Working Paper

A Review of the Global Soil Status Research

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"Soils are fundamental to life on Earth but human pressures on soil resources are reaching critical limits. Careful soil management is one essential element of sustainable agriculture and also provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services and biodiversity."
(FAO 2015b, p. 4)

Abstract

During the last decades, the total area of arable land decreased worldwide, mainly due to unsuitable land usage related to agricultural practices. The Third Agricultural Revolution and growing food demands have put critical stress on agricultural land resulting in serious soil degradation. As a result of modern agricultural practices, both chemical and physical degradation of soil can occur. An interrelated factor contributing to the loss of arable land is erosion, which is a naturally occurring process, but can be accelerated by human activities. This paper reviews research conducted on the soil situation in the six continents (Asia, Africa, North America, South America, Europe and Australia) and provides, therefore, a global overview. Geographically specific causes for soil loss are also given. Soil management and monitoring systems are recommended, however, it should be noted that each system needs to be adapted to its specific environment.

Keywords: soil, global soil status, soil degradation, erosion

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Introduction

During the last few decades, technological innovations, economic development and hyper-globalisation, have made significant changes to the fundamental structure of the Earth. This includes the soil, which is one of the most important substances for living creatures. Due to over-production in agriculture, unsustainable intensification practices, and the unsuitable use of the landscape, the agricultural land[1] has been decreasing. According to data from The World Bank (2014), the agricultural land in 1991 took up 39.47 % of global area, while this slightly number dropped to 37.49 % in 2014. This situation may result from various reasons, such as urbanisation and land erosion. Although the change is slight, considering the growing population, increasing food demand, and the changing climate dynamics, the current industrial agriculture model will accelerate the process. The Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES 2018) stresses this point in the report on land degradation and restoration, which was widely picked up by the media. The report assesses the situation of land degradation worldwide in detail and also discusses different restoration measures.

Soil is a combination of minerals, organic matter, water and air. Once soil is formed, plants and microorganisms absorb nutrients from it and make them available for humans and animals. According to Tarbuck, Lutgens & Tasa (2008), in good quality surface soil, about one half of the total volume is a mixture of disintegrated and decomposed rock and humus. They also pointed out, that the remaining half consists of pore spaces that enable the circulation of water and air. The water inside soils refers to a complex solution, which contains soluble organic matter and metal ions. The air space supplies the oxygen and carbon dioxide to most of the microorganisms and plants (Tarbuck, Lutgens & Tasa 2008). Humus can enhance the ability of soil to retain water.

The pressures on soil resources are rapidly increasing up to a critical point. This causes a rapid increase in soil degradation and erosion processes, while the formation rate of soil is extremely slow. Soil degradation is defined as the decline in soil health condition, as a result of which the capacity of ecosystems to provide goods and services for its beneficiaries is diminished (FAO 2018). Soil degradation can be classified as erosion, chemical and physical degradation. Increasing human demands and activities have caused the so-called human-induced soil degradation. Removal of natural vegetation for economic or urban development purposes, overgrazing, agricultural activities, over-exploration and industrial activities are the main influencing factors (Oldeman 1992).

Soil Erosion

The erosion of soil is a naturally occurring process in all arable land. It involves the movement of rocks and minerals that are transported and deposited in other locations by agents such as wind, water, glaciers and gravity. Water and wind erosion are the dominant erosion forms.

Water erosion is a consequence from rain detaching and transporting vulnerable soil, which causes directly by rain-splash, or indirectly by rill and gully erosion (Favis-Mortlock 2017). Rain-splash requires a great amount of rainfall to move the particles to a short distance, but the particles will merely be redistributed back over soil surface. The rainfall is also able to transport the soil indirectly with water runoff in rills and gullies (Favis-Mortlock 2017). This is the dominant form of water erosion. Such runoff flow is caused by the over-saturation of moisture in the soil or fast and strong precipitation. The runoff creates a thin diffuse film of

[1] Agricultural land is the sum of lands under arable land, permanent crops, permanent meadows and pastures OECD (2007).

water with small power, which is incapable to transport particles. As the runoff gets stronger, it is able to transport, or even detach soil particles (Favis-Mortlock 2017).

