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RUVIVAL
Publication Series

05

09/2019

RUVIVAL Publication Series Volume 5

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Identification
ISSN: 2567-8531
DOI: https://doi.org/10.15480/882.2339
URN: https://nbn-resolving.org/urn:nbn:de:gbv:830-882.043948

September 2019

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From the Editors

Preface by Ruth Schaldach

This is the fifth volume of the RUVIVAL Publication Series. This open access publication series is developed within the e-learning project RUVIVAL, which you can visit under www.ruvival.de.

Our project is part of an initiative developed by the City of Hamburg together with all public universities in Hamburg to establish the Hamburg Open Online University (www.hoou.de). Since 2019 the HOOU has been institutionalised and it is now not just a pilot project for promoting Open Education Resources (OERs). Now the idea to make university knowledge not just available online for the broader public, but also to invite people to participate in the knowledge production and exchange will be pushed even more in Hamburg.

RUVIVAL is one of the first HOOU pilot projects and dedicated to sharing knowledge necessary to face rising environmental challenges, especially in rural areas. Therefore, not just to inform, but to empower people to restore and rebuild these areas by themselves. RUVIVAL collects practices and research conducted at the Institute of Wastewater Management and Water Protection (AWW) at Hamburg University of Technology (TUHH), but also from all over the world. Each contribution in this publication is connected to further interactive multimedia material, which can be found, read, tested, watched, shared and extended on the RUVIVAL website, sorted by topic into several toolboxes (https://www.ruvival.de/toolbox/).

Each volume of the RUVIVAL Publication Series takes on a topic, which represents a cornerstone of sustainable rural development. The approach draws a systematic and interdisciplinary connection between water, soil, nutrition, climate and energy. Measures which enable sustainable use of land resources and improvements of living conditions are reviewed and new ideas developed with consideration of their different social, political and demographic contexts.

Volume 5 is introduced by an overview on the global soil status. This article points out which areas are especially affected and most vulnerable for erosion. This is followed by an article on soil erosion, which explains the mechanisms leading to the devastating current state of our soil resources. Connected to this literature review is the RUVIVAL Toolbox, where you can check the soil status in your own area or try out one the recommended measures (https://www.ruvival.de/soil-erosion/). The final article concentrates on measures in regard to water. This last article branches out to Rainwater Harvesting Methods (RWH); however, this time concentrating on local methods based on inherited knowledge with a long reaching usage tradition, often called Traditional Ecological Knowledge (TEK). This article has not only the purpose to draw attention to specific methods, but is also an example to help to draw attention to local inherited methods, which may also be useful in other parts of the world with similar conditions. At this point I would like to invite each reader to contribute to enlarge this knowledge by providing us information on

RWH methods, which are maybe only known in your area. For example, you can contribute with your knowledge to our timeline with examples of systems from all over the world: https://www.ruvival.de/traditional-rainwater-harvesting-timeline/.

The volumes of the Publication Series are a small collection of normally three reviews or introductory texts written in collaboration with Master students, PhD students and researchers at the AWW Institute at TUHH. The work is supervised by at least one senior researcher at the AWW Institute, who is specialised in a related subject. The entire process entails several feedback rounds. This outcome is then published on the RUVIVAL webpage as a working paper and the broader audience is asked to participate with further feedback or ideas in our RUVIVAL Community (https://www.ruvival.de/ruvival-community). The final version of the literature review is only included in the Publication Series once all the feedback has been incorporated and the paper has been reviewed once again by the supervising researchers.

Beyond providing open access to research to a broader public and making it available for practitioners, we strive to directly include our readers in developing our materials. In this way, we hope to connect with the knowledge of a broad audience and provide a deeper understanding of research fields important for sustainable rural development and in areas in need of landscape restoration.

Introduction by Ralf Otterpohl

The UN Millennium Ecosystem Assessment, published in 2005, was a wakeup call for many people around the world. One Third of all arable land has been strongly degraded or even destroyed between 1950 and 1990. It is getting worse in many parts of the world. However, there are many great ways and projects that can reverse degradation, even in a profitable way for the farmers and communities involved. These projects do not get a lot of attention and legislation should include these methods to reverse further land degradation. The RUVIVAL system and Publication Series is covering those approaches to encourage their implementation.

Politicians and media keep repeating statements about the difficulties of a rising world population. They are right only if the soil continues to be destroyed. With all arable land destroyed, our civilisation will be gone. As so many other civilisations before us over the millennia, this will happen again and again to a large extent through soil depletion (see the book ‘Dirt’ by David Montgomery). If all land is restored, which is well possible with the help of millions of people, even a much larger population than the one of today can live in wealth and dignity for all.

An Introduction to the Global Soil Status

It is strange that the most important physical status of our planet: soil health, is not researched in a more comprehensive way. People of our team at TUHH working on this publication were frustrated about the lack of really solid data. The UN Millennium Ecosystem Assessment is still by far the most solid work. This article reviews the literature to show the actual development as good as possible. One of the main threats of erosion is the loss of food production, the loss of water reproduction and the disruption of the local and global climate. A scary fact is that for a specific eroding land area, there is a point of no return after most of the topsoil is gone due to erosion or salinisation by inappropriate irrigation methods. This virtually wipes out many generations of people who could otherwise live off this land.

A Literature Review on Soil Erosion Quantification and Measurements

A proper understanding of soil erosion can help to find good ways of restoration. It is stunning that so many methods of restoration are known (to a few) and proven over decades, but still not generally applied. However, agriculture is developing fast beyond eroding their production systems. The same researcher, David Montgomery of Berkeley University in the USA, who has shown the historic dimensions of the destruction of so many civilisations by the plough in 'Dirt' has now published another book about the solutions. In 'Growing a Revolution' he travels through many countries to collect local solutions. North America is globally far ahead in regenerative agriculture, but the methods can work all over the world in all arable lands and climates. Regions that started to work with nature can be detected by the wealth of those regions. Humans can restore and live with nature and from the land; they can be productive and active. Agriculture with nature, regenerative methods of no-till – highly diverse green manure and direct seeding in combination with rotational grazing have proven to dramatically restore land and productivity over a timespan of only a few years. Agroforestry can help in this process. While numbers in scientific reports are important to assess the situation, these numbers should get more people joining in to work towards restoration.

Traditional Ecological Knowledge (TEK): Rainwater Harvesting Methods – A Review

Many cultures around the world have developed excellent approaches for rainwater harvesting. Solutions range from simple onsite systems to complex improvements on the catchment level. The virtue of these methods is that they are mostly very feasible even without capital investment. At the same time, good knowledge is crucial. Even seemingly simple systems need to be well implemented. A system that works well in a specific situation may even do harm in another one. It is impressive that there are very large historic systems that could not be improved with all the knowledge and computer modelling we have available today. It is also impressive, that well-terraced valleys in dry regions create creeks that flow all year, even throughout the dry seasons. Once implemented with a massive amount of local materials, good knowledge and many people, such systems can serve for hundreds, if not thousands of years.

Inside This Volume

An Introduction to the Global Soil Status

Zhuoheng Chen and Tavseef Mairaj Shah

> *'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.'*
>
> Food and Agriculture Organization of the United Nations
> (FAO 2015b, p. 4)

Please cite as: Chen, Z & Shah, TM 2019, 'An Introduction to the Global Soil Status' in R Schaldach & R Otterpohl (eds), RUVIVAL Publication Series, vol. 5, Hamburg, pp. 7 – 17, <https://doi.org/10.15480/882.2339>.

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 these six continents: Asia, Africa, North America, South America, Europe and Australia, and therefore provides 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*

Introduction

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 50 % of the total volume consists of a mixture of disintegrated and decomposed rock and humus. The remaining 50 % is filled with 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.

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] in the world has been decreasing. According to The World Bank (2014), agricultural land in 1991 took up 39.47 % of the total global area, while this number slightly dropped to 37.49 % in 2014. This situation may result from various reasons, such as urbanisation and land erosion. Although the change is minor, 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) stresses this point in their report on land degradation and restoration, which was widely picked up by the media. The report assesses in detail the situation of land degradation worldwide and also discusses different restoration measures (IPBES 2018).

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 conditions resulting in a diminished capacity of ecosystems to provide goods and services for its beneficiaries (FAO 2018). Soil degradation can be classified into erosion caused by wind or water and into 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 (Montgomery 2007; Oldeman 1992).

Soil Erosion

The erosion of soil is a naturally occurring process in all arable lands. 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 (Oldeman 1992).

Water erosion is a consequence from rain detaching and transporting vulnerable soil,

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

which is caused directly by rainsplash, or indirectly by rill and gully erosion. Rainsplash requires a great amount of rainfall to move the particles a short distance, but even then, the particles will merely be redistributed on the soil surface. Rainfall is also able to transport soil indirectly with water runoff in rills and gullies. This is the dominant form of water erosion. Such runoff flow is caused by the oversaturation of moisture in the soil or fast and intense precipitation. The runoff creates a thin diffuse film of water with insignificant power, which is usually incapable of transporting particles. However, as the runoff gets stronger, it is able to transport, or even detach soil particles (Favis-Mortlock 2017). 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 1,100 M ha. Deforestation (43 %), overgrazing (29 %) and agricultural activities (24 %) are the dominant causative factors (Oldeman 1992, p. 26).

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 sediments away and leaves the coarser particles. As a result, the entire surface will be lowered, which, over time, represents a significant problem (FAO 2015a).

The global extent of soils affected by wind erosion is around 550 M ha, accounting for about 28 % of the world soil erosion and degradation areas, in which overgrazing contributed to around 60 % of the erosion (Oldeman 1992, p. 27).

Normally, soil erosion occurs naturally. However, human intervention accelerates the process, leading to degradation of the soil.

Soil Degradation

Soil degradation can be categorised either as physical or as chemical. Physical degradation is a gradual process that begins with structural deterioration and ends in differential loss of finer particles through erosion (Omuto 2008). Chemical degradation is defined as ‘the degradation of a substance by a chemical agent or energy source such as light, heat, or electricity’ (NAL 2018, p. 2991). While soil degradation can occur naturally, it can also be human-induced.

Human activities increase the pressure on land, which leads to both physical and chemical soil degradation. According to Oldeman (1992) and the Global Assessment of Human-induced Soil Degradation database (GLASOD) (FAO 2019), human-induced soil degradation can have the following causes and consequences:

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, it 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 ma-

chines, loss of biodiversity caused by monoculture, pesticides and herbicides, usually found in industrial agriculture systems, 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 chemical degradation of soil, such as acidification and contamination.

Regarding chemical degradation, a total area of almost 240 M ha is affected worldwide, which makes up around 12 % of the world soil erosion and degradation area (Oldeman 1992, p. 28). On the other hand, physical degradation can be identified on only 83 M ha and around 4 % of the total area affected by soil degradation worldwide. The major causes of physical degradation are compaction, sealing and crusting, which make up over 80 % of the total physical degradation terrain (Oldeman 1992, p. 29). The ratio of degraded/eroded land area to the inhabited area for each continent is: 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).

