11 Soils and Society

Kibebew Kibret, Girma Abera, and Sheleme Beyene

Abstract

Humans and soils have been intricately linked since antiquity, for soil touches people's lives in many ways, including serving as the source of food and clothing, and for its multiple ecological services, such as filtering drinking water and maintaining environmental health (for which it is often called 'a geologic kidney' by environmentalists). It has influenced the rise and decline of many civilizations across the world. However, improper use and management of this basic natural resource have led to its gradual degradation with consequent loss in capacity to function. It influences human life in many ways that include, but not limited to, wealth, nutrition (quantity as well as quality of food), and health. It affects human health directly or indirectly and positively or negatively. The indirect effects come from the food produced on soils since the nutritional value of many foods is markedly influenced by the soil's ability to supply essential nutrients to food systems and most of the elements that are essential for plants are also essential for human health. The direct effects could come from the exposure of humans to soil contaminated by various chemicals and pathogens through ingestion, inhalation or absorption. Geophagy, the habit of eating soil, is often one way through which humans ingest soil. The harmful substances and pathogens as well as deficiencies of nutrients could be causes of many diseases of complex nature. The soil materials to which humans could be exposed include heavy metals, organic pollutants, toxic materials in fertilizers and other agro-chemicals such as pesticides and herbicides, radioactive materials, pathogens, and polluted water. On the positive side, soils have been the origins of a large number of medicines (e.g., antibiotics) that are used for curing or treating a large number of human health problems. In Ethiopia, where agriculture is the main stay of the economy and supports the livelihood of about 79% of the population, soil is a strategic resource. However, unwise use and improper management have exposed it to degradation of intense nature, reducing its capacity to support life systems and exposing the country to persistent struggles to ensure food security. Fertility depletion is among the challenges the country has been facing since many decades, leading to the production of food that is both insufficient and nutrient-poor. Most of the beneficial physical, chemical, and biological soil attributes are below their expected threshold levels and thus the soils are unhealthy. The country carries the greatest burden of many of the soil-transmitted diseases such as helminths and podoconiosis. Most of the cultivated soils require restoration interventions that help them regain their quality.

Keywords

Civilization • Degradation • Geophagy • Health • Nutrients • Wealth

11.1 Introduction

The global demand for considerable increases in agricultural production is ever-growing to meet food and energy requirements, together with access to the necessary resources. Soil is one of the most important resources over most of human history as people got most of their food from plants grown in soils (McNeill and Winiwater 2010). Humans interact with soils in the process of crop and livestock production through continued plowing, overgrazing,

K. Kibret (✉)
School of Natural Resources Management and Environmental Sciences, Haramaya University, P.O. Box 138 Dire Dawa, Ethiopia
e-mail: kibebew.kibret@haramaya.edu.et

G. Abera · S. Beyene
School of Plant and Horticultural Sciences, Hawassa University, Hawassa, Ethiopia

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deforestation, erosion, desertification and use of various agro-chemicals: fertilizers, herbicides, insecticides and fungicides that contaminate and pollute the environment.

Humans and soils have been intricately linked since antiquity, as soil touches people's lives in many ways. Soils have served as foundations for many ancient civilizations and are still playing a pivotal role in modern-day civilizations. Many earlier civilizations began where farming was productive and that depended on the availability of good soil. Historically, highly developed political systems existed around Aksum in the northern part of Ethiopia on productive soils, and the Axumite Kingdom declined probably due to land degradation (Butzer 1981). Wylde (1901) expressed Ethiopia's agriculture as "producing everything that man wants in this world", giving a long list of crops cultivated at Yeju village in the then Wag. Gradual decline in soil fertility, together with a devastating drought, exposed the country to recurrent famine.

Decades of rapid population growth have contributed to soil degradation through over-farming and deforestation (Haile and Teller 2005). As a result, many previously habitable areas have now been transformed into dry lands and deserts (Haile and Teller 2005). Continuously tilled soils coupled with the removal of plant residues depletes OC, total N, available P, K, S and other nutrients and also limits the soil microbial diversity, abundance and activity. A farmer in Alaba district, southern Ethiopia, expressed "we are responsible for making our soils continuously poorer and poorer through removing plant residues from our farms" (Sheleme 2003). The regions with the greatest damage due to soil degradation are also the ones most affected by food insecurity. Certainly, soil degradation results in a higher vulnerability to famine. Soil fertility and wealth are also closely related. Societies that inhabit the fertile parts of the country are relatively better economically and in terms of food security than those that leave on degraded lands of the country.

Sizeable portion of Ethiopian highlands soils are either strongly or moderately acidic, which could be attributed to the inherent soil properties, climate and management practices. Currently, about 43% of Ethiopian soils were classified as acidic soils (EthioSIS 2014), of these about 28.1% of soils in Ethiopia are dominated by strong acid soils (pH 4.1–5.5). On the other hand, poor irrigation water management and operation coupled with the absence of drainage system cause salinization and considerable losses in crop yields.

Soils that provide a healthy, nutrient-rich growth medium for plants will result in adequate concentrations of elements required for human life in plant tissues. Soil type also influences the micronutrient concentration in food items (e.g., Joy et al. 2015; Chilimba et al. 2011). Most Ethiopian soils have fertility issues that can affect food quantity and quality. The soils are generally deficient in major nutrients like nitrogen and phosphorus. Besides, about 94% of the soils are deficient in Zn (EthioSIS 2014). Protein malnutrition, stunting and wasting in children were observed in young children around Hawassa Zuriya, southern Ethiopia, (Abebe et al. 2007) which could be attributed to N and Zn deficiencies in the soils. Application of Zn increased the concentration of Zn in seeds of chickpea (Legesse et al. 2017) and haricot bean (Abay et al. 2015) which in turn resulted in mean weight gain of young children consuming the seeds.

Soils can affect human health positively as well as negatively through their influence on food quantity and quality (Lal 2009). Soils are the origin of many medicines that are used to treat many health problems. Medicines derived from soils include mostly antibiotics, prescription drugs, and cancer drugs (Pepper et al. 2009). On the other hand, there are so many diseases that are associated directly or indirectly with soils. The country carries the greatest burden of the disease originating from soils (Deribe et al. 2017; Davey 2010) with more than one million people affected. Leta et al. (2020) indicated that soil-transmitted helminths are also almost endemic to Ethiopia and are posing serious health problems. Very common among these diseases is Podoconiosis, which is common among barefoot individuals who are in long-term contact with irritant soils of volcanic origin (Deribe et al. 2013a, b; Davey et al. 2007; Price 1990, 1976).

Potential health concerns related to soils are many and may include cancers, respiratory diseases, neurological disorders, diseases of the excretory system, skin diseases and secondary diseases like heart failure, increased susceptibility to infections and others (Nieder et al. 2018). Geophagia practiced by pregnant women on contaminated soil resulted in exposure to toxic minerals, pathogenic microbes, and helminthic infections (Steinbaum et al. 2016). Humans can also be exposed to contaminated soils through ingestion, respiration, and skin absorption or penetration (Brevik 2013). Important radioactive materials in soils that could harm human health upon exposure include radon, isotopes of cesium, cobalt, curium, neptunium, strontium, plutonium, uranium, technetium, tritium, thorium, americium, radium, and iodine, the sources of which can be natural or anthropogenic.

11.2 Soil Resource and Human Interactions

11.2.1 Principles

Human community survival has always depended, and still depends, on certain environmental goods and services. Soil is one of the most important resources over most of human history as people got most of their food from plants grown in soils (McNeill and Winiwater 2010). As human history goes on, its direct dependence on soil obviously increased; at the same time, its impact on soil significantly increased perhaps through eroding, degrading and enriching. Thus, the survival, prosperity and power of almost any given farming community rested on its success in resolving the problem of long-term nutrient depletion/loss. Egypt was the chief exception. There the waters of the annual Nile flood brought a regular nutrient subsidy left behind by receding flood waters on the banks of the Nile (McNeill and Winiwater 2010). Historically, highly developed political systems existed around Aksum in the northern part of Ethiopia until the seventh century. The Axumite Kingdom then declined probably due to land degradation (Butzer 1981). Everywhere, long-term economic trajectories, the ebb and flow of political power and the waxing and waning of populations rested on the successful management of soils.

Soil is so fundamental to human life that it has been reflected for millennia in our languages. However, soil is a very slowly renewable resource, and the use we make of them today as in much of the past-history, is often quite unsustainable. Humans must manage and manipulate soils to utilize them successfully in a sustainable manner. Ethiopia has mosaics of soil resources attributed to the diverse physiographic and climatic conditions, which has made possible the presence of diverse faunal and floral resources (Simachew 2020). Ethiopia's economy primarily depends on agriculture, which in turn is based on soil health and its sustainable use. However, mismanagement of soils leads to widespread environmental problems, soil loss, nutrient decline, acidification, salinization/solidification and overall soil degradation.

Soil degradation is a human-induced or natural process which impairs the capacity of soil to function. For instance, in 3000 BC, the Sumerians built large cities in the deserts of Southern Mesopotamia. Using irrigation, they farmed the desert soils and created large food surpluses that made their civilization possible. But around 2200 BC, the civilization collapsed due to the mismanagement of irrigation water and soils. Irrigating in dry climates can cause a build-up of salt through a process of salinization. When unregulated/excess irrigation water is applied to soils, soluble slats rise from the sub-surface horizon to the surface layer, resulting in a build-up of salinity due to high evaporation in semi-arid and arid areas. This could be a potential problem in irrigated farms of semi-arid and arid parts of Ethiopia, particularly in the vast Rift Valley region.

Humans interact with natural resources and soils in the process of crop and livestock production through continued plowing, overgrazing, deforestation, erosion, desertification and use of various agro-chemicals: fertilizers, herbicides, insecticides and fungicides that contaminate/pollute the environment. Recent studies have shown that rapid land use change and soil fertility degradation have been observed in various agro-ecologies of Ethiopia as human-soil interaction progresses. The shift from a natural ecosystem to a managed ecosystem is the main direction of change (Daniel 2020). The outcomes of these changes are deterioration of soil physicochemical properties, increased soil erosion or soil compaction (Rao and Pant 2001) and land degradation (Khresat et al. 2008; Woldeamlak and Stroosnijder 2003). These land use changes can lead to soil quality deterioration that affects the productivity of the soils and its sustainable use in the future. Overall, despite the close connections we have with soils, many fail to preserve the health of soils for generations to come.

11.2.2 Population Growth Nexus Soil Degradation

Most of the population of Ethiopia are making their livelihoods with soil. This population is growing rapidly over the last several years, on average by about 2 million every year. Decades of rapid population growth have contributed to over-farming and deforestation, which have degraded the environment and undermined development (Haile and Teller 2005). Most researchers believe that the fast-growing population of Ethiopia is playing a significant role in hastening land degradation in a way that the increasing population abused land through deforestation and overgrazing for more cropland and grazing areas, resulting in a loss of soil productivity (Temesgen et al. 2014; Berry 2003; Paulos 2001). Thus, population growth exacerbates land degradation, in line with the classical theory of Malthus. The central tenet of Malthus is "the growth of human population always tends to outstrip the productive capabilities of land resources".