Wind is capable of moving loose debris to another location, most effectively in arid and semi-arid regions. In contrast, wind erosion is negligible in humid regions. Unlike water erosion, wind erosion is only capable of transporting fine particles and spreading them over large areas.

Deflation is one type of wind erosion, which occurs after the lifting and removal of loose material. The wind transports the fine sediment away and leaves the coarser particles. As a result, the entire surface will be lowered, which, over time, represents a significant problem.

According to the NAL Agricultural Thesaurus (NALT) by the National Agricultural Library of United States Department of Agriculture (NAL 2018, p. 2991), "chemical degradation is defined as the degradation of a substance by a chemical agent or energy source such as light, heat, or electricity". It refers to the accumulation of toxic chemicals and chemical processes which changes the chemical properties in soil that affects life processes (Logan 1990). However, it does not refer to cyclic fluctuations of the soil chemical conditions under relatively stable agricultural systems, in which the soil still has its ability to maintain its productivity, nor to gradual changes in the chemical composition causing by the processes of soil forming (Oldeman 1992).

Organic matter is a key component of soil and it controls many vital functions (Jones et al. 2012). The change of soil organic carbon (SOC)[2] is one of the important indicators of chemical degradation of soil. The changes of organic carbon occur mostly when the carbon supply through vegetation decreases, or mineralisation increases (Sanchez 1981).

Nutrient imbalance is one of serious soil problems and an indicator of the soil status. Since the application of artificial synthetic fertilisers and intensive agriculture, the balance of soil nutrient has been destroyed.

Acidification is a widespread problem related to soil, especially in coastal regions. It is caused by improper use of nitrogen fertiliser and heavy precipitation, which leads to the leaching of cations and the emission of SO_2 from burning fossil fuels.

Soil contamination is one of the major threats around the world. Most human activities may result in the pollution of soils and adjoining water bodies. The substances that cause soil contamination may come from an over-use of fertilisers, improper use of pesticides and herbicides, pollution from mining, oil spillage, waste disposal from households and industry.

Soil Degradation

Physical degradation of soil is considered to be a gradual process, which begins with structural deterioration and ends in differential loss of finer particles through erosion (Omuto 2008). It also refers to several processes and morphometric forms, mainly the deformation of the inner soil structure by compaction (eds Gliński, Horabik & Lipiec 2011). Through this type of degradation, physical properties, such as pore area in soil, the capacity of drainage, aeration, permeation, etc. are changed. Soil erosion can be considered physical degradation (Oldeman 1992).

The compaction of soil has become a severe issue since the introduction of farm tractors and heavy field equipment in agricultural areas. The porous system in the soil provides water and necessary air to the living creatures. However, when soil is compacted, the soil particles are

[2] Soil organic carbon (SOC) refers to the carbon component of organic compounds in soil WAAA (2017); WAAA (2017).

pressed together, reducing soil porosity. As a result, the water and air content in soil decrease and their movement in the pores becomes restricted.

Sealing/capping refers to the covering of the ground by impermeable materials and it has caused a significant loss of top soil. Due to development pressures, sealing/capping on the soil surface is necessary in urban areas in order to create more space for roads and buildings (Oldeman 1992).

Waterlogging refers to over-saturation of water in soil, which is a common problem in irrigation, especially in flat areas. The major types of waterlogging can be defined as permanent waterlogging such as natural swamplands and occasional waterlogging in flood prone areas. It is mainly caused by poor drainage management, urban/industrial development and deforestation.

Human activities increase the pressure on the land, which leads to human-induced soil degradation, such as contamination and physical degradation. According to Oldeman (Oldeman 1992) and the Global Assessment of Human-induced Soil Degradation project (GLASOD), human-induced soil degradation can have the following causes:

1. Deforestation or removal of natural vegetation: clearing land for agricultural purposes, urbanisation, large-scale commercial forestry, etc.
2. Overgrazing: due to insufficient regeneration time, may cause compaction, water and wind erosion.
3. Agricultural activities: nutrient imbalance caused by insufficient or excessive use of fertilisers, land compaction caused by the application of heavy machines, loss of biodiversity caused by monoculture which normally is industrial agriculture, etc.
4. Overexploitation of vegetation for domestic use: the remaining vegetation does not provide sufficient protection against soil erosion.
5. Bio-industrial and industrial activities: directly related to soil chemical degradation, such as acidification and contamination.