Physical Soil Degradation

Physical degradation refers to several processes and morphometric forms, mainly the deformation of the inner soil structure by compaction (Blum 2011). Through this type of degradation, physical properties, such as soil pore area, drainage capacity, aeration and permeation, among others, are changed. Soil erosion can also be considered as a form of 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 the air necessary to support life. However, when soil is compacted, the soil particles are pressed together, reducing soil porosity. As a result, the water and air content in the soil decreases and their movement in the pores becomes restricted (FAO 2015a).

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

Waterlogging refers to the over-saturation of water in the soil, which is a common problem in irrigation, especially in flat areas. Waterlogging decreases the amount of air in the soil, limiting oxygen content and nutrient movement. 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 (FAO 2015a).

Chemical Soil Degradation

Chemical degradation refers to the accumulation of toxic chemicals and chemical processes which change the chemical properties of the soil that affect life processes (Logan 1990). However, it does not refer to cyclic fluctuations of chemical soil conditions nor to gradual changes in the chemical composition caused by soil forming processes (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) is one of the important indicators of chemical degradation of soil. Organic carbon changes occur mostly when the carbon supply through vegetation decreases, or mineralisation increases (Sanchez 1981).

Nutrient imbalance is one of the most serious soil problems and an indicator of the soil status. Ever since the application of artificial synthetic fertilisers and intensive agriculture became common practice, the balance of soil nutrients has been destroyed (FAO 2015a).

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 sulphur dioxide from burning fossil fuels (FAO 2015a).

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 over-usage of fertilisers, improper use of pesticides and herbicides, pollution from mining, oil spillages and waste disposal from households and industry (FAO 2015a).

Global Soil Status

According to a report from IPBES (2018), modern day attempts at quantifying the extent and scale of land degradation have generally proven to be difficult. As a result, different published studies have had different kinds of shortcomings. Other recent reviews (Prince 2015; Sonneveld & Dent 2009; Gibbs & Salmon 2015; Bai et al. 2008; Cai, Zhang & Wang 2011; Campell et al. 2008) pointed out that the ‘world map’ of desertification used by Oldeman (1992) was flawed because different methods for assessing soil degradation were used.

Different mapping methods for degraded lands lead to vastly different results. Figure 1 (see p. 12) compares the mapping techniques used in GLASOD, the FAO’s Global Assessment of Land Degradation and Improvement (GLADA) project, Campbell et al. (2008) and Cai, Zhang & Wang (2011) to demonstrate this disparity. The GLASOD map relies on estimations made by local experts when there is no field data available (Gibbs & Salmon 2015). The GLADA project applied the normalised difference vegetation index (NDVI) to quantify the degradation events during 1981 – 2003 (Bai et al. 2008). However, Wessels, van den Bergh & Scholes (2012) pointed out that the GLADA was not capable of evaluating the degradation results in humid tropics. 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).

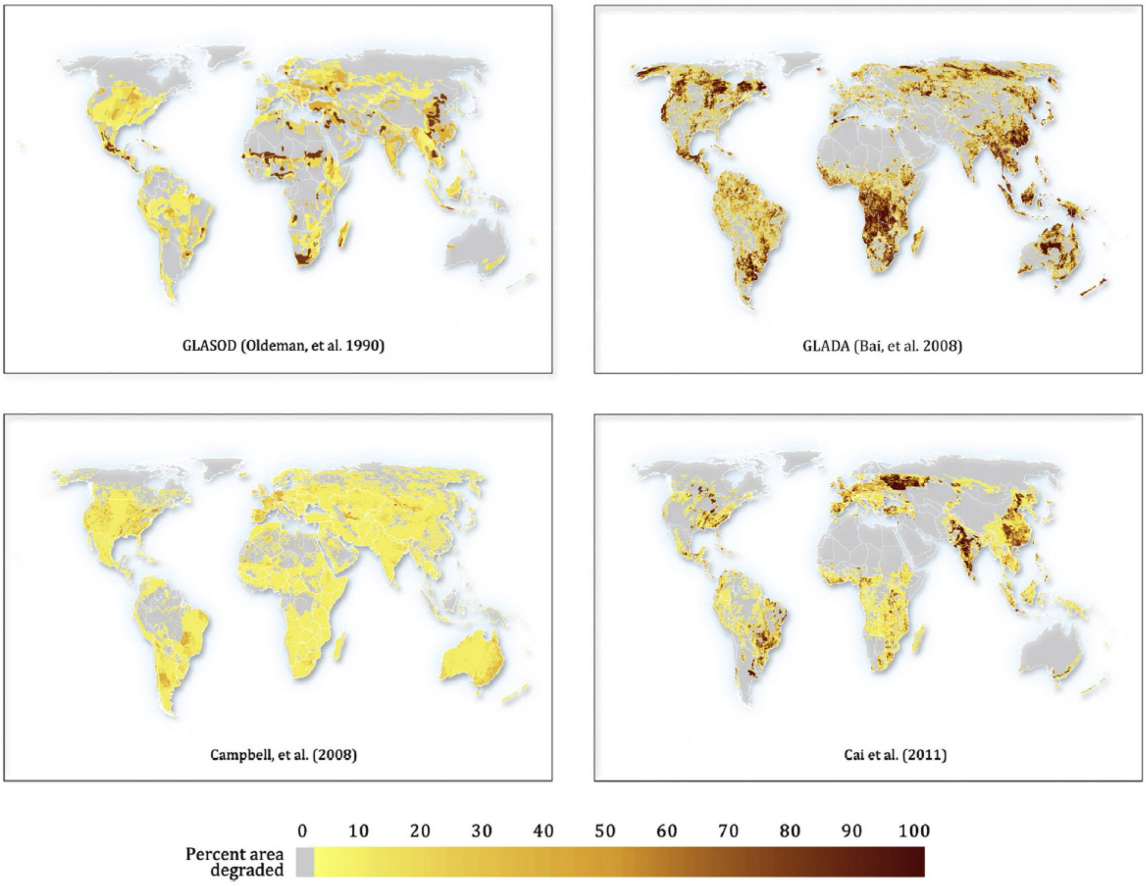

Figure 1 Maps of Land Areas Affected by Degradation According to Different Methods (Gibbs & Salmon 2015, p. 17)

In 2014, the global agricultural area was about 37.49 % of the total global 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 large gaps in the data lead to the widespread use of expert estimation. A very rough estimation of global water erosion provided by FAO (2015a, p. 101) is 20 – 30 Gt soil/a over the 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 (FAO 2015a, p. 101; Middleton & Thomas 1997). SOC stocks have reduced 4.2 % since 1850, and FAO (2015a, p. 118) reported that worldwide the SOC stocks in the topsoil (above 1 m depth) have been estimated to be at around 1,500 Pg. About 30 % of the ice-free land of the topsoil is affected by acidification (FAO 2015a, p. 123). Between 1995 and 2011, the global urban area increased by 41.98 %, which resulted in permanent land loss of up to 1,036,830 km^2 (Liu et al. 2014, pp. 765–6).

Table 1 (see p. 13) provides a brief summary of the global soil conditions on different continents. This table illustrates that the factors affecting soil vary regionally, with the soil conditions in the Middle East and North Africa being the most degraded. The evidence and consensus of soil conditions are uncertain in different regions, due to different levels of technologies and measuring techniques.

World soil is generally threatened the 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.

Soil Situation in Asia

Soil erosion is one of the main threats to soil in Asia. Serious water erosion occurs from 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 suffers from soil degradation, of which 37 % is influenced by water erosion and 4 % by wind erosion (Velayutham and Bhattacharyya 2000, cited in FAO 2015a, p. 305). Organic carbon change is also a severe soil problem in Asia. Crop yield enhancement retains SOC in croplands of East and South-East Asia, while it decreases in South Asia, due to the usage of crop residues for purposes of fuel and fodder. In Japan, the average SOC decreased 0.95 Tg C/a between 1980 and 1990 and 1.06 Tg C/a between 1990 and 2000 (FAO 2015a, p. 310). China reported that, between 1980 and 2000, the total SOC changed in the range from –0.143 Pg C/a to +0.094 Pg C/a (FAO 2015a, p. 299). According to FAO (2015a), some evidence and consensus suggest that soil conditions in Asia will continue to deteriorate.

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	Middle East & North Africa	South-West Pacific
Soil Erosion	🟠🟠🟠	🟡🟡🟡	🟠🟠🟠	🟡🟡🟡	🟠🟠🟠	🔴🔴🔴	🟡🟡
Organic Carbon Change	🟠🟠	🟡🟡	🟠🟠	🟠🟠	🟠🟠	🟠🟠	🟠🟠
Nutrient Imbalance	🟠🟠🟠	🟠🟠	🟠🟠	🟠🟠	🟠🟠🟠	🟢	🟡🟡🟡
Contamination	🟠🟠	🟢🟢🟢	🟡	🟠🟠🟠	🟢	🔴🔴🔴	🟢🟢🟢
Compaction	🟠🟠	🟡	🟠🟠	🟡🟡	🟢	🟠🟠	🟡🟡
Waterlogging	🟡🟡	🟢🟢	🟡🟡🟡	🟡🟡🟡	🟢	🟢🟢🟢	🟢🟢
Sealing	🟠🟠	🟡	🟡🟡	🟠🟠🟠	🟢	🔴🔴🔴	🟢🟢
Acidification	🟠🟠🟠	🟢🟢🟢	🟡	🟡🟡	🟠🟠🟠	🟩🟩🟩	🟠🟠

🔴 : Very Poor 🟠 : Poor 🟡 : Fair 🟢 : Good 🟩 : Very Good
●●● High Evidence & Consensus ●● Limited Evidence & Consensus ● Low Evidence & Consensus

Soil Situation in Africa

According to FAO (2015a, p. 247), soil erosion contributes over 80 % of land degradation in South Saharan Africa (SSA), affecting about 22 % of agricultural land and all countries in the region. Laker‘s research (cited in FAO 2018, p. 257) concluded that 25 % of arid and semi-arid areas in South Africa were affected by wind erosion, accounting for about 109,000 km^2. The loss of organic carbon in SSA is another serious problem. A study reported that losses of up to 69 t C/km^2 per annum in the topsoil were common (Nandwa 2003, p. 20).

In the Middle 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/a and 76 % of the total area was under erosion threat. In Morocco, erosion was a serious issue, which caused around 12 – 14 t/a of soil loss (Benmansour et al. 2013, p. 97).