As population increases, more forest lands are converted to agricultural farms. People must travel long distances to find firewood, the principal fuel, which reduces time spent for farming and related activities. Without sufficient firewood in the vicinity, many farmers resort to burning animal dung, instead of using it to fertilize their depleted soil. Without trees to help hold soil in place, the soil erodes from the steep highlands. As a result, many previously habitable areas have now been transformed into dry lands and deserts (Haile and Teller 2005). Pressure from the growing population forces the farmers to cultivate marginal lands and discontinue the use of crop residues to maintain soil fertility (Tilahun et al. 2001). Moreover, the impact of population increase on landholding size led to limiting soil fertility restoration practices such as fallowing, crop diversification and rotation, which in turn resulted in depletion of soil nutrients (Corbeels et al. 2002).

Soil degradation manifests itself through soil erosion, nutrient depletion and loss of organic matter, acidification and salinization (Haile and Fetene 2012; Bewket and Teferi 2009). The current population of Ethiopia is nearly 120 million and is expected to increase at an alarming rate in the years to come. Available evidence shows that, over the last several years, the national land holding size per household has declined. In addition, agricultural soils are moderately to severely degraded, mostly in the Ethiopian highlands, where more than 88% of the country's population lives (Birhanu 2014). Considering the increasing population, land degradation in Ethiopia is bound to proceed at aggravated rates unless significant measures are made in conservation and rehabilitation. Currently, one-third of rural households cannot produce adequate amounts of food to meet their subsistence needs as they cultivate less than half hectares of land per capita (Demise et al. 2010). On top of this, future trends in population growth, corresponding increases in food and energy demand, climate change, and globalization add challenges to agriculturists to develop innovative production systems that are highly productive and environmentally sound (Hanson et al. 2007). Overall, agriculture is known to be extractive and a resource-intensive dynamic enterprise that requires investment, innovation and contemporary knowledge for sustainable production. Therefore, the economic and societal health of any nation is largely based on soil health and sustainable ecosystem function.

11.2.3 Health Cares

Soil is one of the spectacular products of nature, serving as a medium for food, feed, fiber and medicinal crop production; regulation of water resources and health of the environment. It is a habitat for diverse soil microorganisms and regulates atmospheric concentrations. The quality of soil determines the nature of plant ecosystems, the types of wild and domestic animals and the overall capacity of the land to support human society. In addition, any process that takes place in soil has far reaching impact on earth's biosphere and beyond.

The soil is the critical element of life support systems because it delivers several ecosystem goods and services such as carbon storage, water regulation, soil fertility, and food production, which have significant effects on human well-being (FAO 2015; Jones et al. 2013). These ecosystem goods and services are broadly categorized as provisioning, supporting, regulating, and cultural services (Millennium Ecosystem Assessment 2005). Soil is so complex, there are still knowledge gaps, and fundamental research is still needed to better understand the relationships between different facets of soils and the array of ecosystem services they underpin, although enough is known to implement best practices (Smith et al. 2015).

Ethiopia's arable land soils are estimated to be 113 million hectares. The proportion of land under agriculture has been slightly increasing in recent years, with an average of 33.6% in 2018. Major grain crops: cereals, pulses and oilseeds are produced on about 13 million hectares of land in Ethiopia. Small grain cereals and oil seed crops are commonly produced on highland agro-ecologies, where there is severe erosion and high soil fertility degradation. Whereas vegetables, root crops, fruit crops, coffee, khat, hops and sugar cane are produced on about 2 million hectares of land across various agro-ecologies of Ethiopia. Some segments of arable land soils are also allocated for the production of forage and feed crops, although the estimates vary from year to year. Overall major crop production and productivity have been increasing over the last three decades by conversion of other land uses to agriculture, besides the use of improved technologies (fertilizers, improved seeds, etc.). Chemical fertilizers use has been increasing over the last four decades in Ethiopia, from a minimum of 0.1 kg ha^{-1} of arable land in 1961 to a maximum of 36.2 kg ha^{-1} of arable land in 2018. However, still, soil fertility has been steadily declining because smallholder farmers use very low rates of chemical and organic fertilizers.

Soil will continue to supply nearly all foods. All grain crops (cereals, pulses, and oil seeds), forest trees and livestock feeds (grasses, legumes, forage trees and shrubs) grow on soils. Most of the fiber we use for lumber, paper and clothing has its roots in the soils of forests and farmlands. In addition, biomass-feed stocks for fuel manufacturing grow on soils. Furthermore, in the twenty-first century as the population increases, demand for all these products may increase, while the amount of available soil remains constant. Indeed, the resource base has been and will be shrinking because of soil degradation and urbanization. Hence, our understanding and management of soil resources must improve.

Most medicinal plants (trees, shrubs and herbs) grow on diverse types of soils in natural forests. Ethiopia is the origin and/or center of diversity for many medicinal plant species (Endashaw 2007) attributed to the diverse soil landscapes and climates. Most medicinal plants have been produced on fertile soils in forest ecosystems, but currently they are under threat due to soil degradation. The proportion of consumers who rely on harvesting medicinal plants is the highest in the rural area, since collecting them from natural forests is most accessible and cost effective. The greater diversity of medicinal plants found in south and southwestern Ethiopia is a reflection of the biological and cultural diversity (Edwards 2001), high rain fall, dense vegetation cover, and fertile soils. As land degradation becomes the hallmark of Ethiopia, correspondingly medicinal plant species become endangered. In nutshell, soil is the greatest reservoir and the last frontier of biodiversity. It may harbor a wide diversity of organisms that function in the production of various medicines. Most known antibiotics are produced from organisms that were isolated from the soil. For example, Penicillin was a medicine produced from *Penicillium*, a fungus found in soil, while Vancomycin was produced from a bacterium isolated from dirt soils.

11.2.4 Impact of Land Use Types on Soil Fertility Degradation

Land use and land cover (LULC) change is the human modification of Earth's terrestrial surface from existing management of the land or land cover to new management of land or new land cover type (Hailemariam et al. 2016). Land use and land cover change and its management have a significant impact on various soil chemical and physical properties. In Ethiopia, LULC change is mainly dominated by the conversion of natural vegetation to agricultural activities (Fasika et al. 2019; Gashaw et al. 2018). According to FAO (2020), the forest cover in Ethiopia has decreased from 13.3% of the total area of the country (14.69 million ha) in 1993 to 11.4% of the total area (12.54 million ha) in 2016 with an estimated annual rate of change of 0.8% (104,600 ha·year^{-1}). On the contrary, the agricultural land of the country has increased from 27.66% (30.54 million ha) in 1993 to 32.83% (36.26 million ha) in 2016 (FAO 2020). Land use and land cover change in Ethiopia is triggered by the interaction of various demographic, socioeconomic, institutional, and biophysical factors (Birhanu et al. 2019). A plethora of studies have shown that population pressure, widespread agricultural expansion and settlement, rural poverty, inadequate management of common property resources, and land tenure insecurity resulted in land use and land cover change (Ajanaw 2021; Berihun et al. 2019; Fasika et al. 2019; Alemu et al. 2015; Ariti et al. 2015; Bewket and Abebe 2013).

Several studies conducted across various agro-ecologies of Ethiopia revealed that soil pH declined in cultivated/crop lands as compared to forest and grass lands (Daniel 2020; Yifru and Taye 2011). The reasons could be cation nutrients removal by grains and biomasses, as a result, exchangeable acidity and exchangeable aluminum increased in cultivated lands. Moreover, the use of acid forming chemical fertilizers contributes to the decline of soil pH in cultivated soils, and continuous cultivation also enhanced organic matter decomposition and soil acidification. Similarly, the conversion of native forest to crop land and the subsequent cultivation resulted in a distinct decrease in OC and total N content of surface soils (Daniel 2020; Okolo et al. 2019; Yifru and Taye 2011). However, the absence of long-term field trials and the non-existence of OC databases are among the major drawbacks of land use change studies in Ethiopia (Okolo et al. 2019). Soil OC and total N contents of surface soil crop lands declined as compared to grass land and native forest lands in selected Bale highlands (Yifru and Taye 2011; Fantaw et al. 2007) (Tables 11.1 and 11.2, respectively). A study conducted in northwestern Ethiopia showed that OC content of the cultivated land was low as compared to other land uses (Yihenew et al. 2015). The OC content followed the order grassland > cultivated land > *Eucalyptus* woodlot in the upper layer soils of Jaldu area, central Ethiopia (Daniel 2020). *Enset* land use also showed significantly higher OC content as compared to crop and grazing land uses in southern Ethiopia (Bahilu2014). In Kersa sub-watershed, east Harareghe of Oromia region, the highest OC content was recorded under grazing land (1.87%), while the lowest was observed in soils under the fallow land (Table 11.3) (Mulat et al. 2021). The results imply that under the cultivated land use system, losses of OC were not fully compensated by organic matter inputs from the crop residues and any other sources.

11.2.5 Management-Induced Degradation of Soils

Land degradation is a broader concept that includes degradation of soil, vegetation and water resources, and biodiversity/soil organisms degradation therein. According to Paulos (2001) land degradation is a temporary or permanent decline in the productive capacity of the land, or its potential for environmental management. In Ethiopia, natural resources including soils are under the influence of various interconnected factors. These factors include population pressure, agricultural expansion, deforestation, overgrazing, rapid

Table 11.1 Effects of land use types on carbon and total nitrogen at Sinana Dinsho, Bale

Land uses	Total nitrogen (%)				Organic carbon (%)			
	Soil depth (cm)				Soil depth (cm)			
	0–5	5–15	15–30	30–60	0–5	5–15	15–30	30–60
Forest land	0.80	0.50	0.34	0.19	12.95	7.76	4.54	2.86
Grassland	0.44	0.31	0.25	0.17	7.03	4.65	2.31	2.39
Fallow land	0.21	0.13	0.12	0.09	5.71	3.33	2.64	1.72
Cultivated	0.21	0.19	0.17	0.16	2.75	2.45	2.18	1.97
LSD (0.05)	0.07	0.05	0.05	0.03	1.44	0.91	0.69	0.65

Source Yifru and Taye (2011)

Table 11.2 Effects of land use on soil pH, organic carbon (%) and total N (%) (Mean + SE) at Bale highlands