Normally, soil erosion occurs naturally, however, human intervention accelerates the process. Human activities also cause severe soil degradation through contamination, acidification and sealing, which can result in irreversible damage to soil.

Global Soil Status

This chapter will give a brief summary of the global soil status. Subsequently, it will provide more specific information on research on the soil status on the six main continents.

In 1991, the global agricultural area was estimated to be 39.47% of global land area (The World Bank 2014). According to a widely cited report from Oldeman (1992, p. 26), water erosion is the most serious soil erosion problem, which accounts for about 56 % of the total soil erosion and affects an area of around 11 Mkm^2. Deforestation (43.1 %), overgrazing (29.3 %) and agricultural activities (24.3 %) are the dominant causative factors (Oldeman 1992, pp. 26–9). The global extent of soils affected by wind erosion is around 5.5 Mkm^2, accounting for about 28 % of the world soil erosion and degradation areas, in which overgrazing contributed to around 60.6 % of the erosion (Oldeman 1992, pp. 26–9). Regarding chemical degradation, a total area of almost 2.4 M km^2 is affected worldwide, which makes up around 12 % of the world soil erosion and degradation area (eds Behnke & Mortimore 2015)(eds Behnke & Mortimore 2015)(Oldeman 1992, pp. 26–9). Regarding physical degradation, it is identified on only 0.83M km^2 and around 4 % of the total area affected by soil degradation worldwide. The major cause of physical degradation is compaction, sealing and crusting, which makes up over 80 % of the total physical degradation terrain. The ratio of degraded/eroded land area to the inhabited area for individual continents ranges from 12 % in North America, 18 % in South America, 19 % in Oceania, 26 % in Europe, 27 % in Africa and Central America and 31 % in Asia (Oldeman 1992, p. 25). According to report from Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services (IPBES 2018), modern day attempts at quantifying the extent and scale of land degradation have generally proven to be difficult. As a result different studies published till now had different kinds of shortcomings. According to the report, the land degradation assessment from Oldeman (1992) had a limited focus on soil. While as otherrecent reviews (Prince 2015; Sonneveld & Dent 2009) also pointed out that the 'world map' of desertification used by Oldeman (1992) was flawed. According to the research from Gibbs & Salmon (2015), they used different data of assessments on soil degradation to map the degraded land of the world (Bai et al. 2008; Cai, Zhang & Wang 2011; Campbell et al. 2008).

Figure 1 presents the distribution of global degraded land according to four previous researches. The map of Global Assessment of Human-induced Soil Degradation (GLASOD) is generally based on estimations by local experts where there is a lack of field data (Gibbs & Salmon 2015). FAO's Global Assessment of Land Degradation and Improvement (GLADA) project applied the normalised difference vegetation index (NDVI) to quantify the degradation event during 1981 – 2003 (Bai et al. 2008). However, Wessels, van den Bergh & Scholes (2012) pointed out that the GLADA was fatally flawed to assess the degradation results in humid tropics, due to the assessment which is only able to measure the changes in productivity. The research of Campbell et al. (2008) measured the actual situation instead of potential changes, but also excluded the land degradation outside of abandonment and included lands not necessarily degraded (Gibbs & Salmon 2015). Cai, Zhang & Wang (2011) used a biophysical model of agricultural productivity to identify degraded or low-quality cropland, while the research only focused on current cropland and excluded the vegetation degradation (Gibbs & Salmon 2015).