Soil Situation in North America

Soil erosion in North America accelerated after the arrival of European settlers, who cleared large areas for agriculture and overgrazed the land (Montgomery 2007). The report from FAO (2015a) claims 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 have remained at a rather high level in the northern Midwest of the United States and agricultural areas of central and Atlantic Canada. The US National Resources Inventory reported that the water erosion rate and wind erosion rate both decreased up to 41 % between 1982 and 2010 (USDA 2013, p. 7). Many regions of North America have experienced and continue to experience excess application of nutrients, which will lead to surplus nitrogen and phosphorus in the soil. In Canada, the residual soil nitrogen increased from 940 kg N/km^2 in 1981 to a maximum of 2,530 kg N/km^2 in 2001, while slightly reducing to 2,360 kg N/km^2 in 2011 (Drury et al. 2016, p. 118).

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 et al. (2010, p. 243) 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, cited in FAO 2015a, p. 374). In Argentina, more than 12,000 km^2 (32 % of the agricultural lands) were affected by moderate to severe water erosion (SAGyP & CFA 1995, cited in FAO 2015a, p. 384).

Soil Situation in Europe and Eurasia

In highly populated areas of Western Europe, soil sealing is one of the greatest threats to the soil. Between 1990 and 2000, the sealing in the EU-15[2] increased by 6 % and over 2.75 km^2 of soil was lost per day, while from 2000 to 2006, the average annual soil loss increased by 3 % (Prokop, Jobstmann & Schönbauer 2011, p. 15). 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 obvi-

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[2] The EU-15 countries were comprised of the following: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom.

ous in most agricultural areas, 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, p. 340).

Soil Situation in South-West 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 et al. (2003, p. 1) estimated that the annual value of agricultural production loss, caused by soil acidity, was A$ 1,585 million. 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 (the total area of New Zealand is around 0.27 million km^2), a study reported that sheet erosion[3] affected 100,000 km^2, while wind erosion affected 30,000 km^2 (Eyles 1983, cited in FAO 2015a, p. 486).

Conclusion

This paper provides an introduction to the global soil erosion and degradation status. The degradation of natural resources in arable lands is considered as 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.

Picture Credits

Figure 1 (p. 12) Maps of Land Areas Affected by Degradation According to Different Methods ‘Maps of land areas (percent of cell area) affected by degradation; each panel represents one of the methods described, all shown with common legend and 20 km grid’ <https://doi.org/10.1016/j.apgeog.2014.11.024> by Gibbs & Salmon is licenced under CC BY-NC-ND <https://creativecommons.org/licenses/by-nc-nd/3.0/>.

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[3] A type of water erosion caused by runoff where the water removes a uniform layer of soil particles (eds Gliński, Horabik & Lipiec 2011).

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A Literature Review on Soil Erosion Quantification and Measurements

Antonio Seoane Dominguez and Ruth Schaldach

> *'The on-site and offsite- impacts of accelerated soil erosion must be alleviated and managed to sustain agricultural productivity and environmental quality. Costs of erosion are high and affect the livelihood of all inhabitants particularly in poor regions of the world. Soil not only provides food security and maintains water resources clean but also affects the global climate.'*
>
> (Blanco & Lal 2008, p. 17)

Please cite as: Seoane Dominguez, A & Schaldach, R 2019, 'A Literature Review on Soil Erosion Quantification and Measurements' in R Schaldach & R Otterpohl (eds), RUVIVAL Publication Series, vol. 5, Hamburg, pp. 18 – 31, <https://doi.org/10.15480/882.2339>.

Abstract

Soil erosion is a geomorphological process caused by nature or human activities. It exists throughout the world and erosion rates are highly variable, depending on climatic and topographic conditions as well as local soil properties. Most commonly, soil erosion is associated with water (rain splash or runoff); however, wind, especially in arid and semi-arid regions can cause erosion, too. Many studies investigate the effects of soil conservation practices in different regions of the world, showing that there is no single principle applicable to all cases. In addition to tailoring soil conservation measures to the specific environment, some local agronomic measures may also prevent erosion. The application of vegetation cover increases soil moisture and organic matter content. This also improves infiltration rates of rainwater. Furthermore, the use of organic mulch proves to protect soil against water erosion and improve its physical properties. Whenever possible, agricultural practices should be combined with soil management strategies. Mechanical measures, such as windbreaks and terraces, are rather expensive and are regarded as additional erosion prevention, but never as a stand-alone approach. There is a high need for governmental action to improve education about soil conservation and apply stronger policies regarding the sustainable use of land.

Keywords: *soil erosion, soil conservation, water erosion, infiltration, land use*

Introduction

The soil provides a diverse range of key functions that are necessary to maintaining a healthy ecosystem. These include food production, storage of organic matter, water and nutrients, thus affecting soil fertility. Moreover, it is also a habitat for a variety of organisms. Nevertheless, soil degradation is occurring globally, and its most widespread form is soil erosion (Panagos et al. 2014). Soil erosion is the result of natural geomorphological processes, which are both affected by and have consequences for human activities, often leading to economic and social damage (Montgomery 2007; Rickson & Morgan 1995). Comparing arable land influenced by human activities with undisturbed forests, the erosion losses from arable land are 70 – 2,000 times higher than in undisturbed forests (Berendse et al. 2015, p. 882). Zhao et al. (2013, p. 499) further estimate that about ten million hectares of cultivation area are lost due to soil erosion each year.

Particularly, accelerated (or human induced) soil erosion can cause catastrophic floods, droughts, desertification, and famine, threatening food and environmental security worldwide. The latest Intergovernmental Science-Policy on Biodiversity and Ecosystem Services (IPBES) assessment showed that land degradation caused by human activities is compromising the well-being of 3.2 billion people, driving mass species extinctions and accelerating global climate change (IPBES 2018, p. XX). Moreover, the assessment names land degradation as a major contributor to mass human migration and increased conflict. It is estimated that 4 billion people will be living in drylands by 2050 (IPBES 2018, p. XX).

Traditionally, soil erosion is associated with agriculture in tropical and semi-arid areas. Nowadays, soil erosion spreads globally. A dramatic example is the Loess Plateau, also known as the Huangtu Plateau, located in north-western China. More than 70 % of the once high, flat plain plateau has been transformed into a gully-hill dominated region (see chapter Erosion Processes & Erosion Measurement) due to extreme soil erosion over the last 25 years and intense human activities for thousands of years (Zhao et al. 2013, p. 499). Since the Loess Plateau is critical for Chinese national economic development regarding food and energy production, the livelihoods of millions of people who live there are constantly threatened (Zhao et al. 2013). Another example is the Mediterranean region, where intense erosion is widespread (García-Ruiz et al. 2013). Here, vineyards possess the highest erosion rate in Europe (Rodrigo Comino et al. 2015).

Panagos et al. (2014) discovered that organic matter has an important impact on soil erodibility, i.e. non-resistance of soil to erosion. Countries with high concentrations of organic matter have the lowest soil erodibility (e.g. Ireland, Estonia, Denmark, the Netherlands, the United Kingdom, Finland, Sweden, Latvia), and those with a low concentration of organic matter have the highest (Belgium, Luxembourg, central European countries, Spain, France). Vrieling, Hoedjes & van der Velde (2014) conducted a large-scale analysis of water induced soil erosion in Africa, which shows high values of erodibility in Sub-Saharan countries.

As stated before, soil erosion has a direct, or on-site, effect on agricultural land, lowering food production and food security. Moreover, loss of soil fertility may lead to consequences from increased fertiliser costs to the abandonment of land, all of which result in a substantial decline of land value. In addition to this, there are also off-site effects associated with soil erosion. High amounts of sedimentation downstream/downwind can reduce the capacity of rivers and drainage ditches, enhance the risk of floods, block irrigation canals and decrease the life of reservoirs. In addition, sediments (and the chemicals absorbed to them) can increase the level of nitrogen and phosphorus in rivers and lakes, leading to eutrophication in water bodies. Lastly, previously bound CO_2 may be released into the atmosphere due to the breakdown of soil aggregates, enhancing the atmospheric greenhouse effect (Morgan 2005). These environmental damages often involve high economic impacts as well. Annual costs associated with soil erosion sum up to US$ 30 – 44 Billion in the US, £ 90 Million in the UK and US$ 400 Million in Java (Indonesia) alone (Morgan 2005, p. 1).

Three main factors influence the severity of erosion: energy, resistance and protection. Energy is the potential capability of rainfall, runoff and wind to cause erosion (erosivity). The resistance (or quality) of soil is based on its characteristics regarding erosion (erodibility). For instance, good infiltration indicates high quality soil, whereas low infiltration rates deplete the soil's capability to absorb water and sustain plant growth (Zeedyk & Jansens 2006). Protection refers to the plant cover on the soil surface. Vegetation can reduce soil erosion by intercepting rainfall and reducing the velocity of wind or runoff (Styczen & Morgan 1995). With respect to these factors, Morgan (2005) illustrates the main principles for erosion control strategies. These can be summarised as agronomic measures, such as the use of vegetation to protect soils against erosion, soil management measures, like the preparation of soil to promote plant growth and improve its structure to be more resistant and, lastly, the use of mechanical methods, such as engineering structures like wind breaks or terraces, to control the flow of water and air.

Erosion Processes & Erosion Measurement

Soil erosion can be defined as the detachment, entrainment and transport of soil particles. The erosive forces leading to these processes can be anthropogenic (tillage, land levelling, crop harvesting) or natural (rain, runoff, wind, gravity) (Martín-Fernández & Martínez-Núñez 2011). Natural soil erosion is divided into water and wind erosion. This chapter will illustrate the basic principles of these two erosion mechanisms.

Soil is principally degraded by water erosion (Ochoa et al. 2016). Thus, understanding the mechanism of water erosion plays an essential role in implementing adequate erosion control strategies (see chapters Soil Conservation Principles and Soil Erosion Control Measures – State of the Art). The main water erosion processes, which will be further illustrated, include rain splash erosion, rill and gully erosion and overland flow.

As the name implies, rain splash erosion is caused by the erosive forces of raindrop splashes. Therefore, splash erosion is the first mechanism with respect to the soil erosion process. A detailed image analysis of the splash processes is given in the video 'How water drops impact soil surfaces'[1] produced by the Faculty of Organic Agricultural Sciences from the University of Kassel (Reinisch 2015). As a result of the erosive forces of raindrop splashes, soil particles are detached from the soil surface and further transported over short distances. Depending on the soil, splash erosion can displace soil particles as high as 0.6 m vertically and up to 1.5 m horizontally (Jenkins & Alt 2005). The intensity of splash erosion depends on the resistance of the soil to erosion and on the kinetic energy of the raindrops. Generally, the amount of detached particles increases with the rainfall intensity. Especially on bare soil surfaces, the impact of raindrop splashes is strong. They may enhance soil bulk density due to compacting and crusting, but also form small craters due to the redistribution of particles, subsequently leading to an increase of the soil surface roughness. The resulting crust may hinder plant establishment, since germination and seedling growth are inhibited and infiltration rates are reduced (Fernández-Raga et al. 2017). Reduced infiltration rates may produce an accumulation of water on the soil surface. Especially in warm climates, this water will evaporate quickly, hindering the recharge of underlying aquifers.

