryland areas–Executive summary*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

Wani, S. P., Rockström, J., & Sahrawat, K. L. (2011). *Integrated watershed management in rainfed agriculture*. Taylor & Francis. https://doi.org/10.1201/b11424

Wassie, B. (2000). *Project planning, implementation and evaluation*. Kenya, United Nations Center for Regional Development, Africa Office.

Wassie, B. (2000). *Project planning, implementation and evaluation*. Kenya, United Nations Center for Regional Development, Africa Office.

Woldearegay, K. (2012). *Cost and benefit of catchment management and regreening in Tigray*. Mekelle University.