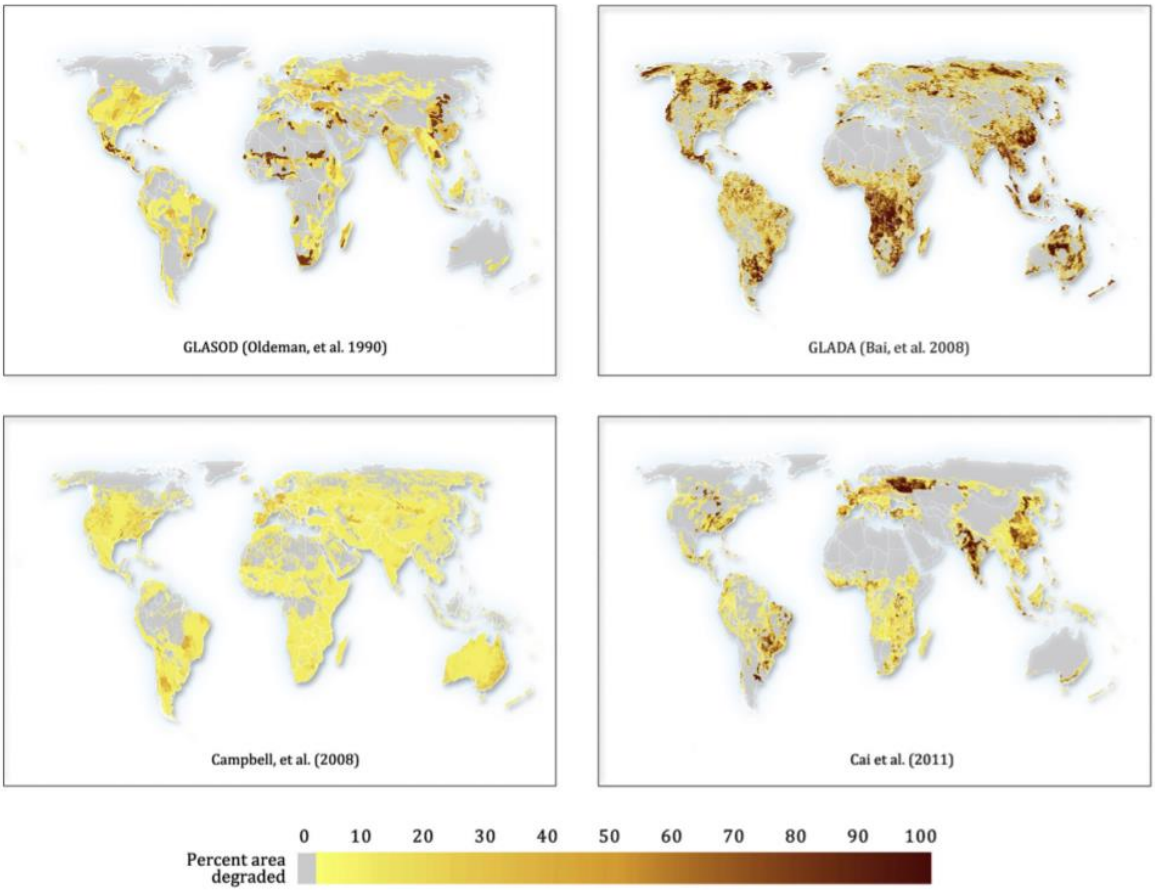

Figure 1. Maps of land areas affected by degradation according to different methods (Gibbs & Salmon 2015)

In 2014, the global agricultural area was about 37.49 % of the land area, which is a decrease of 5.3 % compared to the 1991 projections (The World Bank 2014). However, the assessment of soil degradation is highly uncertain, as it is based on estimates due to a lack of data. A very rough estimation of global water erosion provided by (FAO 2015a) is 20 - 30 giga-tons soil/year over recent decades. Wind erosion is difficult to estimate due to the differences in regional conditions, but approximately 40 % of the Earth`s surface is susceptible to wind erosion (Middleton & Thomas 1997). SOC stocks have reduced 4.2 % since 1850, and (FAO 2015a) reported that the SOC stocks worldwide in topsoil (above 1 m depth) have been estimated to be at around 1500 petagram. About 35 % of ice-free land of topsoil is affected by acidification (FAO 2015a). Between 1995 and 2011, the global urban area had increased by 41.98 %, which resulted in permanent land loss counting up to 1036830 km^2 (Liu et al. 2014). The following table introduces a brief summary of the global soil conditions on different continents.

This table illustrates that the factors affecting soil vary regionally, with the soil condition in Near East and North Africa being the most degraded. The evidence and consensus of soil condition are uncertain in different regions, due to different levels of technologies and measuring techniques. World soil is generally threatened most by erosion and nutrient imbalance. The organic carbon change is also a common problem. The following is a regional analysis of the soil status.