Surface water may concentrate in depressions or low points within fields, producing shallow drainage lines. These so-called rills are normally less than 30 cm deep and may lead to soil erosion when filled with surface water runoff. Rill erosion is common in agricultural, especially overgrazed land and freshly cultivated soils, where the soil structure has been loosened (Jenkins & Alt 2005). Rills can usually be removed with farm machinery and erosion caused by rills can be reduced by mechanical methods (see chapter Soil Conservation Principles), such as filter strips, ripped mulch lines and contour drains (Jenkins & Alt 2005).

Channels deeper than 30 cm are called gullies. They occur when rills unite in a concentrated flow of surface runoff. The steeper the soil surface, the higher the velocity of the surface flow and thus, the energy of the erosive forces (Zeedyk & Jansens 2006). This may sometimes lead to deep cuts of tens of metres in depth and width (Pourghasemi et al. 2017, p. 765). In the gully surface, runoff is concentrated, leading to higher flow velocities. Surface protection is constantly reduced and any disturbance can lead to a migrating headcut, but also lateral widening may occur (USDA 2005).

Gullies can decrease soil productivity dramatically by incising agricultural lands, which consequently leads to restrictions in land use, roads and structures (Pourghasemi et al. 2017). Poesen (2018) states that gullies transfer runoff and sediments from uplands to valley bottoms, increasing the connectivity in the landscape. Hence, many cases of sediment and chemical damage to watercourses and properties by runoff from agricultural land are a result of gullying. Both rill and gully erosion can contribute significantly to the catchment sediment yield and to off-site effects such as flooding and reservoir sedimentations (Vannoppen et al. 2015).

Castillo & Gómez (2016) conducted a meta-analysis of the most relevant studies from the last century regarding gully erosion. Their meta-analysis shows that gully erosion

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[1] The video can be found at: https://vimeo.com/130951674.

has been described in a large number of countries, led by Spain, the United States, Australia, China, Ethiopia and South Africa. Their study also illustrates that gully erosion exists in all climates (excluding polar climates). They noted that gully erosion is often seen in grazing and crop lands, pointing to the direct link between agricultural activities and gully erosion initiation.

Raindrop impact, as well as shallow surface flow (overland flow) can lead to the removal of soil in thin layers. This is referred to as sheet erosion. These fine soil particles contain a vast amount of nutrients and organic matter; and therefore play a significant role with respect to soil quality (Jenkins & Alt 2005). With overland flow, soil loss occurs gradually and often goes unnoticed, leading to large soil losses. Soils most vulnerable to overland flow erosion are overgrazed and cultivated soils with a reduced protective vegetation coverage. Early signs of overland flow erosion are bare areas, water puddling as soon as rain falls, visible grass and tree roots, and exposed subsoil or stony soils (Jenkins & Alt 2005). Furthermore, ponding, sheet and rill overland flow may decrease soil infiltration rates, therefore decreasing the availability of water for plant growth (Fernández-Raga et al. 2017).

Wind erosion is a common erosion process in arid and semi-arid regions, where the soil moisture content is at wilting point or below (Jenkins & Alt 2005). Three environmental conditions make soil susceptible to wind erosion:

1. the wind is strong enough to mobilise the soil particles,
2. the soil texture, as well as organic matter and moisture content, make the soil susceptible to wind erosion,
3. there is mostly no vegetation, stones or snow on the soil (Borrelli et al. 2014).

Although wind erosion has always occurred naturally, today the geomorphic effects of wind are locally increased by anthropogenic pressures; e.g. overgrazed rangeland pastures and cultivated areas that remain fallow for long periods of time (Borrelli et al. 2014). Early signs of wind erosion include dust clouds, soil accumulation along fences, and a withered appearance of the soil (USDA 2012).

Soil erosion occurs in several forms; however, soil is principally degraded by the impact of water through erosive forces caused by either rain splash or runoff. Wind erosion is almost exclusively found in arid and semi-arid regions and only under certain conditions. However, when these conditions occur, wind erosion may also cause severe soil degradation.

Measuring Erosion

The average annual rate of erosion on a field can be predicted with the use of the Universal Soil Loss Equation (USLE). This equation integrates the local rainfall pattern, soil type, topography, crop system and management practices. Nevertheless, the USLE equation has two main limitations. Firstly, the USLE equation is an estimate based on different variable factors. Therefore, the resulting soil loss must be viewed as a long-term average. Secondly, the USLE equation only accounts for soil losses due to sheet or rill erosion on a single slope. Soil losses from gully erosion, wind erosion or tillage are not included (Stone &

Hilborn 2012). The Soil Erosion Calculator[2], which is available at the open access e-learning website www.ruvival.de, is a tool that integrates the USLE equation to directly calculate an estimate of annual soil erosion losses on a specific field.

There is a computerised version of the USLE equation, named Revised Universal Soil Loss Equation (RUSLE). RUSLE is an improved formula that integrates more complex combinations of tillage and cropping practices. RUSLE also includes multiple slope varieties. A further upgraded version is RUSLE2, which can do event-based erosion prediction. RUSLE2 requires expansive input information, which may not be available everywhere often due to different legislation (Stone & Hilborn 2012).

The most advanced soil erosion simulation system is the Water Erosion Prediction Project (WEPP). It is a physically-based soil erosion calculator, which integrates hydrology, plant science, hydraulics and erosion mechanisms to predict erosion at both the hillslope and watershed scale. It is capable of modelling and assessing a variety of land uses, climate and hydrologic conditions (USDA 2016).

Soil Conservation Principles

The aim of soil conservation is to reduce the erosion extent in a way that the maximum amount of sustainable agriculture, grazing or recreational activities can be obtained without damaging the environment. Strategies used for soil conservation must be based on: growing soil cover to protect it from raindrop impact, increasing infiltration rates to reduce runoff, improving the aggregate stability of the soil and increasing the surface roughness to reduce the velocity of runoff and wind (Morgan 2005).

Erosion is a natural process which cannot be completely prevented. However, it can be reduced. The measures used to prevent soil from eroding can be subdivided into three principles: agronomic measures, soil management and mechanical methods. Depending on the local situation and the cause of erosion a different measure (or a combination of measures) may be favourable.

Agronomic measures most commonly refer to preventing soil from eroding by using a vegetation cover. A soil surface cover is crucial in regard to soil and water conservation and is commonly used to prevent soil and water losses, especially on sloped land (Duan et al. 2017). Land cover can include litter and living vegetation, and it prevents soil erosion in several ways:

1. it protects the soil surface against raindrop impact and runoff erosion,
2. it decreases runoff volumes and velocities by enhancing the soil's infiltration capacity and its surface roughness,
3. it reduces sediment transport by capturing sediments (Vannoppen et al. 2015).

Over time, planting vegetation will also improve the soil structure and texture (Zeedyk & Jansens 2006). Most attention in scientific literature has been given to above ground mass, as Poesen (2018) points out. Therefore, most models predicting sheet and rill erosion are focussed on plant canopy characteristics. Nevertheless, below ground mass (especially plant roots) play a significant role when inci-

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[2] The calculator can be found at: http://www.ruvival.de/soil-erosion-calculator/.

sive erosion processes, such as rill and gully erosion, become dominant (Poesen 2018).

Besides land cover itself, land use and land management factors affect soil loss, including the type of crop and tillage practices (Panagos, Borrelli et al. 2015). Extensive tillage activities and herbicide treatments keep soils bare and prone to erosion (Keesstra et al. 2016) and should therefore be avoided.

Vannoppen et al. (2015) argue for some beneficial effects of conservation tillage in respect to crop yields and conducted a meta-analysis of 47 European studies that compare crop yields under conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) techniques. They conclude that conservation tillage (RT techniques, together with crop residue management and crop rotation) may be a viable option for European agriculture from the viewpoint of agricultural productivity. However, there is a great amount of literature pointing to the increase of soil erosion rates and the decrease of crop yields due to tillage practices (Heckrath et al. 2005; Lindstrom 2002; Muñoz-Romero et al. 2010).

Ochoa et al. (2016) conducted research on vegetative cover and discovered that the change from natural vegetation cover to that used in pastures or croplands can evoke a rapid decline in the organic matter content of soil, leading to its depletion and a risk of desertification. Generally, a deep, medium-textured, moderately permeable soil that has subsoil characteristics favourable for plant growth will be more resistant to soil erosion than soils with shallow root zones or high percentages of shale at the surface (Renard et al. 1997). Plant roots further modify mechanical and hydrological soil characteristics, including the soil aggregate stability by root exudates, soil cohesion, infiltration rate, and the soil moisture and organic matter content. Their effectiveness in reducing concentrated flow erosion is dependent on several root and soil properties, such as root density, root architecture, soil texture and soil moisture (Vannoppen et al. 2015). Consequently, interference with nature such as deforestation should generally be avoided to keep the soil cover in good condition (IPBES 2018; Ochoa et al. 2016).

Mechanical soil conservation methods are typically based on engineering structures and depend on changing the surface topography to control/reduce the flow of water and air (Morgan 2005). These methods may include the installation of wind breaks, terraces, one-rock dams, log mats, felled trees, brush dams, etc. (Zeedyk & Jansens 2006). Mechanical methods are generally effective for controlling the transport phase of soil erosion, but have only little effect with respect to soil detachment (Morgan 2005).

Finally, it is worth mentioning that agronomic measures in combination with accurate soil management can influence both the detachment and transport phases of erosion. Furthermore, preference should always be given to agronomic measures, since these measures are typically inexpensive and directly affect the raindrop impact, further increasing infiltration rates, reducing runoff volumes and decreasing water and wind velocities (Morgan 2005). Lastly, they are usually combinable with existing farming systems and have positive effects on the biodiversity of the ecosystem.

Soil Erosion Control Measures – State of the Art

A meta-analysis with published data from more than 400 sites worldwide was conducted by García-Ruiz et al. (2015), illustrating that globally there is an extraordinarily high variability of soil erosion rates. Detailed analysis revealed a positive relationship of soil erosion rates with slope and annual precipitation. Furthermore, it was found that land use has a significant effect, with agricultural lands yielding the highest erosion rates, whereas forests and shrublands yielded the lowest.

A study conducted by Keesstra et al. (2016) investigates the impact of different management strategies on soil properties from agricultural land (fruit orchards) in Vall d'Albaida, Spain. Their findings illustrate that vegetation cover, soil moisture and organic matter were significantly higher in covered plots than in tilled and herbicide treated plots. Especially the use of herbicides (leading to bare soils the whole year round) had a significant effect on soil erosion rates: herbicide treatment caused 1.8 and 45.5 times more erosion than tilled and covered soils, respectively (Keesstra et al. 2016, p. 357). Moreover, the highest runoff sediment concentrations were found on tilled plots, showing that extensive tillage, as well as the use of herbicides, should be avoided. The authors further explain that tillage was the only management strategy used by farmers in Vall d'Albaida until the 1990s, when the use of herbicides was introduced, which lead to an increase of runoff and soil losses. Nevertheless, some pioneering farmers used alternative management measures, such as chipping after pruning and spreading the chips on the soil's surface instead of burning them. This led to soil recovery, increasing the soil organic matter and reducing soil bulk density.