Variables	Depth (m)	Land uses			
		Cropland	Grazing	Native forest	Overall
pH	0.0–0.2	6.03(0.14)	5.63(0.14)	5.59(0.14)	5.75(0.14)
	0.2–0.4	6.00(0.14)	5.55(0.14)	5.10(0.14)	5.55(0.14)
	0.4–1.0	6.11(0.14)	5.53(0.15)	4.91 (0.14)	5.52 (0.15)
	Overall	6.04(0.08)a	5.57(0.08)b	5.20 (0.08)c	
OC	0.0–0.2	5.04(0.43)	6.33(0.43)	6.65(0.43)	6.00(0.25)a
	0.2–0.4	3.67(0.43)	5.17(0.43)	5.08(0.43)	4.64(0.25)b
	0.4–1.0	2.29(0.43)	4.57(0.45)	4.19(0.43)	3.68(0.25)c
	Overall	3.67(0.25)a	5.35(0.25)b	5.31(0.25)b	
Total N	0.0–0.2	0.56(0.04)	0.66(0.04)	0.72(0.04)	0.64(0.02)a
	0.2–0.4	0.38(0.04)	0.54(0.04)	0.55(0.04)	0.49(0.02)b
	0.4–1.0	0.27(0.04)	0.39(0.04)	0.51(0.04)	0.39(0.04)c
	Overall	0.40(0.02)b	0.53(0.02)a	0.59(0.02)a	

Source Fantaw et al. (2007)
Means followed by the same letters across rows and columns (last column) show non-significant difference at $p < 0.05$

Table 11.3 Means of soil quality parameters' scores in the different land use types in Kersa sub-watershed, East Harareghe, Oromia

Land use type	Clay	Sand	WSA	OC	CEC	pH	BD	Av. P	SQI
Grassland	0.93	0.91	1.00a	0.24a	0.84a	0.51b	0.86a	0.29a	0.69a
Cropland	0.90	0.91	0.98b	0.11b	0.67b	0.50b	0.78ab	0.15b	0.62b
Fallow	0.92	0.89	0.87b	0.03c	0.63c	0.59a	0.75b	0.12b	0.59b
LSD (0.05)	NS	NS	0.03	0.02	0.04	0.08	0.09	0.11	0.03
CV (%)	14.9	10.4	1.72	2.03	2.16	8.17	6.16	29.2	2.24

Source Mulat et al. (2021)
Means followed by the same letters within a column are not statistically different at p lt; 0.05

urbanization, resettlement, climate change, and environmental pollution. Population pressure has been putting a great burden on the sustainability of almost all types of natural resources. Thus, the degradation of land, water, forest, rangeland, and wildlife resources appear to feed off each other. These result in severe soil loss, low vegetative cover, unsustainable farming practice, continuous use of dung and crop residues for fuel, overgrazing, and destruction and/or migration of wildlife, which again intensify the degradation of available resources in a vicious circle (Simachew 2020).

Soil is a natural entity which is formed as a result of both natural and managed processes and varies greatly in space and time. The rate and extent of soil formation depend on the types of rocks, climate, vegetation, organisms, topography and time. Ethiopia is marked with a great variation in these soil forming factors. Soil is very important for Ethiopia where most of the economic activities are dependent on agriculture (Engdawork 2015). Managed lands (crop and livestock production) share the largest proportion of arable lands in Ethiopia. Correspondingly, average crop production makes up 60% of the sector's outputs, whereas livestock accounts for 27% and other areas contribute 13% of the total agricultural value added (Gebre-Selassie and Bekele 2010). These contributions can be sustained when we are able to maintain healthy and fertile soil conditions.

Soil degradation is the loss of the intrinsic physical, chemical, and/or biological qualities of soil either by natural or anthropogenic processes, which result in the diminution or annihilation of important ecosystem functions (Nunes et al. 2020). Land use and land cover change, and agricultural soil management practices significantly affect the status of soil health. For instance, various researchers from different corners of Ethiopia reported that the conversion of native forest/grasslands to croplands and grazing lands resulted in substantial soil degradation (Fasik et al. 2019; Mengistu et al. 2017; Fantaw et al. 2007). Historically, highly developed political systems existed around Aksum in the northern part of Ethiopia until the seventh century, when the soil was not much degraded. The Axumite Kingdom then declined probably due to soil degradation subsequently (Butzer 1981). Soil degradation can be regarded as a direct result of the past agricultural practices. Soil erosion by water must be considered the most important of all degradation processes in the Ethiopian highlands (Hurni 1988).

Table 11.4 Ideal and root restricting bulk densities

Soil texture	Ideal bulk density (g/cm^3)	Bulk density restricts root growth (g/cm^3)
Sand, loamy sand	<1.60	>1.80
Sandy loam, loam	<1.40	>1.80
Sandy clay loam, clay loam	<1.40	>1.75
Silt, silt loam	<1.30	>1.75
Silty clay loam	<1.40	>1.65
Sandy clay, silty clay	<1.10	>1.58
Clay	<1.10	>1.47

SDA (1999). Soil quality test kit guide. USDA Soil Quality Institute. Washington, D.C

The regions with the greatest damage due to soil degradation are also the ones most affected by food insecurity. Certainly, soil degradation results in a higher vulnerability to famine. Generally, the northern and eastern regions have much thinner soil than the central, western, and southern regions of Ethiopia. The differences, apart from topography and pedogenic arguments, can be explained by the history of the land mismanagement, which proceeded from the north to the center and then toward the south and west of the country (Hurni 1988). Indeed, land degradation and soil fertility decline have posed tremendous challenges to increasing agricultural productivity and economic growth in Ethiopia. Nutrient depletion in Ethiopia has several causes. The major ones are nutrient export via harvested products (grain, stover), soil erosion, leaching and acidification. The crop productivity decline attributed to the loss of soil fertility may limit Ethiopia's opportunities in striving for food security, development and self-reliance.

Agriculture is highly extractive and exploitative of soil resources. It depletes OC, total N, available P, K, S and other nutrients. It also limits the soil microbial diversity, abundance and activity. The situations can be nastiest under subsistence smallholder, and low input farming systems. Globally, several long-term agricultural experiments revealed a large decline in OC, total N and other essential nutrients. In Ethiopia, the impact of agriculture on soil nutrient depletion has been documented by various researchers. Conversion of forest to farmland contributed greatly to enhanced erosion rates over a large part of Ethiopia. Excessive tillage for some crops, e.g., tef, wheat, maize (the main grain crops), tilling sloping land, reduction of fallow period and crop rotation practices, and overgrazing are some of the agricultural practices that might have enhanced erosion (Bezuayehu et al. 2002). Continuous cropping without adequate crop nutrition is also causing soil nutrient mining and erosion (Zhang et al. 2018; Tittonell et al. 2010).

(a) **Physical soil degradation**

Physical soil degradation comprises very different processes and morphometric forms, mainly through the deformation of the inner soil structure by compaction, caused by tracking with heavy agricultural machinery (Blum 2011). Physical soil degradation reflects structural decline (compaction and surface sealing or crusting) and mass movement. Soil compaction is the reduction of soil volume due to external factors; this reduction lowers soil productivity and environmental quality. This physical deformation may affect total soil porosity, its water holding capacity, bulk density, nutrient retention, microbial diversity and microbial activity of soils. Soil compaction leads to low water infiltration, water ponding, high surface runoff, and soil erosion after heavy rains. Physical degradation also includes soil erosion by water and wind as well as the formation of crusts at the soil surface (soil crusting). The most direct effect of soil compaction is an increase in the bulk density of soil. However, optimum bulk densities for soils depend on the soil texture (Table 11.4).

As a large mass of Ethiopian soil is tilled by oxen power, compaction may not be a serious problem except in selected areas such as Arsi-Bale mechanized farms and large-scale irrigated farms in the central Rift Valley of Ethiopia. Moreover, knowledge and scientific evidences on soil compaction are limited in Ethiopia. Nevertheless, soil compaction may be expected in teff farmlands as land preparation often include pressing/trampling the seedbeds by driving livestock on fields. Continuously tilled soils over the last many decades and low organic matter containing soils may be prone to physical compaction. Currently, Ethiopia is heading towards mechanization of agricultural practices, tillage and harvesting activities. Therefore, soil compaction may be a potential threat to Ethiopian soils unless proper management are crafted along with the introduction of mechanized technologies. There must be a precaution to avoid the potential challenges of soil compaction. Indeed, soil compaction becomes a serious problem when soils are tilled at very dry and very wet conditions. In general, soil scientists, practitioners and farmers don't give due attention to the impact of tillage on soil compaction and its consequences, as the problem is perceived to be insignificant.

Soil erosion is the greatest challenge to Ethiopia. It is the main driver of land degradation in Ethiopian highlands, and in the whole region of East Africa (Adugna et al. 2015). However, the soil losses have shown spatio-temporal variations. The soil loss rate by water ranges from 16 to over 300 Mg ha^{-1} yr^{-1} in Ethiopia, mainly depending on the degree of slope gradient, intensity and type of land cover and nature of rainfall intensities (Tesfaye et al. 2014; Tamrie 1995). According to Adugna et al. (2015), soil loss estimate made by means of the Revised Universal Soil Loss Equation (RUSLE) showed ranges of 4.5 Mg ha^{-1} yr^{-1} in forest to 65.9 Mg ha^{-1} yr^{-1} in cropland in Northeast Wollega. Based on field assessment of rill and inter-rill erosion, Bewket and Teferi (2009) estimated an annual soil loss of 93 Mg ha^{-1} yr^{-1} for the entire Chemago watershed, Blue Nile Basin, Ethiopia. Whereas, about 97% of Kilie catchment, East Shewa recorded an estimated soil loss of 0–10 Mg ha^{-1} yr^{-1} (Haile and Fetene 2012). In the Borena district of south Wello, the rate of soil loss was estimated to be between 10 and 80 Mg ha^{-1} yr^{-1} 10 (Abate 2011). Approximately, 75% of the total area of the Gerado catchment, Northeastern Ethiopia, was found to have rates of soil losses which were above 25 Mg ha^{-1} yr^{-1}. Berhan and Mekonnen (2009) estimated a soil loss of 35.4 Mg ha^{-1} yr^{-1} at the Medego watershed with steep mountains (slope 30–50%). A similar study in the highlands of Ethiopia showed a soil loss by water erosion ranging from 3.4 to 84.5 4 Mg ha^{-1} yr^{-1} with an average of 32.0 4 Mg ha^{-1} yr^{-1} (Berry 2003). All exceeded both the suggested soil loss tolerance limit of 18 Mg ha^{-1} yr^{-1} (Hurni 1983a) and the estimated soil formation rate ranging from 2 to 22 Mg ha^{-1} yr^{-1} (Hurni 1983b).

Soil erosion is taking place all over the country but because of the effect of overpopulation on land that is already fragile (steep and mountainous), and mismanagement of the land in the northern and central highlands are the worst affected (Paulos 2001). The most common types of soil erosion include sheet, rill and gully erosion by water and wind energy. Deforestation, population growth, overgrazing and use of marginal lands intensify erosion, and the intensification of agriculture production also results in high erosion rates. About 43% of the country is classified as highland (above 1500 m a.s.l.), where most of the population (about 88%) carry out mixed crop-livestock agriculture activities (Bewket and Teferi 2009). Generally, soil erosion by water is the most pressing environmental problem in Ethiopia, particularly in the highlands where the topography is highly rugged, population pressure is high, steeplands are cultivated and rainfall is erosive (Bewket and Teferi 2009).