Table 1. Global soil conditions and confidence of the condition (based on: (FAO 2015a).

	Asia	North America	South America	Europe & Eurasia	Africa, South of the Sahara	Near East & North Africa	South-west Pacific
Soil Erosion	Poor ●●●	Fair ●●●	Poor ●●●	Fair ●●●	Poor ●●●	Very Poor ●●●	Fair ●●
Organic Carbon Change	Poor ●●	Fair ●●	Poor ●●	Poor ●●	Poor ●●	Poor ●●	Poor ●●
Nutrient Imbalance	Poor ●●●	Poor ●●	Poor ●●	Poor ●●	Poor ●●●	Good ●	Fair ●●●
Contamination	Poor ●●	Good ●●●	Fair ●	Poor ●●●	Good ●	Very Poor ●●●	Good ●●●
Compaction	Poor ●●	Fair ●	Poor ●●	Fair ●●	Good ●	Poor ●●	Fair ●●
Waterlogging	Fair ●●	Good ●●	Fair ●●●	Fair ●●●	Good ●	Good ●●●	Good ●●
Sealing	Poor ●●	Fair ●	Fair ●●	Poor ●●●	Good ●	Very Poor ●●●	Good ●●
Acidification	Poor ●●●	Good ●●●	Fair ●	Fair ●●	Poor ●●●	Very Good ●●●	Poor ●●

● : Very Poor ● : Poor ● : Fair ● : Good ● : Very Good

●●● High Evidence & Consensus ●● Limited Evidence & Consensus ● Low Evidence & Consensus

Soil Situation in Asia

Soil erosion is one of the main threats to soil in Asia. Serious water erosion occurs in South Asia to East Asia in both dry and wet seasons, particularly in the landscapes of hilly and mountainous areas without sufficient vegetation cover. Wind erosion mainly takes place in the most western and northern arid and semi-arid regions of Afghanistan, Pakistan, India, and China (FAO 2015a). In India, 45.9 % of the total agricultural area is suto soil degradation is of which 37 % is influenced by water erosion and 4 % by wind erosion (Velayutham & Bhattacharya 2000 as cited in FAO 2015a, p. 305). Organic carbon change is also a severe soil problem is Asia. Crop yield enhancement retains SOC in croplands of East and Southeast Asia, while it decreases in South Asia, due to the usage of crop residues for purposes of fuel and fodder. In Japan, during 1980s and 1990s, the average SOC change rate in the arable land was -0.95 teragram C/year and -1.06 teragram C/year between 1990 and 2000 (FAO 2015a, p. 310). China reported that, during 1980-2000, the total SOC changed in the range from -0.143 petagram C/year to +0.094 petagram C/year (Piao et al. 2012). According to (FAO 2015a), some evidence and consensus suggest that soil conditions in Asia will continue deteriorating.

Soil Situation in Africa

According to FAO (FAO 2015a), soil erosion contributes over 80 % of land degradation in SSA (Africa, South of the Sahara), affecting about 22 % of agricultural land and all countries in the region. Laker`s research (as cited by FAO 2018, p. 257) concluded that 25 % of arid and semi-arid areas in South Africa were affected by wind erosion, accounting for about 10.9 million ha. The loss of organic carbon in SSA is another serious problem. A study reported that losses of up to 69 t C/km² year in the top soil were common (eds Gichuru et al. 2003). Evidence indicates that both of the situations will continue and soil will further deteriorate.

In the Near East and North Africa, soil erosion is severe, compared to other regions in the world. FAO (2015a, p. 411) reported that the soil loss caused by erosion in Iran is about 1-2 billion t/year and 76 % of the total area was under erosion threat. In Morocco, erosion was a serious issue which caused around 12-14 tons/year soil loss (Benmansour et al. 2013). Based on the available evidence, the consensus is that this situation will keep deteriorating.