Ochoa et al. (2016) conducted a study in the semi-arid Catamayo basin in the Ecuadorian Andes. They found, likewise, that the land cover (often referred to as C-factor) is an important factor to estimate the risk of soil erosion, stating that in protected areas with evergreen vegetation, the soil erosion risk was very low, even with steep slopes and high annual rainfall amounts. On the other hand, where ground cover was sparse, soil erodibility is the most important factor, especially during the dry season in agricultural areas. They conclude that for semi-arid, mountainous regions, during rainy seasons, soil erosion vulnerability is highly influenced by the erosivity factor, followed by the land cover and, to a lesser degree, by topographic and soil erodibility factors. However, during the dry season, soil erodibility and topographic factors become more important, in particular when poor vegetation is present. Concentrating on the soil cover factor, many results found in literature highlight the positive effects of mulching (Fernández-Raga et al. 2017; Grismer & Hogan 2005; Smets, Poesen & Knapen 2008; Zeedyk & Jansens 2006). Mulching is a common practice, which can act as a forest soil litter cover, protecting the soil against erosion and improving the soil physical properties. It is a very effective practice to control soil erosion, especially by water; however, its effectiveness is variable depending on many other factors, such as slope gradient, soil type, rainfall erosivity, and rate of mulch application (Smets, Poesen & Knapen 2008). Smets, Poesen & Knapen (2008) discovered in an analysis of 41 studies that the plot length is important in determining the effectiveness of a mulch cover in reducing soil erosion by water. In particular, the analysis showed that, on short plots, a mulch cover is significantly less effective in reducing relative soil loss by water erosion compared to longer plots.

A state of the art study by Vannoppen et al. (2015) examined the effect of a root variable on different kinds of soil erosion by water. They found that above ground biomass (vegetation cover) was more effective in reducing splash erosion, whereas below ground biomass (plant root system) was more effective in reducing (inter-)rill erosion. Consequently, they suggest a combination of a well-established vegetation cover together with a dense root system in the topsoil as an efficient soil management strategy against water erosion. To further improve this strategy, Berendse et al. (2015) recommend using a variety of plant species for the soil cover. In a three-year long field experiment, they investigated the effect of 1, 2, 4 and 8 plant species on soil loss through erosion on a simulated dike. They found that erosion resistance was reduced with loss of plant species diversity. Their analysis revealed that the main mechanism explaining the strong effects of plant species diversity on soil erosion is the so-called insurance effect: 'the capacity of diverse communities to supply species to take over functions of species that went extinct as a consequence of fluctuating environmental conditions' (Berendse et al. 2015, p. 881). This leads to the assumption that especially in changing climates, a high variety of soil cover species is beneficial for protecting and restoring soil.

A further study by Fattet et al. (2011) compared the effects of tree planting and understory vegetation on steep terrain. The study suggests that in steep terrains, understory vegetation has a better protection effect against erosion processes than tree planting. Fattet et al. (2011) explain that when trees are planted in steep slopes, the understory vegetation is often removed mechanically or cannot grow in shady conditions, resulting in increased runoff and inter-rill erosion. Moreover, root biomass density and root depth is usually lower than in natural forests at an equivalent age, augmenting the risk of shallow landslides, particularly in regions with very high rainfall events. However, an optimal mixture of functional plants can also improve the stability of steep slopes (Fattet et al. 2011). Further, by enhancing biodiversity, different species support each other through water uptake, infiltration and erosion control (Ellison et al. 2017). Particularly in areas with steep slopes, agroforestry systems[3], have the potential to reduce runoff and control soil erosion (Blanco & Lal 2008).

There are many studies pointing to the importance of the infiltration rate of a soil for its capability to resist erosion (Duan et al. 2017; Grismer & Hogan 2005; Keesstra et al. 2016; Smets, Poesen & Knapen 2008; Zeedyk & Jansens 2006). Duan et al. (2017) conducted a study in southern China investigating the effect of rainfall patterns and land cover on runoff generation processes. They found that the total runoff and surface flow values were highest for bare land under all four investigated

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[3] For more information on Agroforestry Systems, take a look at Volume 1 of the RUVIVAL Publication Series: https://www.ruvival.de/ruvival-volume-1/.

rainfall patterns and lowest for the covered plots. The soil cover leads to a decrease in total runoff by increasing the soil water storage capacity and infiltration rates. Mixing topsoil and vegetation litter (such as roots) increased the hydraulic conductivity and permeability of the topsoil, providing favourable conditions for subsurface flow generation.

In general, if a soil has characteristics that prohibit infiltration of water (e.g. crusting, slacking and/or lack of macro pores) the runoff coefficient will be higher, leading to more erosion. However, if the soil has a rough or covered surface, the runoff will be delayed by ponding water, allowing water to infiltrate and reducing soil erosion on such sites (Keesstra et al. 2016).

In case it is not possible to improve the soil structure by vegetation cover, Zeedyk & Jansens (2006) suggest directing water to sites where greater infiltration rates occur. Slowed down water can soak in more easily and cling to soil particles, in addition to enlivening microorganisms which help transport water from the soil pores to plant roots. Also, if moisture is retained long enough, dormant seeds in the soil may germinate. In particular for dry regions with scarce rainfall events, Zeedyk & Jansens (2006) recommend the use of the following water harvesting techniques:

1. structures that retain or divert storm water runoff, such as rolling dips, diversion drains, swales and berms, and micro-catchments,
2. structures that slow the flow of water, increasing the infiltration time, such as one-rock dams, rock lines on contour, straw wattles, and straw-bale dams,
3. mulching the soil with organic mulch, which protects the soil against wind erosion and evaporation and adds organic matter while decomposing.

Grismer & Hogan (2005) compared different soil treatment methods for granitic and volcanic soils in the Lake Tahoe Basin (United States), which is a semi-arid, high-altitude environment of relatively shallow soils, minimal summer rains and long winters. These treatments involved pine-needle mulching, use of compost and planting a grass/vegetation cover. Their results show that the average sediment concentrations declined for the granitic soils by approximately 50 % and sediment yields fell by over 30 % due to the improved soil tilth, water-holding capacity, nutrient cycling and increased infiltration rates (Grismer & Hogan 2005, p. 496). Since volcanic soils contain more fine-sized particles and have relatively high runoff sediment concentrations (in comparison to granitic soils), the grass treatments only reduced rainfall splash erosion, while offering little additional infiltration capacity. They conclude that especially for bare volcanic soils, a more complete restoration is necessary to increase the soil infiltration capacity.

Apart from soil management strategies, a crucial element in conserving our soils is the education of land owners (Arnalds 2005; FAO 2014; Ochoa et al. 2016; Panagos, Ballabio et al. 2015). Ochoa et al. (2016) state that especially in developing countries, where there is a high demand for timber, farmers tend to exploit their lands using slash-and-burn agriculture for quick profits instead of long-term use of their forests. In order to solve this problem, the authors propose more environmental education and land conservation policies. Arnalds (2005) investigated the effects of different soil conservation programmes in Iceland. His study shows that top-down approaches often lacked in incentives for land-user participation. He states that instead of implementing single-issue soil conservation methods, more holistic and integrated approaches to land husbandry were helpful. In conclusion, FAO (2014) recommends the implementation of strong regulations and associated governmental investments, as our soils crucially contribute to the extinction of hunger and poverty.

Conclusion

Soil erosion occurs all over the world and its dependency on climate conditions, soil characteristics and topography makes the rate at which erosion spreads highly variable. Consequently, there is no single soil management strategy that is generally applicable. Nevertheless, there are some conclusions to be drawn from the literature:

1. Agronomic measures, especially covering the soil with vegetation, are highly beneficial as they increase the soil moisture and organic matter content, improve infiltration rates and lead to denser root systems. It is furthermore recommended to use a variety of plant species to enhance the so-called insurance effect. The benefits of a well-established vegetation cover were shown for almost all regions and conditions.
2. A combination of agronomic measures and soil management will lead to higher soil resistances, since agronomic measures are generally more effective against splash erosion, whereas a high amount of underground biomass makes the soil more resistant against rill erosion.
3. Mechanical methods should generally be used as additional erosion control strategies to support agronomic measures and soil management, never as a stand-alone soil conservation measure. They are typically expensive to construct and maintain, and there is no noticeable effect against soil particle detachment.

A specific soil conservation measure to be highlighted is the use of organic mulch. It functions as a mixture between agronomic measures and soil management. Its benefits include direct protection of the soil from water erosion and improvement of the soil’s physical properties. However, it should be noted that the effectiveness of a mulch cover is dependent on the plot size, showing better effects with increasing plot sizes.

Lastly, it should be mentioned that the conservation of our soils is not only a technical and scientific matter, but also a political one. Governments and municipalities should educate local farmers on how to conserve their soils and provide them with financial incentives to prevent exploitation of arable lands. Moreover, strong regulations need to be implemented to further ensure a sustainable use of our soils.

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Traditional Ecological Knowledge (TEK): Rainwater Harvesting Methods – A Review

Sumbal Tasawwar and Rahel Birhanu Kassaye

> *'While few would argue for a complete return to the old ways, it is important to highlight the wisdom of traditional knowledge and its value in contributing to solving our contemporary ecological problems.'*
>
> (Menzies 2006, p. 16)

Please cite as: Tasawwar, S & Kassaye, RB 2019, 'Traditional Ecological Knowledge (TEK): Rainwater Harvesting Methods – A Review' in R Schaldach & R Otterpohl (eds), RUVIVAL Publication Series, vol. 5, Hamburg, pp. 32 – 47, <https://doi.org/10.15480/882.2339>.

Abstract

Over centuries, people in diverse geographical regions relied on rainwater and developed techniques to harvest it, creating a wealth of indigenous knowledge. This paper introduces both traditional ecological knowledge and indigenous knowledge and provides an overview of some traditional rainwater harvesting (RWH) methods. These are divided into two categories: micro-catchment methods and macro-catchment and floodwater methods. Bamboo drip irrigation and rice-fish farming in India are reviewed as case studies. In order to prevent and even reverse environmental degradation, it is important to develop holistic and sustainable strategies. For this, it is vital to learn from what local people already know and practice. There is an urgent need to identify and apply this knowledge for the planet's benefit. These traditional RWH practices may be a little difficult to implement, but they can provide water conservation solutions, especially in vulnerable regions.