Although indigenous soil conservation techniques have been applied for centuries in Ethiopia (Ciampalinia et al. 2012; Beshah 2003), institutionalized soil and water conservation (SWC) programs have been significant only since the 1970s (Osman and Sauerborn 2001). Indigenous soil and water conservation techniques date back to 400 BC in Ethiopia. In order to reduce/mitigate the anthropogenic soil erosion, institutionalized soil water conservation (SWC) activities have begun since 1970s (Haregeweyn et al. 2015). Various nationwide SWC initiatives have been undertaken, especially since the 1980s supported by multiple donors, and then have undergone a series of changes in terms of approach, technologies, and technical standards. These initiatives include food-for-fork (FFW) (1973–2002), managing environmental resources to enable the transition to more sustainable livelihoods (MERET 2003–2015), productive safety net programs (PSNP 2005–present), community mobilization through free-labor days (1998–present), and the national sustainable land management project (SLMP 2008–2018). The FFW program started in the form of food aid and gradually shifted in the 1980s to a development-oriented program through engaging the community in the rehabilitation of degraded lands (Devereux et al. 2006).

(b) **Chemical soil degradation**

Chemical soil degradation is manifested by nutrient depletion, acidification, salinization and soil pollution. The large proportions of Ethiopian soils are nutrient depleted due to mismanagement and continuous cultivation with less chemical and organic fertilizer inputs. Nutrient depletion has caused serious nutrient imbalances in soils under low-nutrient input agriculture systems (Osman 2014). Few earlier nutrient balance studies of agricultural soils of Ethiopia exhibited negative NPK balances (Abegaz et al. 2007; Haileslassie et al. 2005). A country-wide analysis of nutrient balance indicated a depletion rate of 122 kg N ha^{-1} yr^{-1}, 13 kg P ha^{-1} yr^{-1} and 82 kg K ha^{-1} yr^{-1} (Haileslassie et al. 2005). They further stated that soil stocks in all regional states of Ethiopia were decreasing with the exception of areas under permanent and vegetable crops. They accounted soil erosion as the major cause for nutrients depletion in Ethiopia, although the model result has high uncertainty. Recent nutrient balance studies of agricultural soils of Ethiopia exhibited negative NK, but positive P balance in northern parts of Ethiopia (van Beek et al. 2016; Shimbahri et al. 2020; Girmay et al. 2021). This positive P balance observed in most agricultural soils of Ethiopia may be related with P fertilization and P fixation in soils. According to Abebayehu et al. (2011), a comparative analysis of soil nutrient balance in the Jimma Zone revealed an average depletion of 55.61 kg N ha^{-1} yr^{-1}, 9.7 kg P ha^{-1} yr^{-1} and 49.81 kg K ha^{-1} yr^{-1} at the highlands and 35.73 kg N ha^{-1} yr^{-1}, 9.1 kg P ha^{-1} yr^{-1} and 29.69 kg K ha^{-1} yr^{-1} at lowlands. The landscape position (highlands and lowlands) showed large differences for N and K contents. The P depletion was observed to be low, thus attributed to the high P fixation and building up of P in soils when P fertilizer was regularly applied to soils.

Most land use studies conducted across various agro-ecologies of Ethiopia also exhibited soil fertility degradation in crop lands as compared to native forests and grasslands (Mulat et al. 2021; Mengistu et al. 2017; Yifru and Taye 2011; Fantaw et al. 2007). Recent records show that about 43% of the agricultural lands of Ethiopia are acidic. These acidic soils are sparingly suitable for crop production, albeit the degree of acidity varies across agro-ecologies of Ethiopia. Liming is an ancient method of reclaiming acid soils. Moreover, the modeling approach developed for estimation of soil nutrient depletion in current management practice showed 16% reduction of OC in Cambisols and 32% reduction in Luvisols in the northern Ethiopian highlands. The depletion rates of soil N are similar to those in OC under current management conditions (Abegaz and Keulen 2009).

Soil acidification is one of the most important soil chemical degradation processes attributed to the inherent soil properties, climate and management practices. A sizeable portion of Ethiopian highlands are either strongly or moderately acidic (Fig. 3.9). Currently, about 43% of Ethiopian soils were classified as acidic soils (Ethio SIS 2014), of these about 28.1% of soils in Ethiopia are dominated by strong acid soils (pH 4.1–5.5). The soil acidity is increasing in scope and magnitude in Ethiopia. Thus, soil acidity is a critical agricultural problem in certain agro-climatic zones of Ethiopia. However, the extent of soil acidity varies from semi/arid lowlands of eastern Ethiopia to the high rainfall areas of south, southwestern and western Ethiopia. For instance, the high rainfall areas of western Oromia have been adversely affected by soil acidity and associated soil quality problems; as a result, farmers' livelihood has been significantly affected (Bulti and Abdulatif 2019). Soil acidity and associated low-nutrient availability, and toxicity of certain nutrients (Al and Mn) are some of the major constraints to crop production on acid soils. For instance, a shortage of available K, Ca, P and Mo on the one hand, and an excess of soluble Al, and Mn are effects of high acidity problems in soils (Agegnehu and Sommer 2000; Somani 1996). When the pH of a soil is less than 5.5 phosphates can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients (Agegnehu and Sommer 2000; Sanchez 1977), and the yields of crops grown in such soils are very low. On the other hand, in a soil pH between 5.5 and 7, P fixation is low and its availability to plants is higher. Toxicity and deficiency of Fe and Mn may be avoided if the soil reaction is held within a soil pH range of 5.5 to 7; this pH range seems to promote the readiest availability of plant nutrients (Somani 1996). It is important to note that most crops' performance was observed to be deleteriously affected by soil acidity in the highlands of Ethiopia. Liming is one of the best soil acidity management strategies in various parts of the world. In Ethiopia, currently, it is widely practiced through establishing lime producing factories in different parts of Ethiopia such as in Amhara, Oromia and SNNP regions. Moreover, indigenous soil acidity management practices appears to be critically important in Ethiopia. This indigenous practice includes keeping livestock overnight for certain days on a fenced plot (barn) for manure production. It is an environmentally resilient and locally adapted indigenous practice used by farmers to ameliorate acidic soil with organic manure, and thereby improve soil quality and crop productivity (Bulti and Abdulatif 2019).

(c) **Biological soil degradation**

Soil biology is one of the most unexplored frontiers associated with understanding the dynamics of soil resources' health or quality (Lehman et al. 2015). However, soil represents one of the most important reservoirs of biodiversity. Soil biology is an interesting area of soil sciences and has yielded considerable information that is used in soil fertility management. In Ethiopia, soil biological teaching and studies have been very limited to biological N_2 fixation, due to limited laboratory facilities, knowledge and skills. Few experiments have been conducted on carbon and nitrogen mineralization studies in Ethiopia. These include the C and N mineralization studies with glutamate and legume residues amendment in laboratory, greenhouse and field conditions. Thus, the results are a good indicator of soil biological properties and a proxy indicator of soil health (Girma et al. 2012). Even when fertilizers are applied to soils, it become useable by the action of soil microorganisms. For instance, urea (NH_2CONH_2) and diammonium phosphate $(NH_4)_2HPO_4$ can only be mineralized into usable mineral nitrogen and phosphorous with the presence of significant microorganisms including nitrifying bacteria.

Few nitrogen mineralization studies from soil organic matter (SOM) were conducted in situ and in laboratory incubation under different soil moisture regimes with coffee and crop land use soils (Awassa, Yirgalem, Wondogent and Ziway) in southern Ethiopia. The results showed that extractable NO_3^--N and mineral N were strongly increased, while NH_4^+-N declined in response to soil moisture increase (from air dry to 100% FC, field capacity) during laboratory incubation. In situ extractable NO_3^--N and mineral N were strikingly low in December (dry) in both coffee and crop lands. However, they were consistently greater during March to August due to more rain flushes, suggesting better N release during the cropping season. The nitrogen mineralization of coffee land use was about double of crop land attributed to its higher soil organic matter content. Accordingly, the soil biological processes, the microbiota may be higher in coffee land than in crop land. Generally, the knowledge of annual patterns of nitrogen mineralization in relation with soil moisture is necessary to synchronize crop N demands with plant-available N in the soil (Girma et al. 2012).

Biological degradation of soil occurs due to the impairment or elimination of one or more "significant" populations of microorganisms in soil, often with a resulting change in biogeochemical processing within the associated ecosystem. "Significant" microorganisms are those for which an ecologically significant role is understood (Sims 1990). Increases in SOM, particularly in biologically-available forms, are intimately linked to changes in the size, activity and composition of the soil microbial community, enhanced cycling and retention of nutrients, improved aggregate stability, and increased water-holding capacity of soils (Lehman et al. 2015). Soil management practices that increase SOM and enhance soil health create expanded habitats and greater niche diversity for soil biological communities. Inputs of organic matter from plant residues and exudates provide carbon and energy sources for soil organisms.

11.2.6 Rain-Fed Agriculture

Over 95% of Ethiopia's agriculture is rain fed, subsistence smallholder agriculture. Soil resources in Ethiopia are considered as an asset but its management is treated as a challenge (Engdawork 2015). The severe rain fed agricultural soil degradation in Ethiopia is attributed to mismanagement, overexploitation (over-cultivation, overgrazing), removal of crop residues, use of manure (dung) for fuel, limited use of chemical fertilizers and erosion which causes billions of tons of topsoil removal every year and, and reduction/loss of the functions and services that soils provide.

Soil degradation can be regarded as a direct result of the past agricultural practices. Soil erosion by water must be considered the most important of all soil degradation processes in the Ethiopian highlands (Hurni 1988). Very few estimates are available about the overall soil loss rates at regional or national scale (Haregeweyn et al. 2015; Hurni 1988) estimated a nationwide annual gross soil loss of 1.5×10^9 tons, extrapolating data obtained from six soil conservation research project stations in which the highest loss was from croplands (42 t ha^{-1} yr^{-1}). Sonneveld et al. (2011) provided a tentative nationwide mean annual soil loss map combining the results of different model estimates. They stated that soil loss varies remarkably from 0 t ha^{-1} yr^{-1} in the eastern and southeastern parts of Ethiopia to more than 100 t ha^{-1} yr^{-1} in the northwestern part of the country. Moreover, various studies have also been reported on chemical soil degradations across agro-ecologies of Ethiopia (Tamene et al. 2017). These include soil fertility decline as observed by depletion of OC, total N, available P and acidification, and which is also substantiated by crop response to chemical fertilizers.