Soil Situation in North America

Soil erosion in North America accelerated after the arrival of European settlers, who cleared large areas for agriculture and over-grazed the land (Montgomery 2007). The report from (FAO 2015a) claimed that the reduction of tillage and improvement of residue management have lowered erosion rates in regions such as the Great Plains in Canada. However, water erosion rates stay at a rather high level in the northern Mid-West of the U.S. and agricultural areas of central and Atlantic Canada. The US National Resources Inventory (USDA 2013) reported that the water erosion rate and wind erosion rate both decreased up to 41 % between 1982 and 2010. Many regions of North America have experienced and continue to experience excess application of nutrients, which will lead to the surplus nitrogen and phosphorus in the soil. In Canada, the residual soil nitrogen had increased from 940 kg N/km² in 1981 to a maximum of 2530 kg N/km² in 2001, while slightly reducing to 2360 kg N/km² in 2011 (eds Clearwater, Martin & Hoppe 2016). However, evidence shows that this situation will continue to deteriorate.

Soil Situation in South America

In South America, water erosion is the dominant erosion type, while wind erosion prevails in specific areas with arid and semi-arid climates. Duvert (2010) pointed out that 42 % of flood events contribute to 70 % of sediment export. Nearly 50% of the agricultural lands were strongly affected by surface soil erosion in the range between 15 - 25% (Oldeman 1992). In Argentina, more than 12,000 km² (32 % of the agricultural lands) were affected by moderate to severe water erosion (SAGyP & CFA 1995). Evidence and consensus indicate that the soil erosion situation in South America will continue deteriorating.

Soil Situation in Europe and Eurasia

In highly populated area of Western Europe, soil sealing is one of the greatest threats to the soil. Between 1990 and 2000, the sealing in the EU-15 increased by 6 % and over 2.75 km² of soil was lost per day, while from 2000 to 2006, the average annual soil loss increased by 3 % (Prokop, Jobstmann & Schönbauer 2011). Due to fast development and urbanisation, there is strong evidence that land sealing will become worse in future. The loss of organic carbon is very obvious in most agricultural land, as about 45 % of the land in Western Europe has low or extremely low organic matter content, which is between 0 - 2 % for organic carbons (FAO 2015a). The trend of this phenomenon will vary in future, as sustainable land management practices are being implemented.

Soil Situation in Southwest Pacific

Soil acidification is an insidious and widespread problem that may cause irreversible damage to soils, particularly in southern Australia and tropical landscapes. An assessment by Lockwood (Lockwood et al. 2003) estimated that the annual value of agricultural production loss, caused by soil acidity, was 1585 million Australian Dollar. Concrete evidence shows that the situation of soil acidification will continue to deteriorate. The soil erosion rate in Australia and New Zealand has been reduced by advanced land management practices, however, the problem is still affecting some districts. In New Zealand, (Eyles 1983) reported that sheet erosion[3] affected 0.1 million km^2, while wind erosion affected 30,000 km^2 (the total area of New Zealand is around 0.27 million km^2). The general consensus is that the status of soil erosion in Southwest Pacific will be improved.

Conclusion

This literature review provides an overview of global soil erosion and degradation status. The degradation of natural resources in arable lands is considered one of the main threats to agricultural production all over the world, as it diminishes agricultural productivity and increases food insecurity. Moreover, the land we can use is limited and economic developments lay heavy stress on it. The growing population also increases the burden on the land, owing to unequal access to resources. Additionally, if the land is still lacking proper management, the extent of irreversible deterioration will keep growing.

On the other hand, nutrient imbalance, such as the excessive usage of fertilisers and contamination caused by herbicides and pesticides is also pushing fertile lands towards becoming wastelands, which are no longer suitable for agriculture. Compaction, capping, sealing and waterlogging are also serious problems, which can cause irreversible damage to land.

Therefore, efforts have to be made to design and implement sustainable regional land management, considering the complexity and spatial variability. For example, the depletion of nutrients is one of the severe issues in most of the developing countries, while over-saturation of nutrients is one of the main problems in some developed countries. Sufficient nutrients should therefore be given to the arable area in arid regions, while over-fertilisation has to be controlled in developed countries. Application of permaculture, agroecological strategies, agroforestry systems, check-dams and key-line systems, can significantly improve the soil conditions.

[3] A type of water erosion caused by rain-splash.

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