Keywords: *Traditional Ecological Knowledge, rainwater harvesting, indigenous knowledge, micro-catchments, macro-catchments, floodwater, India*

Introduction

Indigenous knowledge is the continuous development of knowledge over a long time by a society. It is mostly passed from one generation to another through oral storytelling traditions. It is not limited to tribes, original dwellers or rural people in a region. Instead, it can be any community which carries traditional knowledge, be it rural or urban, settled or nomadic, indigenous inhabitants or migrants (Mbilinyi et al. 2005). Experience gained from adapting to the environment and to changing climatic conditions shaped this knowledge.

Oftentimes, Traditional Ecological Knowledge (TEK) is regarded as a subdivision of indigenous knowledge that is specific to agricultural and natural systems (Martin et al. 2010). Berkes, Colding & Folke (2000, p. 1252) define it as follows:

> ‘[TEK is] a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment.’

TEK matures over many years according to human needs and can provide tools and expertise for long-term sustainability and resource conservation (Martin et al. 2010).

Kabo-Bah et al. (2008) identify the lack of adequate, clean drinking water as a significant obstruction to economic development and progress. Akpinar Ferrand & Cecunjanin (2014) state that a large percentage of the world population still relies on traditional agricultural practices for their livelihood and agricultural output. In areas threatened by climate change, the re-emergence of ancient low-technology rainwater harvesting (RWH) practices, almost forgotten over the years, could provide easily adoptable approaches for greater food and water security. This is especially important for arid, semi-arid and tropical wet-dry climatic regions, where water availability is typically seasonal, and hence determines human survival (Akpinar Ferrand & Cecunjanin 2014).

RWH is a process that concentrates, collects and stores rainwater for a number of purposes. Rainwater can be used either onsite or transported to a different area. The water can be used immediately or later. The term RWH refers to a variety of collection techniques from a linked runoff catchment/production area to an individual receiving area (Mbilinyi et al. 2005).

RWH was more commonly used in the past (Akpinar Ferrand & Cecunjanin 2014). Studies (Angelakis 2013; Mbilinyi et al. 2005) indicate that minor dams and runoff prevention measures for agricultural projects are traceable back to early history. Oweis, Hachum & Bruggeman (2004) suggest that farmers from West Asia and North Africa were the first to use surface runoff and RWH methods for agriculture on a large scale. Assumedly, these systems first originated in Iraq approximately 5,000 years ago. The practice of RWH in India and China goes 4,000 years back. North Africa used RWH techniques expansively before the Roman era. Runoff agriculture, also called runoff farming, is dated back to the 10th century BC in the Negev Desert (Oweis, Hachum & Bruggeman 2004). A system in Yemen (dated to 1000 BC) rerouted runoff water to irrigate 20,000 ha to reap agricultural harvests which served up to 300,000 people (Oweis, Hachum & Bruggeman 2004, p. 4). In Pakistan, several ancient systems are still used, such as sailaba and karez. To this day, the meskat, the jessour and the mgoud water harvesting systems are used in Tunisia. For the north-west coast in Egypt, the custom was to use cisterns and wadi-bed runoff farming (Oweis, Hachum & Bruggeman 2004).

Communities built and developed indigenous RWH techniques, as they depended entirely on rainwater. These measures were mainly aimed at improving water availability for agricultural purposes (Mbilinyi et al. 2005). But they were also used to ensure an adequate water supply for the settlements, particularly for areas in arid and semi-arid climate conditions (Angelakis 2013).

Traditional rainwater management techniques changed according to the amount and distribution of rainfall, the type and depth of soil and the surrounding landscape. This led to the development of a wide variety of different practices such as bunding, pitting, micro-catchments and flood/groundwater harvesting (eds Malesu, Oduor & Odhiambo 2007). Other studies (Lucero, Gunn & Scarborough 2011; Pandey, Gupta & Anderson 2003) illustrate that the development of ancient and traditional RWH technologies were invented due to former climate change events, including yearly and multi-decadal fluctuations in rainfall patterns. Hence, some researchers (Lucero, Gunn & Scarborough 2011; Pandey, Gupta & Anderson 2003) suggest these methods could be used for climate change adaption.

As time went on, more and larger dams were constructed, leading to a centralisation of water resources. Water was transported along channelled rivers from farther and farther distances, finally replacing the traditional RWH practices. However, these centralised systems are not always efficient or sustainable. Particularly in tropical regions with a significant number of small-scale farmers, this has proven unsustainable, as they lose water access with every change to the system (Akpinar Ferrand & Cecunjanin 2014).

It is important to study TEK due to the rapid loss of indigenous languages and cultures; and therefore ecological knowledge. Additionally, TEK is a continual process; hence, there are many changes being made to TEK challenging researchers (Menzies 2006). One of the biggest changes to TEK is the influence of Western science and culture, particularly the effects of colonialism and capitalism (Martin et al. 2010). Much of the studies on TEK take place in locations heavily influenced by these forces (Laureano 2007), and it is crucial that researchers study the original, uninfluenced practices.

Traditional RWH methods can be found all around the world. This literature review provides an overview of some major traditional RWH techniques, categorised under micro- and macro-catchments and floodwater methods. Two case studies based in India, in the Northern Himalayas and the North-Eastern Hills are discussed. Challenges and limitations of indigenous RWH are reviewed with a focus on implementing holistic approaches.

Traditional Rainwater Harvesting Practices around the World

Although there is a wide variety of traditional RWH systems, they all have three elements in common: the catchment area, the storage facility and the target area. The catchment area can be as small as a few square metres or as vast as several square kilometres. Its topography can vary, influencing if some or all of the rainwater from the catchment transfers to another area outside its borders. Some examples of storage facilities are surface reservoirs, subsurface reservoirs, soil and groundwater aquifers. Here, all runoff water is collected and stored for later use. The target area defines where the harvested rainwater is used. This is usually the agricultural production area, with a focus on plants and animals; however, it can also be defined to include domestic purposes (Oweis, Hachum & Bruggeman 2004).

In different regions, similar techniques may have different names; while in other regions, they may have the same names, but work completely differently. RWH methods can be classified in several ways, mostly according to the storage type or its use. However, the most common method is based on its catchment size (Oweis, Hachum & Bruggeman 2004). Figure 1 presents an overview of ten different RWH systems sorted into micro- and macro-catchment methods, and then sub-divided accordingly.

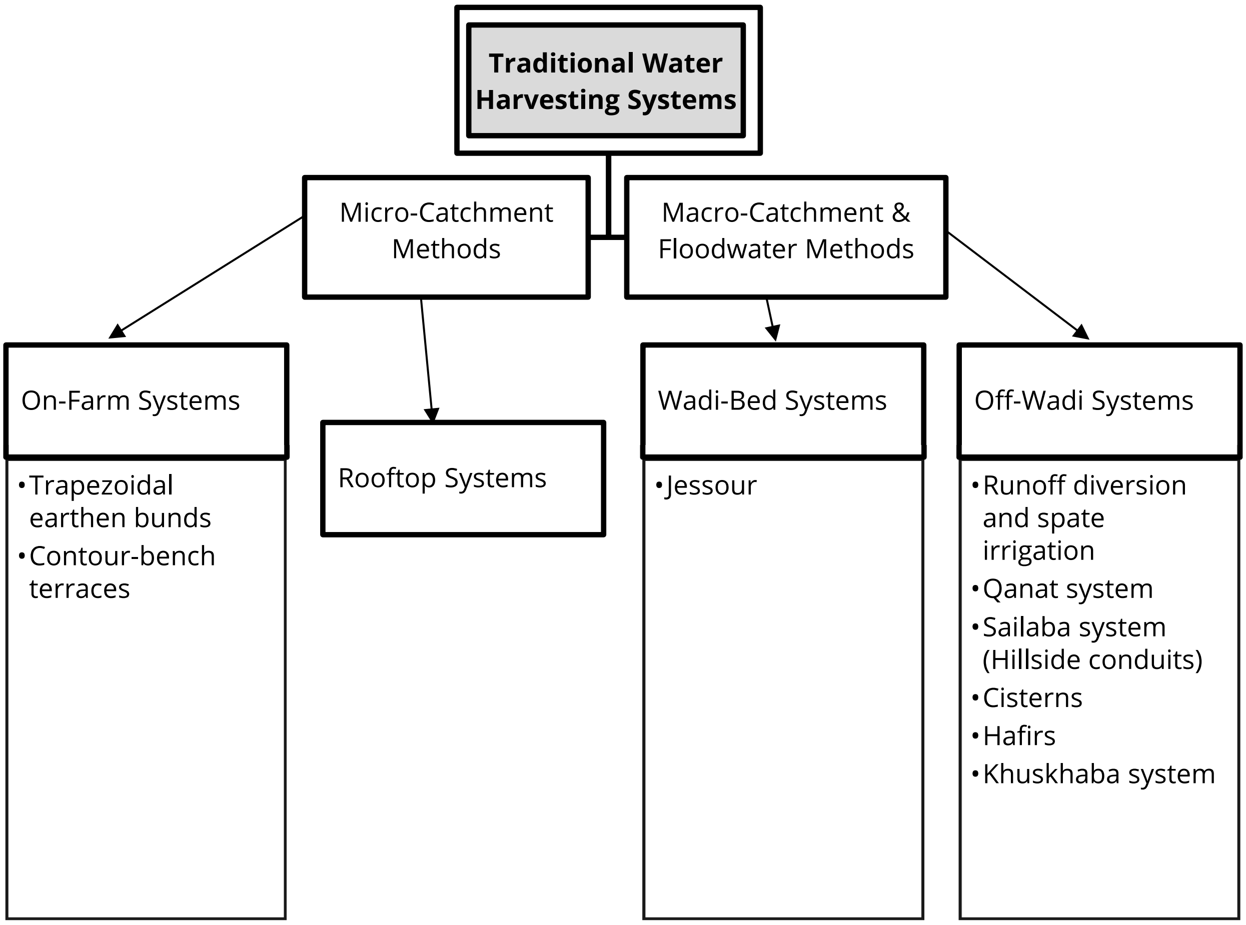

Figure 1 Categorisation of Different Traditional Water Harvesting Systems, Based on Oweis, Hachum & Bruggeman (2004, p. 10)

Micro-Catchment Methods

Collection of surface runoff in a small catchment area over a short distance defines a micro-catchment system. Since these systems have a simple design, replication is easy and adaptable. They mostly do not require a water transportation system. Micro-catchment methods can be divided into two sub sections: on-farm and rooftop RWH systems (Oweis, Hachum & Bruggeman 2004).

On-Farm Systems

This system collects rainfall right where it falls and makes sure that crops effectively use the rainwater. It prevents net runoff from any given cropped area by holding the rainwater and increasing the infiltration time. It is designed to boost infiltration of rainwater into the soil (Mbilinyi et al. 2005). The following are examples of on-farm systems.