Agriculture is highly extractive and exploitative of soil resources. It depletes soil OC, total N, available P, S and other nutrients. It also limits the soil microbial diversity, abundance and activity, and thereby limits soil biological processes. The situations can be nastiest under subsistence, smallholder and low input farming systems. According to Gete et al. (2010), declining soil fertility is one of the most significant constraints to increased food production in Ethiopia. Globally several long-term experiments revealed a large decline in soil OC, total N and other essential nutrients due to agriculture practiced. In Ethiopia, the impact of agriculture on soil nutrient depletion has been documented by various researchers. For instance, Ethiopia is one of the 14 SSA countries with the highest nutrient deficit (−41 N, −26 P and −6 K y^{-1}) in agricultural fields.

A meta-data analysis on fertilizer application across various agro-ecologies of Ethiopia showed substantial positive crop response in most highlands of Ethiopia. The lowlands areas also had limited crop response (Tamene et al. 2017). This data shows a good representation of Ethiopian highlands that were generated by FAO and others. The meta-data results show that there is a limited response to N and P in the absence of the other, while combining N and P results in large increases in yield. Not including P in crop nutrition has a greater effect on attainable yield in areas with low than with high (>4 t ha^{-1}) unfertilized/control yield. Therefore, recommendations for fertilizer must likely include both N and P fertilizer sources. With fertilizer application, many observations indicate elevated yields beyond the national averages. There was a positive response to N, P and S with the test crops (wheat, maize, teff and rice) although some of the observations show no response/ negative responses to the applied nutrient (Tamene et al. 2017). This is perhaps related with the nutrient balance issue, as some nutrients increase may create an antagonistic relationship with non-applied essential nutrients.

11.2.7 Degradation of Soils in Irrigated Agriculture

Ethiopia has about 4–5 million hectares of irrigable land area. Out of these about 400,000 to 500, 000 hectares were already developed. Traditional irrigated agriculture is widely distributed across wider agro-ecologies, while commercial and large-scale irrigated agriculture are limited to semi-arid and arid agro-ecologies of Ethiopia. Overall, irrigated agriculture is very much limited in geographic coverage and technologies. Nevertheless, commercial large-scale irrigated agriculture is practiced in some Sugar Estat farms such as Wonji, Metahara, Fincha, Tendaho, Kuraz, Didessa and Wolikayti areas. Some of these sugar estate farms are young, while others are more than three decades old. In addition, there exist commercial irrigated vegetables, fruits and flower farms in middle Awash, Upper Awash and central rift valley areas, where potential salinity development is expected if not properly managed.

Over 11 million ha of land in Ethiopia are known to be salt affected soils (Ruffeis et al. 2008; Taddese 2001). The soil salinity problems in Ethiopia stems from the use of poor-quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel et al. 2018). The arid and semi-arid lowlands prevalent in the rift valley and other areas that are characterized by higher evapotranspiration rates are salt affected soils in Ethiopia (Asfaw and Itanna 2009; Geressu and Gezaghegne 2008; Dubale et al. 2002). The salt affected soils have increased from 6 to 16% of the total land area of Ethiopia (Abraha and Yohannes 2013). According to Zewdu et al. (2014), in Sego Irrigation Farm around Arbaminch, southern Ethiopia, the coverage of moderately and strongly saline areas has increased at an average annual rate of 4.1% and 5.5% respectively from 1984 to 2010. Earlier estimate showed that over 44 million ha (36% of the country's total land area) is potentially susceptible to salinity problems (Hawando 1995). These soils are currently at risk to salinity development due to mismanagement of irrigation water and poor drainage. The Awash basin can be considered as a typical example where salinization has been a critical problem in its many large and medium scale irrigation schemes including the Amibara irrigation project in the Middle Awash and the Metahara sugar plantation in the Upper Awash (Ayenew 2007).

The soils of irrigated farms in Ethiopia are challenged by poor drainage and salinity problems. Waterlogging is the main drainage problem in the small-scale irrigation schemes in the Vertisols dominated highland areas while salinity and salinization is a common phenomena in the large and medium scale irrigation schemes located in the lowlands of the country's major river basins with predominantly salt affected soils (Bulti and Abdulatif 2019). Large areas of the middle and lower parts of the Awash basin are also saline or sodic and thus potentially exposed to salinization and sodicity (Ruffeis et al. 2008). Salinization is more spreading in irrigated lands because of inappropriate management of irrigation and drainage. The major sources and/or causes of salinity are shallow groundwater tables and natural saline seeps. Poor drainage and lack of appropriate irrigation water management are also known to facilitate secondary salinization development in Ethiopia (Abebe et al. 2015). Improperly planned irrigation projects not supported by improved irrigation and drainage management technologies had invited serious degradation causing salinity and sodicity problems in the Awash basin which accounts for about one-third of the total irrigated area of the country (Dubale et al. 2002; Ruffeis et al. 2008). This high salinity problem is also related to uncontrolled irrigation practices and lack of knowledge on crop water requirements and water management leading to increased saline groundwater levels or capillary rise (Ayenew 2007). Climate is also a key factor in the salinization process. The high temperature of the Middle Awash (annual average 26.7 °C) and low annual rainfall (500 mm) and the high free evaporation of water have aggravated the salinization process (Ayenew 2007; Bekele 2005).

Salt affected soils are characterized with excess concentrations of calcium (Ca^{2+}), sodium (Na^{+}) and chloride (Cl^{-}) which are easily soluble (Bekele 2005). This has an adverse effect on the seedling growth of several crops, by creating an osmotic deficit in the rhizosphere of the plant. Thus, the soluble salts also inhibit the absorption of water or create toxicity effects due to Na^{+} and Cl^{-} to the roots and the whole crop (Singh 2015; Abraha and Yohannes 2013). When salt affected soils are intensively cultivated without proper caution for the gradual accumulation of salts and soluble substances, it may result in severe land degradation. Poor irrigation water management and operation coupled with the absence of drainage system can cause groundwater rise (waterlogging), salinization and considerable losses in crop yields which ultimately led to the abandonment of substantial irrigable areas. The problems of salinity and waterlogging persist in many regions where farmers apply excessive irrigation water, and where farmers and irrigation departments fail to invest in its proper management.

Considering the country's agriculture dependent economy, increasing food demand due to increasing population and insufficient rain fed agriculture, it is evident that the country should plan to promote irrigated agriculture. Provided that the likely target of planned expansion would not be out of the highland or lowland areas which are being affected or vulnerable to waterlogging and salinity problems respectively; drainage technologies are inevitable. The literatures referred in this paper signals the importance of drainage in boosting crop yields by controlling the above-mentioned drainage problems in irrigated agriculture.

It can be concluded that drainage is as important as irrigation for a productive and profitable irrigated agriculture that could help the country achieve its planned development goal. The unavoidable challenges that might be faced in the process are related to costs and technology in the design, implementation, operation and maintenance of drainage systems. But this might be copped by introducing low cost technologies like BBF for small-scale irrigators and the modern surface and sub-surface drainage systems.

11.2.8 Soil Pollution

Soil pollution refers to the contamination of soil with anomalous concentrations of toxic substances. It is a serious environmental concern since it harbors many health hazards. It is important to understand that all soils contain compounds that are harmful/toxic to human beings and other living organisms. However, the concentration of such substances in unpolluted soil is low enough that they do not pose any threat to the surrounding ecosystem. When the concentration of one or more such toxic substances is high enough to cause damage to living organisms, the soil is said to be contaminated. The root cause of soil pollution is often one of the following:

- Excessive/improper use of pesticides in agriculture
- Excessive industrial activity
- Poor management or inefficient disposal of waste

The extensive use of pesticides in agricultural production can degrade and damage the community of microorganisms living in the soil, particularly when these chemicals are overused or misused as chemical compounds build-up in the soil. It harms and destroys the beneficial organisms in the soils and affects their natural fertility and pest resistance. Although many studies have found deleterious effects of pesticides on soil microorganisms and biochemical processes, the full impact of pesticides on soil microorganisms is still not entirely understood.

Generally, there are very limited studies in Ethiopia with respect to soil pollution. In recently flourished flower farms, soil pollution is perceived to be a critical danger to soils and aquatic ecosystems, for example in rift valley areas. In large cities like Addis Ababa, soils are expected to be polluted due to the use of polluted water as a source of irrigation water for vegetable production. Another source of soil pollution can be improper disposal of agricultural as well as agro-processing/industrial wastes. Therefore, poor waste collection, control, storage, transfer, process, and disposal may be another good reason to expect soil and environmental pollution in Ethiopia. For instance, some Ethiopian soils are polluted by misuse and mismanagement of soils. These polluted soils are largely concentrated in the rift valley area and in Upper Awash State Farm associated with residues of floriculture and horticulture industry, coffee processing byproducts and gold mining residues across various parts of Ethiopia. According to Degytun (2011), the floriculture industry's inappropriate choice of cultivation methods and wide range of use of chemicals and fertilizers have negatively impacted soil and water condition. Upper Awash Agro Industry Enterprises is one of the major state farms in Ethiopia with known large-scale pesticide use. The major contaminants identified comprised of previously used persistent organic pollutants (POPs) and currently used insecticides. Low concentrations or non-detectable levels of certain POPs (aldrin, dieldrin, endrin, and heptachlor) indicate a positive phasing out of these persistent organic pollutants (POPs). Similarly, HCHs were found in soils at low concentrations. Endosulfans and DDTs were detected in substantial amounts in the soils with endosulfans up to 56,000 and DDTs up to 230ngg^{-1}dry weight, which is a threat to the surrounding and downstream ecosystems. Moreover, considering the investigated POPs constituted 29,000L of the 63000L of pesticides applied annually on the fields. Additional apprehension must be raised concerning the synergistic effects of all pesticides added.

A total heavy metal (Cr, Cd, Pb, As, Cu, Ni, Zn, Co) concentration study was performed on 33 soil samples taken from different profiles and soil types in a highly urbanized and industrial sector of Addis Ababa, central Ethiopia. The results show a relatively high content of the analyzed trace metals in the soil attributed to anthropogenic and geogenic sources. According to the heavy metal SE analysis, the major heavy metal contribution is from the residual followed by the hydroxide phases (Molla and Stefan 2006). Another potential pollutants of soil and water in Ethiopia are the coffee processing byproducts, pulp and husk, which are often damped to soils or streams and rivers within the vicinity of the processing plants. A report showed that in western Ethiopia large quantities are either dumped into streams or burnt in big piles, whic contributes to environmental hazards (Bikila 2019). However, these byproducts can be good organic fertilizer sources if properly managed and utilized as a soil amendment. Gold mining is a tremendously important economic activity in rural districts of Ethiopia. Gold mining removed colossal volumes of soil from the mining landscape. In addition, various chemicals used in the gold mining process can also be sources for soil and aquatic ecosystem pollution in various parts of Ethiopia.

11.3 Civilization, Soil Fertility and Wealth

11.3.1 Soils and Civilization

Humans and soils have been intricately linked since antiquity, for soil touches people's lives in many ways, including serving as the source of food and clothing, and for its multiple ecological services, such as filtering drinking water and maintaining environmental health (often called 'a geologic kidney' by environmentalists) (McNeill and Winiwarter 2004). Some scholars associate the origin of the word *human* with soil claiming that the Latin root of the word *human* itself is similar to the root of the word *humus*, which means earth. Hillel (1980) wrote, "The primeval association of man with soil is manifested most strongly in the name *Adam*, derived directly from *adama*, a Hebrew word with the composite connotation of earth, land, and soil (*pp xiv*)." Similarly, many other historical accounts in many traditions educe the presence of strong associations between humans and soils, which helped people to recognize the value of soil at least since the dawn of cropped agriculture. Since then, soils have found their way into societies' cultures, religion, history, art, literature, thought, civilization, and livelihood (Minami 2009).

Soils have served as foundations for many ancient civilizations and are still playing a pivotal role in modern-day civilizations. Many earlier civilizations began where farming was productive and that depended on the availability of good soil. At some stage, ancient civilizations have gone to the extent of worshiping soils as a foundry of their life itself since soils provided most of their food and nutrients (McNeill and Winiwarter 2004) through agriculture, arguably the first systematic use of soils (Brevik 2005). This triggered people to make an attempt to organize, preserve, and impart knowledge about soils, leading to the writing of documents in the form of agricultural manuals. Because of these earlier documents, civilizations all around the world showed fairly advanced soil knowledge as early as the fourth century AD including irrigation, the use of terraces to control soil erosion, various ways of improving soil fertility, and ways to create productive artificial soils (Brevik 2005).

When farm productivity declined, usually as a result of soil mismanagement leading to soil degradation, civilizations also declined—and occasionally vanished entirely. Testimonies to this claim include the collapse of the 1700-year-old Mayan civilization in South America around 900 AD (due to soil loss caused by erosion), the demise of civilizations at Mesopotamia (due to salinity and waterlogging) (Essington 2004), Sumerians (due to salinity), and Babylonians (due to siltation caused by sediment washed from the surrounding hillsides which were left barren). On the other extreme, successful civilizations that are worth mentioning in relation to soils include those of the Greeks, Romans, The Mediterranean, Northern Europe, Asia, and many others although the level of soil knowledge of the Greeks and Romans was more refined than the others.

Agriculture has been practiced in Ethiopia, a country with one of the oldest civilizations in Africa, for centuries. Its people are dominantly agrarian where the agricultural productivity relies heavily on soil resources. As such, the contribution of soils to the civilization of the country has been laudable. Butzer (1981) related the rise and fall of the Axum civilization with soils/natural resources. An Egyptian noble, Ibn Fadl Allah Al-Omari, mentioned the cultivation of many cereal crops like wheat, barely, sorghum, *teff*, chickpeas, and lentils and mentioned the possibility of two harvests a year in his geographical work 'MasalikelAbsar' (1342–1349), which was devoted to Ethiopia. Other early writers also gave a good account of Ethiopia's agriculture mentioning the different types of crops (including fruits and vegetables of different kinds) grown, the yield they used to obtain, the good quality of the soil, and irrigation practices around water sources (e.g., Crawford 1958; Alvares 1540; Zorzi 1522-all cited in Westphal 1975). Writers such as Manuel Almeida described Ethiopia to be a very fertile country (Westphal 1975). Ludolphus, writing about Ethiopia in 1684, said: 'The fertility of the Soil of Habessinia is to be admired; for the land where it admits of Tillage, abounds in all sorts of Fruits (Westphal 1975). Burton (1856) described the environs of the walled city of Harar mentioning that the soil on both sides of the path is rich and red.

Ben (1896) described the soil and water conservation experiences of Ethiopians based on his observation that all the surrounding hills in a valley near Yeha are terraced, comparing the appearance of the terraces in Greece and Asia Minor, but with a much greater extent. He further concluded that "Hundreds and thousands of acres must have been under the most careful cultivation, right up almost to the tops of the mountains." Wylde (1901) wrote extensively about Ethiopia's agriculture describing it as "produced everything that man wants in this world", giving a long list of crops cultivated at Yeju village in the then Wag. He also described some of the soil management practices that the farmers were practicing (e.g., burning of roots and weeds on cultivated lands). Bunting (1963) described the farming in Ethiopia as more advanced in terms of management of crops and soils than any other indigenous system in tropical Africa. However, a gradual decline in soil fertility, together with a devastating drought, exposed the country to recurrent famine that claimed the lives of millions of Ethiopians. Soil degradation (through soil erosion, soil fertility depletion, salinization, soil acidity, and others) stands among the top factors that led to a decline in agricultural productivity and persistent food insecurity. This, together with other contributing factors, has been undermining its civilization and economic development.

11.3.2 Fertile Soils and Wealth

Soil fertility and wealth are closely related. The United Nations (2013) declared that soils form the basis for agricultural development, ecosystem functions, and food security and thus are key to sustaining life on earth. This is particularly true in the least developed agrarian countries like Ethiopia whose income is solely dependent on agricultural commodities. Fertile soils contribute towards economic growth, biodiversity, agricultural sustainability, and food security, all of which are fundamental to eradicating poverty. However, until very recently, our dependence on natural resources in general and soils, in particular, seems to have been largely undermined by intellectuals, cultured people, economists, policy makers, and even the society at large. Inauspiciously, many view soil as a 'dirt', which has to be removed or cleaned from a place if possible. Even the neo-classical economics excludes natural resources, including soils, from its theories, erroneously assuming that these entities are nearly free and infinite, and thus should not be a matter of concern (Gomiero 2016). It is only very recently that the UN General Assembly declared 2015 as the International Year of Soils. Emphasizing on the special place and attention soils deserve in the global agenda, one FAO Director-General stated that "the multiple roles of soils often go unnoticed. Soils don't have a voice, and few people speak out for them. They are our silent ally in food production." (Da Silva 2014). Jack et al. (2009) argue that soil should be viewed as an important source of greater wealth; however, establishing a direct relationship between wealth and soil does not lend itself to simplicity (Burras et al. 2013).

As vividly pointed out by Gomiero (2015), there can be no agriculture at a scale without fertile soils and, hence, it is important that people comprehend the tight and delicate link soil health (which includes fertility status) has to land use, food production, people's health, the use of inputs (e.g., fertilizers), and many other environmental and socioeconomic issues. It is through this link that the status of our soils affects society's wealth creation and accumulation. Evidences from different sources (e.g., Montgomery 2007; McNeill and Winiwarter 2006; Diamond 2005; Troeh et al. 2004; Hillel 1991; Dale and Carter 1955) indicate the role soils played in the rise and fall of the wealth of early civilizations claiming that soil degradation (e.g., soil exhaustion, soil fertility depletion, soil erosion, and salinization) contributed to the demise of notable early civilizations that prevailed in the Middle East, Greece, and the Roman Empire, among others. Narrations in many literatures converge towards one reality, i.e., a society without food security can't be viewed as a wealthy society. With soils at the heart of the requirements for ensuring food security, the role they play in wealth creation speaks by itself. Their contribution is direct as well as indirect.

In Ethiopia, largely an agrarian nation, the standard of living of the farming community in particular is very much dependent on the quality and size of land (which includes soils) they own. In general, those societies that inhabit the fertile parts of the country are relatively better economically and in terms of food security than those that leave on degraded lands of the country. This generalization, however, does not preclude the existence of individual differences among those inhabiting fertile lands. Apart from individuals, the country's economy and its growth are heavily dependent on the agriculture sector whose productivity is tellingly influenced by the quality of soil resources, among others. The contribution of agriculture to the country's gross domestic product and foreign export earnings is significant. The other economic sectors, such as industry and service, are heavily dependent on the agriculture sector for inputs. By and large, the contribution of soil fertility towards food security, income generation, and economic development of the county is extraordinarily significant. Equally, the country is losing a huge amount of wealth due to soil degradation, particularly soil erosion. However, the contribution of natural resources including soils to the national economy has always been greatly undermined or underestimated.

11.4 Soils in Relation to Human Nutrition and Health

11.4.1 Principles

Soil, which provides the substrate for almost all terrestrial life, is a basic natural resource for food production, with the major proportion of food that we consume either directly or indirectly coming from it (Silver et al. 2021; Menta 2012). Soil quality, the continued ability of the soil as a vital living system to support important ecosystem functions (Karlen et al. 1997; Pankhurst et al. 1997), determines the quantity (calories) and the quality (nutritional value and safety) of the foods grown on it (Zhu 2009). Soil quality is dictated by the status of physical, chemical, and biological attributes which affect one or more of the many soil functions. Maintaining these soil attributes and their integration at an optimum level is therefore of vital importance in safeguarding global food security.

Soil can also affect human health directly or indirectly. The direct influences could come from the ingestion of soil material accidentally or deliberately through practices such as geophagia. The indirect effects could come from the food produced on soils and consumed by human beings. The effects on human health could be positive or negative. Healthy soils that support the production of healthy and nutritious food will enhance human health, while food produced on unhealthy soils (e.g., polluted soils) could hurt human health through some contents of the food produced on such soils. The influences could range from simple nutritional deficiencies, which can be easily corrected, to complicated diseases such as cancer. Similarly, ingested soil material could be beneficial when it contains essential components such as nutrients or harmful if it contains dangerous substances such as minerals (e.g., radioactive nucleotides, heavy metals) and pathogens. These components can be a source of concern to human health since they can be the cause of many diseases and disorders. The link between soil health/quality and human health should be understood properly and comprehensively so that management scenarios that assist in maintaining soil health/quality, which enhances the production of adequate food that is safe and nutritious, are put in place.

11.4.2 Soils and Human Nutrition

(a) **Soil and food quality**

It was as early as 1921 that McCarrison (1921) was able to link the fertility of a soil with the nutrient content of food crops stating that the fertility of a soil determines the nutrient content of food crops, and therefore the health of humans who ate the crops. The nutritional value of many foods is markedly influenced by the soil's ability to supply essential nutrients to food systems (Allaway 1986), particularly where food is produced and consumed locally, influencing to what extent the nutritional requirements of people are met from the crops grown on these soils. Nevertheless, in more complex food chains where there are different food sources and processed foods are supplemented with essential minerals and vitamins, the contribution of soils in meeting nutritional requirements are less evident (Oliver and Gregory 2015). Naturally, fertile soils are expected to produce healthy and nutrient-rich crops that nourish people and animals (IFOAM 2011). However, a large number of evidences indicate the existence of macro- and micronutrient deficiencies in significant proportions of agriculturally important soils of the world. These deficiencies not only affect crop productivity but also could lead to the poor nutritional quality of crops and animals, often leading to malnutrition in humans. On the other hand, under certain soil conditions, some nutrient elements occur in high concentrations that may diminish crop yield, with potentially negative consequences on human health (Hodson and Donner 2013). Soil conditions like acidity and sodicity dictate as to which elements may accumulate in the soil in toxic concentrations.