Traditional RWH has been extensively practiced in several arid and dry semi-arid environments, such as Kenya, Somalia and Sudan, for growing sorghum and millet. Here annual rainfall is only 150 – 300 mm (eds Malesu, Oduor & Odhiambo 2007, p. 80). Trapezoidal earthen bunds were constructed with winged walls using hands (known as teras) that held water at least up to a depth of 50 cm (eds Malesu, Oduor & Odhiambo 2007, p. 72). Inside this main bund are smaller bunds, where drought-tolerant crops could be planted in advance. Runoff from beyond the cropped area is collected in the trapezoidal bunds. A further expansion of this technique known as fanya chini was practiced in the Arusha region of Tanzania. Here the soil was scattered down-slope instead of up-slope (eds Malesu, Oduor & Odhiambo 2007).

The people of Konso, Ethiopia engineered an impressive structure made from local materials to confine debris and silt. Through practice, they realised that silt flowed in high velocity water; so they came up with structures to moderate the flow of water before it reached its final point. Figure 2 (see p. 37) shows contour bench terracing practiced in the steep mountainous regions (Behailu, Pietilä & Katko 2016). They constructed kilometres of bench terraces (which also allowed water to infiltrate) and planted versatile drought-resistant trees to prevent soil erosion on the steep slopes of Konso. The excess floodwater was collected in ponds specifically made at suitable locations to get maximum agricultural output (Behailu, Pietilä & Katko 2016).

Rooftop Systems

As the term implies, rooftop systems are used for collection and storage of rainwater from large buildings, greenhouses, courtyards, houses and other impermeable objects. The runoff water passes through a settling basin prior to storage. Water collected through this decentralised method is mostly used for drinking water and other household requirements, particularly in rural areas without a central water supply. Such a system is low-cost and provides water for humans and animals in isolated areas. Rooftop systems can also be used for agricultural purposes (Oweis, Hachum & Bruggeman 2004).

Figure 2 (a) A Wooden Mesh to Sieve Debris, (b) Fenced Pond, (c) Preserving Ponds from Silt by Constructing Outside Terraces, and (d) Basins to Collect Silt Coming in through the Flood (Behailu, Pietilä & Katko 2016, p. 8)

Macro-Catchment and Floodwater Methods

Oweis, Hachum & Bruggeman (2004) characterised macro-catchment and floodwater harvesting systems as a comparatively large catchment area that catches runoff. This mostly consists of natural range land, steppe land or mountainous areas. There are two kinds of macro-catchment systems, depending on the location of the target area compared to the valley (wadi) bed. These are the wadi-bed systems and off-wadi systems (Oweis, Hachum & Bruggeman 2004).

Wadi-Bed Systems

In this system, the valley bed is used for water storage. Water can be stored either on the surface, by using water flow blockages, or inside the soil layers, by slowing the water and letting it infiltrate. In this system, individual farmers, or groups of farmers, have water flowing through their lands. This leads to the construction of structures such as small-sized dams or reservoirs. They can use these dams to store runoff water, if an appropriate location exists. An important characteristic of a dam is the construction of a spillway with a certain capacity that is sufficient for high peak flows, which may run through the wadi (Oweis, Hachum & Bruggeman 2004).

In the arid climate of Southern Tunisia, a terraced wadi system is called a jessour (Akpinar Ferrand & Cecunjanin 2014). These high, wall-like structures in steep wadis (made up of earth, stones or a combination of the two) have a stone spillway in them. As years pass by, these walls stop water and, in turn, the sediments settle down and accumulate (Oweis, Hachum & Bruggeman 2004). In these settled sediments behind the dikes (known as tabia), figs and olives are grown. Other crops may also be planted. This technique is not different from cultivation in the valley bed, other than it is practiced on steep areas using spillways to get rid of excess water. Jessours are placed in series along the valley, starting in a mountainous catchment (Oweis, Hachum & Bruggeman 2004; Prinz 1996).

Off-Wadi Systems

Off-wadi systems are those in which harvested rainwater (flowing through the wadi) is altered from its natural route into nearby areas suitable for agriculture using different structures or techniques. This system may be used to collect rainwater from water catchments outside the wadi bed (Oweis, Hachum & Bruggeman 2004; Prinz 1996). Table 1 presents a summary of typical traditional off-wadi RWH techniques.

Rainwater collection, harvesting and storage were the reason for the success of past civilisations in the regions of Central America, South-East Asia and the Middle East. Most of the ancient and traditional RWH technologies in this chapter were established in response to the overall climate of those regions.

Table 1 Some Commonly Practiced Traditional Off-Wadi RWH Techniques

Runoff Diversion and Spate Irrigation	Spate irrigation is a traditional form of water application to irrigable land by diverting runoff of seasonal flash floods from the mountainous catchments through dry wadis and transporting it to arable fields (eds Malesu, Oduor & Odhiambo 2007; Mehari et al. 2008; Mirjat et al. 2011).
Qanat System	Qanat is known by various names such as khettara in Morocco, qanat/karez in Central and Eastern Asia including China and galerías in Spain. It taps into the groundwater (up to 300 m deep) to bring it up to the surface, when the gradient of the tunnel crosses with the water table below (Behailu, Pietilä & Katko 2016, p. 3). Then gravity does the rest of the work without any assistance of power-driven, pumping devices (Behailu, Pietilä & Katko 2016; Oweis, Hachum & Bruggeman 2004).
Sailaba System (Hillside Conduits)	Sailaba systems depend on the natural waterways caused by flooding. Before the runoff water reaches the valley, it is transferred downhill through small channels to planes. These fields are flattened out and enclosed by levees. Using a spillway, extra water can be evacuated to another field that is even further downhill. In this way, all fields are filled up. Then water is let to flow to the valley. This is an ultimate system to make use of runoff water from exposed, scanty vegetated, hilly or mountainous areas (Oosterbaan 2009; Oweis, Hachum & Bruggeman 2004; Rodríguez 2003).
Cisterns	Cisterns were an early form of rainfall water storage used as reservoirs for RWH in arid and semi-arid regions. They were also used to store water for different seasons, transported by conduits. Some were irregularly assembled tanks made of sand and loose rocks, while others were coated with plaster to waterproof them (Angelakis 2013).
Hafirs	Water pans known as hafirs and earth dams/tanks were traditional and fundamental features, with a large water storage capacity for livestock and small scale irrigation in arid and semi-arid lands of Kenya, Somalia, and Southern and North-Eastern Uganda. These were dug into slightly sloping land to collect runoff water (eds Malesu, Oduor & Odhiambo 2007; Oweis, Hachum & Bruggeman 2004).
Khuskhaba	Earthen bunds are built across the land's slope. Rainfall rushes down the incline and is trapped and infiltrated into the soil, supplementing soil moisture, commonly in the valley floors. Part of the land is used for water catchments, while the rest is used for crops. The water runoff from the catchment area is conveyed to the cropped area to enhance yield (Oosterbaan 2009; Rodríguez 2003).

In these very challenging environmental settings such as the dry-wet, semi-arid and arid climatic regions, people were still able to sustain themselves and thrive (Akpinar Ferrand & Cecunjanin 2014; Lucero, Gunn & Scarborough 2011; Pandey, Gupta & Anderson 2003).

Traditional Rainwater Harvesting in India

The Indian subcontinent has a huge variety of impactful and promising RWH practices that extend from wet to arid climatic regions. Presently, the widespread application of RWH in this country is lacking for reasons such as reduced incentives, old colonial-era policies, rise in urbanisation and groundwater extraction and huge irrigation projects for producing cereal. However, the value of RWH techniques within a holistic water resource management is now being realised. The interest is growing due to an increased pressure on natural resources due to the large population (Akpinar Ferrand & Cecunjanin 2014).

Agarwal & Narain (1997) examined many traditional methods of RWH systems developed across India in their book ‘Dying Wisdom’. India has 15 different ecological regions (Figure 3) (eds Agarwal & Narain 1997, p. 26). Each ecological region has its own specific systems, adapted to climate and geography. In this review, two such systems, the ‘Rice-Fish irrigation’ practices in the Eastern Himalayas and ‘Bamboo drip irrigation’ in the North-Eastern Hills are discussed as case studies.

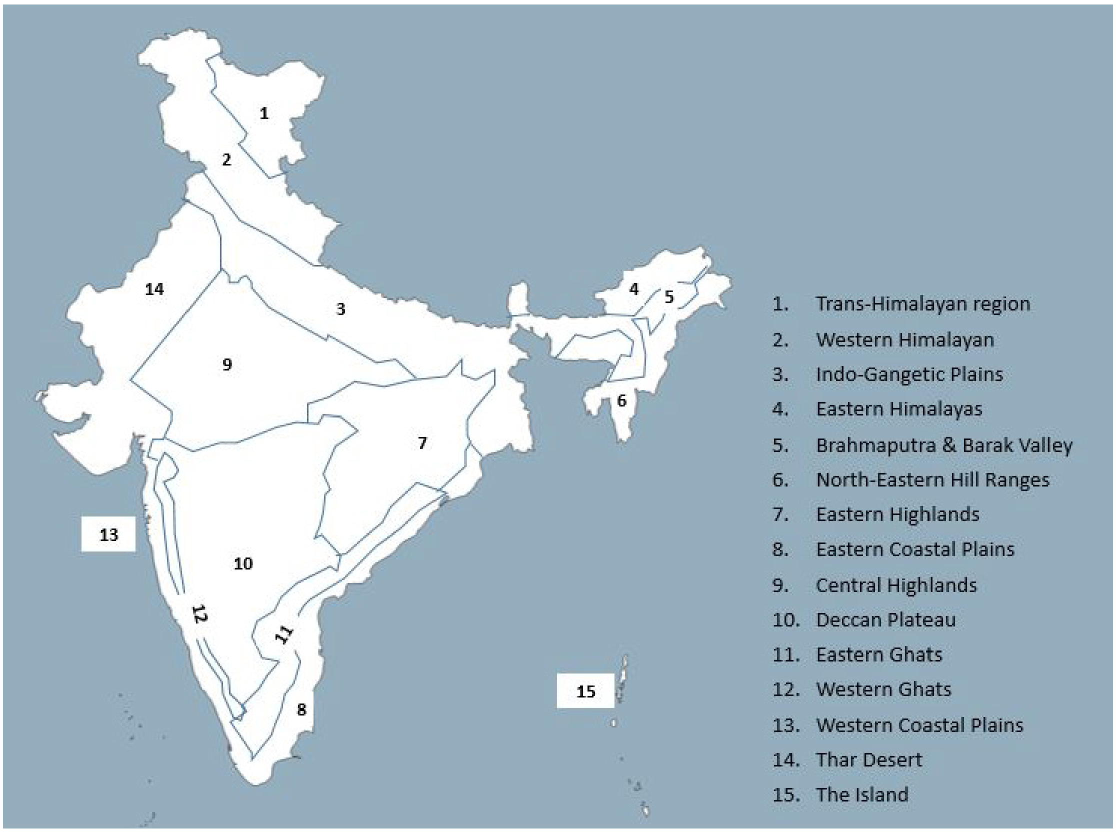

Figure 3 Ecological Regions of India, Based on Agarwal & Narain (1997, p. 26)

Integrated Rice-Fish Farming in the Eastern Himalayas, India

The Ziro Valley in Arunachal Pradesh (in the Eastern Himalayas) consists of 26 main tribes with 110 sub-tribes (Nimachow et al. 2010, p. 25). The combined system of growing rice and fish (Aji-ngyii) is what makes Apatani tribes unique. The rice and fish grown in this system is the main income source for this tribe (Nimachow et al. 2010).