Soil acidity favors the accumulation of toxic concentrations of manganese, aluminum, and iron, while salinity and sodicity could create suitable conditions for toxic concentrations of sodium, boron, and chloride, which could reduce crop production and affect food quality. Anthropogenic activities, such as mining and manufacturing could lead to toxic accumulation of arsenic, cadmium, mercury, and lead, which are carcinogenic and thus could affect the quality of food that we consume (Hodson and Donner 2013). Therefore, from the foregoing discussion, it can be inferred that soil quality affects food quality in at least in two ways. One of these is through the essential nutrient elements which it supplies to plants that make our food. The second way is through its chemical composition which may not be nutrient elements but absorbed by plants indiscriminately. The former affects the quantity and nutritional quality of the food produced on a soil, while the latter influences food safety. Food that is produced on polluted soils (soils containing excessive concentrations of toxic chemical elements and even microorganisms), is unsafe for human consumption since the toxic substances can be transferred to humans via the food we eat.

Mineral or nutrient malnutrition results from crops produced on soils with poor phytoavailability of the elements essential to human nutrition. For example, alkaline and calcareous soils (25–30% of all agricultural land) have small availabilities of Fe, Zn and Cu (White and Greenwood 2013; Broadley et al. 2007), and coarse-textured, calcareous or strongly acidic soils contain little Mg, mid-continental regions have little I and soil derived mostly from igneous rocks contains little Se (Gregory 2012). Consequently, crops also have inherently small concentrations of certain elements (Karley and White 2009; White and Broadley 2009).

Most Ethiopian soils have fertility issues that can affect food quantity and quality. The soils of the country are generally deficient in major nutrients like nitrogen and phosphorus. Besides, the organic matter content of almost all agricultural soils is in the range of very low to low. Most soils in the high rainfall areas of the country are severely affected by soil acidity, while those in vast lowlands are affected by various levels of salinity and sodicity, soil conditions that might result in deficiency of some nutrients and toxic concentration of others-particularly micronutrients. In line with this, a recent study by Gashu et al. (2021) identified soil pH and organic matter as covariates of grain micronutrient concentration in staple cereal grains grown in Ethiopia. The same study reported with-in species variation in cereal grain Ca, Fe, Se, and Zn concentration and attributed it to the spatial variation in soil and landscape factors. Tessema et al. (2019) also reported a significant correlation between soil Zn and serum Zn. Similarly, De Groote et al. (2021) reported that serum Zn was correlated to soil Zn for children and the prevalence of a high level of human deficiency throughout

Ethiopia, while a significant reduction in the prevalence of Zn deficiency in young children was only observed at high soil Zn levels. Contrary to this, Berkhout et al. (2019) found weak associations between soil nutrients, including Zn, and some health indicators, such as child mortality and stunting in sub-Saharan Africa. Studies conducted elsewhere (e.g., Joy et al. 2015; Chilimba et al. 2011) demonstrated the influence of soil type on micronutrient concentration in food items. Crops growing on localized soil types (e.g., Vertisols) have greater micronutrient concentrations than crops growing on more weathered, acidic soils (Ligowe et al. 2020; Joy et al. 2015; Chilimba et al. 2011).

(b) **Essential soil elements for plants and humans**

Tisdale et al. (1993) define an element considered to be essential to plant growth and development as "that involved in plant metabolic functions without which the plant cannot complete its life cycle." Nieder et al. (2018) and Tisdale et al. (1993) recognize 16 elements (carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, chlorine, boron, iron, manganese, copper, zinc, and molybdenum,) as essential to plant growth and development, while Marschner (2012) and Havlin et al. (2005) add nickel to the list. In addition to these elements, sodium, selenium, cobalt, aluminium, bromine, vanadium, and silicon are identified as beneficial or *quasi-essential* elements, which are elements needed by some but not all plants for optimum growth and production (Nieder et al. 2018; Marschner 2012; Havlin et al. 2005). Based on their relative abundance in plant tissues, the essential elements are further divided into macro (carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) and micronutrients (chlorine, boron, iron, manganese, copper, zinc, molybdenum, and nickel). The macronutrients, which constitute greater than 0.1% of dry plant tissue, are used in relatively large quantities to form constituents of organic compounds that act as building blocks for cells or act as osmotica, while the micronutrients are used in relatively small amounts, constituting less than 0.1% of dry plant tissue (Nieder et al. 2018). However, the essentiality criteria applies equally to both macro- and micronutrients. Carbon, oxygen, and hydrogen, the most abundant elements in plants (making up 94–99.5% of the plant tissue), are obtained from air and water and they hardly limit plant growth. It is the other essential elements, called mineral nutrients, which most often limit plant growth and development and the quality or nutrient composition of food products (Nieder et al. 2018; Havlin et al. 2005). These mineral nutrients are obtained from the soil and/or artificially added to soils through fertilizers and manures. The mineral nutrients are taken up by plants in ionic forms. Among the macronutrients, N, P and K are termed major or fertilizer nutrients, while Ca, Mg and S are called secondary nutrients.

Most of the elements that are essential for plants are also essential for human health (Leitzmann 2009; Klasing et al. 2005) although humans may require several others (White and Brown 2010). Around 29 elements are considered essential for human life, of which 13 are essential plant nutrients obtained from the soil and another 5 are beneficial elements obtained from the soil. Only eleven elements comprise 99.9% of the atoms found in the human body, with H, O, C, and N making up about 99% and Na, K, Ca, Mg, P, S, and Cl making up about 0.9% (Combs 2005). Hydrogen (H), O, C and N are called major nutrient elements, while Na, K, Ca, Mg, P, S, and Cl are called minor elements required for human life. Although there is no agreement on the number and identity of the elements by human health experts, many workers have added 18 elements to the above list as essential trace elements (e.g., Leitzmann 2009; Deckers and Steinnes 2004; Abrahams 2002). These trace elements are lithium (Li), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), tungsten (W), molybdenum (Mo), silicon (Si), selenium (Se), fluorine (F), iodine (I), arsenic (As), bromine (Br), and tin (Sn) (Combs 2005).

Therefore, soils that provide a healthy, nutrient-rich growth medium for plants will result in plant tissues that contain many of the elements required for human life. In fact, most of the elements necessary for human life are obtained from either plant or animal tissues (Leitzmann 2009; Shetty 2009). Plant tissues are among the most important sources of Ca, P, Mg, K, Cu, Zn, Se, Mn, and Mo in the human diet and these elements are obtained by plants from the soil. Furthermore, the trace elements that are required for healthy human life cannot be synthesized (McMillian 2002) but obtained from plant tissues, underpinning the strong and direct link between soil, food, and human nutrition. Soil mineral concentration is important not only for crop yields but also for the mineral concentration of the edible portion of crops (Allaway 1986). In Ethiopia, a similar connection has been found between soil zinc deficiency and human zinc deficiency, where the latter was measured in country-wide blood samples (Tessema et al. 2019). A different study in Ethiopia found that soil organic matter influenced the zinc status of crops, though the implications for humans were not directly examined (Wood and Baudron 2018).

11.4.3 Soils and Human Health

If the medium where primary producers of our food are growing does not have a connection with human health, what else can have? Evidences indicate that the connection between soils and human health has a long history with some of them dating back to 1400 BC in the Bible in the book of Numbers (Steffan et al. 2018; Brevik and Hartemink 2010). Soils can affect human health positively as well as negatively through their influence on food quantity and quality (Lal 2009), and human exposure to various chemicals and pathogens present in the soil albeit making a strong scientific connection between the two could be delicate and complex (Brevik and Sauer 2015). Oliver and Gregory (2015) classify the effects of soils on human health into direct or indirect, which can be beneficial or harmful (Pepper et al. 2009). The direct influences come through ingestion, inhalation and absorption of soil or its constituents, while the indirect influences come through dynamic interaction between the pedosphere, biosphere, atmosphere and hydrosphere and are related to the quantity and quality of food that is derived from soil-based agriculture. Ingested soil as much as it potentially supplies essential nutrients, can also expose humans to various dangerous chemicals and pathogens that can cause various diseases. Different workers have reported intestinal obstruction (Henry and Cring 2013), coccidioidomycosis (Stockamp and Thompson 2016) and chronic bronchitis (Zosky et al. 2014) from inhaled soil dust, and podoconiosis (endemicnon-filarial elephantiasis) (Deribe et al. 2013a, b), among others. Potential health concerns related to soils are many and may include cancers, respiratory diseases, neurological disorders, diseases of the excretory system, skin diseases and secondary diseases like heart failure, increased susceptibility to infections and others (Nieder et al. 2018).

In the following sections, soil effects on human health through exposure to soil materials, geophagy, and as sources/origins of different medicines are discussed.

(a) **Human exposure to soil material**

Soils can be a source of materials that are harmful to human health. Humans can be exposed to contaminated soils through ingestion, respiration, and skin absorption or penetration (Brevik 2013). The soil materials to which humans could be exposed include heavy metals, organic pollutants, toxic materials in fertilizers and other agro-chemicals such as pesticides and herbicides, radioactive materials, pathogens, and polluted water. Some of the heavy metals known to affect, especially when they are present in their ionic form and bound to organic molecules, human health are mercury (Hg), cadmium (Cd), chromium (Cr), strontium (Sn) and arsenic (As) (Baird and Cann 2005; Sparks 2003). These heavy metals can get into the human body through various routes, such as inhalation of contaminated soil dust, consumption of crops grown in contaminated soils (Handschumacher and Schwartz 2010) and purposeful or incidental consumption of contaminated soil (Abrahams 2005). The heavy metals form bonds with sulfhydryl groups on enzymes so that the enzyme cannot function properly (Baird and Cann 2005), causing damage to the central nervous system that in turn leads to many health problems that include, but a few, hypertension, gastrointestinal damage, lowering IQ, bone deterioration, and increased cancer rate (Deckers and Steinnes 2004; Sparks 2003). Owing to its many different sources that could cause widespread exposure, lead has been identified as the most problematic heavy metal on a global basis (Balabanova et al. 2017; Baird and Cann 2005).

The most important groups of organic pollutants that are of major concern to human health are the Persistent Organic Pollutants (POPs) (Brevik 2013), which are either recalcitrant to decomposition or bioaccumulate through the food web (Lee et al. 2003). Commonly known POPs in this regard include organochlorines, organophosphates, carbamates, chloroacetamides, glyphosate, and phenoxy herbicides coming from various sources such as pesticides and entering the human body through dermal contact with contaminated soil and ingestion (Peterson et al. 2006). Besides, environmental estrogens, which interfere with the endocrine system and are suspected to cause infertility and increased cancer rates in reproductive organs (Safe 2000), and antibiotic residues, which are feared to result in the development of antibiotic-resistant bacteria (Wellington et al. 2013; Chee-Sanford et al. 2009), are additional organic compounds found in the soil and might present some risks to human health. Veterinary pharmaceuticals and agricultural animal wastes are likely sources of environmental estrogens (Bradford et al. 2008), while the antibiotic residues in the soil could come from animal manures and sewage sludge, implying that the use of these substances as organic fertilizers needs serious health risk considerations before application to soils.

Some chemical fertilizers, usually applied to replenish deficient nutrients, are also known to contain impurities that could be dangerous to human health when accumulated in the soil to toxic levels through repeated applications (Keller et al. 2001). According to different sources, heavy metals are among the toxic materials commonly found in fertilizers, particularly in phosphate and nitrate fertilizers (Fuge 2005), micronutrient fertilizers (Bourennane et al. 2010; Chen et al. 2008), and sewage sludge (Mbila et al. 2001). Lack of stringent regulation on the filler content of fertilizers has allowed some companies to use fertilizers as an inexpensive way to dispose of hazardous wastes.

Important radioactive materials in soils that could harm human health upon exposure include radon, isotopes of cesium, cobalt, curium, neptunium, strontium, plutonium, uranium, technetium, tritium, thorium, americium, radium, and iodine. The sources can be natural or anthropogenic. The natural sources are rocks and minerals that contain these radioactive materials. For instance, granites, felsic metamorphic rocks, organic-rich shales, and phosphatic rocks contain a high amount of uranium, which upon decaying produces radon. Important anthropogenic sources of radioactive materials in the environment include nuclear weapons manufacturing and testing, accidental release from nuclear facilities, the burning of coal, smelting of nonferrous metals, mining activities, and medical wastes (Hu et al. 2010). Different forms of cancer, including lung cancer, and genetic mutations are human health risks often associated with exposure to radioactive materials in the soil (Cheever 2002).

Soil is often called a 'living entity' because of the number and diversity of biological organisms it contains. It is rich in biodiversity. There is no wonder if some of these biological organisms are posing health risks to humans upon exposure to contaminated soils although most of the organisms found in soils are not harmful to humans. The harmful organism can affect human health directly or indirectly through affecting crop production. According to Bultman et al. (2005) and Abrahams (2002), organisms get access to the human body through ingestion, respiration, and skin penetration. Ingestion is arguably the most common way that humans are infected by soil pathogens (Bultman et al. 2005). Groups of organisms that can cause disease include Helminths (hookworms, roundworms, and tapeworms), Protozoa, Fungi, Bacteria, Actinomycetes, and viruses. Recent study by Mestawet et al. (2021) revealed the prevalence of *Ascaris lumbricoides* (56.2%), *Trichuris trichiura* (23.8%), and hookworms 12 (15%) among pregnant women who practiced geophagy.

Water that passes through the soil and gets its way to surface or groundwater sources that could be developed for utilization can pose serious threats to human health by picking up heavy metals, organic pollutants, and soil pathogens that are present in the soil. Counting on soil's ability to filter toxic substances, humans also intentionally dispose of contaminated water into the soil system through septic systems and the application of manure as fertilizers, among others (Kresic 2009; Fetter 2001).

(b) **Geophagy**

Geophagy, a habit of intentionally eating or ingesting soil, is common among animals and humans (Young et al. 2011; Abrahams 2005), particularly children (von Lindern et al. 2016), pregnant women (Steffan et al. 2018) and people of low socioeconomic status (Henry and Kwong 2003; Oliver 1997). It can be beneficial as well as harmful. The benefits come from the soil material ingested being a source of mineral nutrients such as Ca, Fe, Cu, Mg, and Mn (Abrahams 2006; Abrahams 2002), used as a medicine, helpful as a way to detoxify foods and sometimes conciliate hunger (Sing and Sing 2010; Abrahams 2005; Oliver 1997). Pregnant women, who practice geophagia the most, claimed a number of benefits that come from geophagia, which include relief from morning sickness related nausea and stomach upsets (Diko and Diko 2014) and protection of gastrointestinal tract disturbance and/or infections by clay fractions through directly adsorbing distress causing agents, reinforcing the luminal epithelium by absorbing liquids, and lysing bacterial cells (Kambunga et al. 2019).

On the other hand, geophagy can also be a source of human health concerns depending on the nature of the soil ingested and its chemical as well as biological compositions. Deficiency of certain nutrients (e.g., Fe, Zn, and K) due to the high cation exchange capacity of some clays (Abrahams 2005; Oliver 1997), carcinogenic substances like heavy metal toxicity (Singh and Singh 2010; Calabrese et al. 1997), disorders associated with deficiency of iodine and infection by soil pathogens (Singh and Singh 2010; Hough 2007) have been cited as potential disadvantages attributed to geophagy. Soil pathogens such as bacteria and, fungi when ingested through geophagy can cause disorders in big organs such as liver, while the soil ingested can also be a source of many infectious diseases (e.g., hookworm, podoconiosis, geohelminth). Other health risks associated with geophagy include constipation due to accumulation of soil material in the gastrointestinal tract, abdominal pain that reduced absorption of food, perforation of the colon (Abrahams 2005), and intestinal obstruction (Henry and Cring 2013). In pregnant women, geophagia practiced on contaminated soil resulted in exposure to toxic minerals, pathogenic microbes, and helminthic infections (Steinbaum et al. 2016). Even humus in the soil can cause anemia and malnutrition through chelating essential nutrients such as iron (Henry and Kwong 2003).

Similar to many other developing countries, geophagy is practiced among different members of the society in Ethiopia, particularly pregnant women (Mestawet et al. 2021). However, there are no statistics that shows what percent of the society practices geophagia at the national level. Nevertheless, some studies conducted on pregnant women at some places reported that it varies from 20.3% (Sidama zone) (Handiso 2015) to 30.4% (Addis Ababa) (Kuma et al. 2013).

(c) **Effects of soil on human health**

Soil can influence human health positively or negatively as well as directly or indirectly (Steffan et al. 2018). Provision of important nutrients through food produced on soils and/or incidental or intentional ingestion of soil material (e.g., through geophagy) and medicines extracted from soil organisms could be taken as positive contributions, while health risks posed by dangerous chemicals and harmful biological organisms (pathogens) and nutrient imbalances can be viewed as negative effects. However, the connection between soils and human health entails complex interactions, demanding further research. In this section, the contribution of soils in the production of a variety of medicines is emphasized.

Soils have been used as origins of a large number of medicines that are used for curing or treating myriad human health problems. However, this value of soils has not been acknowledged widely although the first antibiotic was isolated from soil actinomycetes in 1940 (Ginsberg 2011). Yet, most of the currently relevant antibiotics are those that are extracted from the actinomycetes (Pepper et al. 2009). Available evidences reveal that many beneficial soil organisms, such as actinomycetes and fungi, can make antibacterial molecules (Wolf and Snyder 2003). Medicines derived from soils include mostly antibiotics, prescription drugs, and cancer drugs (Pepper et al. 2009). Significant number of these medicines had their origin in the soil. Important groups of antibiotics derived from actinomycetes include aminoglycosides, glycopeptides, and tetracyclines, while the cephalosporin group are the antibiotics derived from soil fungi. By and large, though not fairly acknowledged, soils seem to be playing a commendable role in helping humans fight against many diseases.

In addition to the varied antibiotics and other drugs extracted from soil organisms, the soil material itself has been used in enhancing human health in different ways. Typical examples include the use of clay mineral kaolin for treating various health problems. This clay mineral has been used as a digestive aid, for making, in combination with pectin, anti-diarrheal medicine Kaopectate (Allport 2002), included in some toothpaste formulas (EPA 1999), used for treating diaper rash and as an emollient and drying agent in treating poison ivy, poison oak, and poison sumac cases (AJN 1989). Another clay mineral, montmorillonite, has been used for treating poisoning by herbicides paraquat and diguat (Abrahams 2005; Clark 1971). A work by Handschumacher and Schwartz (2010) indicated that pharmaceuticals and cosmetics industries use clays in products that are developed to prevent wrinkles and skin ageing.

In addition to the effects of soil on human health discussed above, soils can also put human health under treat indirectly through nutritional deficiencies in food produced locally. Many studies (e.g., Oliver and Gregory 2015; Black et al. 2008) have documented the multiple effects of under-nourishment on human health leading to various disorders and diseases that range from stunted growth and disability through more serious diseases such as diabetes, cardiovascular diseases, anaemia, and mental retardation. Furthermore, dangerous substances taken up by plants indiscriminately from the soil (e.g., antibiotics, antibiotic resistant genes or bacteria) can pose health risks to humans (Wellington et al. 2013).

In Ethiopia, there are so many diseases that are associated directly or indirectly with soils. Very common among these diseases is Podoconiosis, which is common among barefoot individuals who are in long-term contact with irritant soils of volcanic origin (Deribe et al. 2013a, b; Davey et al. 2007; Price 1990, 1976). The country carries the greatest burden of the disease (Deribe et al. 2017; Davey 2010) with more than one million people affected. It is also one of the most extensively studied diseases in the country (Deribe et al. 2017; Deribe et al. 2015a, b; Tekola Ayele et al. 2013; Geshere Oli et al. 2012; Molla et al. 2012; Alemu et al. 2011; Desta et al. 2003). Different studies have found associations of the disease with soil attributes, together with other environmental factors, such as particle size distribution, clay mineralogy (Deribe et al. 2017; Le Blond et al. 2017; Molla et al. 2014; Kloos et al. 1997) and organic matter content (Frommel et al. 1993).

The results of a recent study by Leta et al. (2020) revealed that soil-transmitted helminths are also almost endemic to Ethiopia and are posing serious health problems. According to this study, the prevalence of any soil-transmitted helminths infection across the study population was 21.7%, with *Ascaris lumbricoides* (12.8%) being the most prevalent, followed by hookworms (7.6%) and *Trichuristrichiura* (5.9%).

11.5 Conclusion

Irrefutably, soil is one of the natural resources that are exploited the most by human beings. It is essentially a living entity that provides a substrate for all terrestrial life. It had been and is playing a central role in the rise as well as the demise of many notable civilizations that this world has witnessed. It is, directly or indirectly, associated with almost everything about humans that include their economic status, nutrition and health. It produces not only food and is involved in many environmental regulatory functions, but also is the origin of many medicines that are used to treat many health problems. However, it has been prone to various intensities and forms of degradation that greatly undermine its capacity to perform multiple functions. This has put the production of adequate and nutritious food for the ever increasing world population in jeopardy. The importance of soil in Ethiopia is ever more pronounced given the number of people that rely on this resource for their livelihood is high and the level of awareness is increasing. It is, therefore, imperative that soils be managed properly and used according to their capacity so that they continue to provide goods and services at the required level, which ensures food security, human health, and economic prosperity.

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