Of the annual 1,758 mm of rainfall, 75 % takes place between May and September (Kumar & Ramakrishnan 1997, p. 51). After this, a dry winter arrives, followed by March and April, which represent the driest time of the year. The specific kind of irrigation used in Aji-ngyii resembles terrace cultivation, but the difference lies in the fact that it is practiced in valleys, which are only slightly sloped. Over time, the Apatanis developed a technical system for field irrigation, which includes moderately flooded rice fields and contour dams dividing the plots in an elaborate design (Kumar & Ramakrishnan 1997).

This multifunctional water management system incorporates land, water and farming systems by providing a barrier against soil erosion, conserving irrigation water and providing a habitat for paddy-cum fish cultures. Held by bamboos and wooden clips, dykes or bunds (0.6 – 1.4 m wide and 0.2 – 0.6 m high) are erected in the fields to maintain the water level (Nimachow et al. 2010, p. 26). To keep the soil as fertile as possible, ploughing is avoided (Nimachow et al. 2010). Millet is also irrigated on dry hilltops as part of dry cultivation (Kumar & Ramakrishnan 1997). Figure 4 shows a flooded rice-fish field.

Figure 4 Rice-Fish Field

Rai (2005) and Nimachow et al. (2010) observed that from the end of one rice harvest until the next plantation, women and men took baskets full of rice husk, pig and chicken droppings, ashes, as well as kitchen waste, to layer it onto these fields to preserve soil nutrients. Moreover, a vital source of manure was supplied by letting out household wastewater into the irrigation canals. This was also reported by Kumar & Ramakrishnan (1997), who mention that oftentimes the rainwater transports human, pig and poultry faecal matter into the local water channels, increasing the nutrient content of the irrigation water.

After harvesting, cattle were allowed to roam freely on the fields, which added to the green manure. Additionally, the fish, themselves, aid in the conservation of soil quality and in the recovery and reuse of nutrients. Lastly, leachate of the decomposed leaves was gathered using pipes connected to a main canal leading to the plots (Nimachow et al. 2010; Rai 2005).

Even though human urine and composted faeces mixed with other items such as wood ash, kitchen and garden waste can meet the potassium and phosphorus needs of plants to enhance the soil structure (Heinonen-Tanski & van Wijk-Sijbesma 2005), caution must be used in their application. A high number of enteric microorganisms (including pathogens) are contained in human faeces, making them unsuitable for agricultural use, unless composted. However, due to its hygienic quality and high nutrient content, urine is a much more reasonable resource for crop fertilisation. Heinonen-Tanski & van Wijk-Sijbesma (2005) identify that even though fresh urine does not contain many enteric microorganisms, some human pathogen microorganisms or helminth eggs can be found in it. Hence, the dosage requirements of urine need to be calculated to avoid health risks. These researchers further argue that in the cultivation of food plants for humans, urine can be used to fertilise the fields, but the urine used to fertilise them should not contain any faeces.

To assist the fish in the Aji-ngyii system, refuge trenches (about 25 – 35 cm) are made, either perpendicularly or irregularly. The dikes in the terraces of varying heights ease the complete drying of the water from rice-fields at an elevation. These water exits made of bamboo screens prevent the fish from escaping. A maximum of 2 – 3 seedlings are sowed at a gap of 20 – 25 cm, hill to hill. After 10 days, fish fries or fingerlings (15 – 20 mm) are stocked at a rate of 2,500 per hectare. Chemical fertiliser is not used in these rice fields. To fix nitrogen, Azolla and Lemna are left to grow. After 3 – 4 months, the fish are harvested (Saikia & Das 2008, p. 127).

If the pesticide input is not managed correctly, fish farming in irrigated rice fields might cause health risks. For example, in Japan, common carp culture in rice fields faced severe setbacks due to pesticide use. Nonetheless, the paddy-fish culture practiced by the Apatani is completely based on organic farming (Nimachow et al. 2010).

Amongst other traditional Indian agro-ecosystems, Apatani agriculture has proved to be extremely proficient, as it has the highest energy efficiency for a rice agro-ecosystem (Kumar & Ramakrishnan 1997). Keeping the aim of maximising rice production, organic practices are given utmost importance. From the Apatani Plateau, the yearly rice production was roughly calculated as 3,000 – 4,000 kg per hectare. Total yearly fish produced from this specific system ranged from 300 – 500 kg per hectare per season without any use of supplements for the fish (Saikia & Das 2004, p. 215). The cultivation cost is low, with very little external inputs (Nimachow et al. 2010; Rai 2005; Saikia & Das 2004; Saikia & Das 2008). Nevertheless, there is a potential for further growth and improvement (Saikia & Das 2004).

It is important that the government, as well as other institutions or non-government organisations (NGOs), pay attention to this eco-friendly technique. There is a great need to spread awareness among the farmers regarding the role of fish as a biological controlling agent. Moreover, educating the locals about their financial options (such as using bank loans and grants to adjust to rice-fish culture) might play an important step in shifting towards sustainable farming practices. Parallel to this, further research on bio-fertilisers and water management should be promoted. Research into selecting and developing different fish species instead of monoculture should also be supported (Saikia & Das 2008).

Bamboo Drip Irrigation in the North-Eastern Hills, India

Bamboo Drip Irrigation is practiced in Meghalaya Hills, one of the seven North-Eastern states in India. With an annual record of about 11,500 mm, it is the wettest and dampest place on Earth (ENVIS Centre 2017). This 200 year old irrigation method is practiced on topography that consists of extreme slopes and rocks, where using ground channels to redirect water is, therefore, not possible (eds Agarwal & Narain 1997). Adapting to their environment, the peoples of the region created the bamboo drip irrigation system.

The Meghalaya hills are home to approximately 3,108 km^2 of bamboo forests of 38 different species (CSE 2011), making bamboo a local, eco-friendly and sustainable renewable resource for their irrigation system (ENVIS Centre 2017). The method works as follows: water enters the bamboo pipe network at a rate of 18 – 20 L per minute. After flowing several hundred metres, the flow rate reduces to 20 – 80 drops per minute at the final plantation site (eds Agarwal & Narain 1997, p. 64). It is common to use this intricate bamboo drip system to irrigate betel leaf and black pepper crops that are sown in areca nut or mixed orchards. Only in dry winter seasons is irrigation water needed. The bamboo pipe system is used for this purpose and is readied before the season's arrival (eds Agarwal & Narain 1997).

From the hilltops, bamboo pipes detour perennial springs to the lower areas, taking advantage of the gravitational force without the need of any energy input. Channels shaped out of bamboo draw out and send water to the plots without any leakage into further subdivisions. Water flows into horizontal pipes are made possible by manoeuvring the position of the intake pipes. The end section allows the water to flow near plant roots; this is only possible due to diversion units and reduced channel sections (eds Agarwal & Narain 1997). These pipelines are 1 – 2 m above the ground, held in place by bamboo or wooden standing structures (Singh & Gupta 2002, p. 37). The farmers take care of the maintenance themselves (ENVIS Centre 2017).

Recently, efforts have been made to bring in modern pipe systems as bamboo supplies decrease. Due to an alarming increase in rodents, gregarious flowering, disease and large-scale extraction, the bamboo of the region has been decreasing (ENVIS Centre 2017). Nevertheless, there is reluctance to the use of new piping materials. Some of the farmers find it difficult and unnecessary to change, due to familiarity with their efficient, traditional RWH system. Others neither trust the materials nor the people who supply them (eds Agarwal & Narain 1997). However, this resistance may not be necessary. Big-scale conservation and protection plans for bamboo are already in action in many regions. These constitute over 50 % of the total amount of bamboo in India, ensuring the security of the supply of bamboo (ENVIS Centre 2017).

Challenges and Limitations

Indigenous knowledge for irrigation and water management developed through practice over many years. These communities cope very well with water shortages, droughts, crops loss, etc. Farmers are able to predict correctly when rainfall will take place and plant their crops accordingly. However, in recent years this has become very difficult due to the change in rainfall patterns. Therefore, farmers are changing the crop types to adapt to this change, for example shifting from cocoa cultivation to drought resistant crops such as cassava. Moreover, vegetable farmers are slowly shifting to the river plains to grow crops, as they do not receive the required amount of water in their current fields. A major source of money earned previously through cocoa farming supplemented the upkeep of families and helped with getting more agricultural input and in developing their farms (Huntington 2000).

According to Martin et al. (2010), even though this current era is oftentimes cited as the information age, a vast amount of information has been lost due to the disappearance of many cultures. At the beginning of the 20th century, there were more than 6,000 languages and cultures, but now half of these have disappeared. About 80 % out of the remaining languages are now just spoken by a small-scale group of older people (Martin et al. 2010, p. 844). This is worrying because losing a language is connected to a loss of knowledge, beliefs, values and practices that the language carries with it. Hence, the fast loss of language and culture makes it even more crucial that research on TEK is carried out with the aim to respect, preserve and maintain indigenous knowledge (Martin et al. 2010).

However, the intentions of scientists studying TEK are viewed sceptically by some. For hundreds of years, design and management methods centred around European science have been favoured over indigenous practices, which have been disregarded, degraded and displaced (Menzies 2006). Hence, TEK researchers should create very clear goals for the local and indigenous groups in order to address this scepticism. Even though the problems related with a reasonable compensation to indigenous and local groups for TEK have not been solved, models are being created that recognise and recompense indigenous cultures for their contributions (Martin et al. 2010).

A study by Ganguly et al. (2014) demonstrated that the unreliability of rainfall is one of the main criticisms against using RWH. Another criticism is that it is unable to fulfil the total water requirement. Other issues include chemical and microbiological contamination of water, creation of mosquito breeding grounds, relatively large investment to income ratios and a potential of inefficiency (Ganguly et al. 2014). Some changes need to be made to allow traditional RWH to meet modern standards.

It is a common belief that rainwater collection systems deliver good quality water without treatment because of the different surfaces used (e.g. rooftops). These surfaces are separated from usual contamination sources, such as sanitation systems. However, these surfaces can also contaminate the water. Dirt, debris and leaves can, and often do, blow into the collection area. Moreover, birds and animals can excrete upon them. Such instances can pollute the water coming into the storage tank, decreasing water quality. Table 2 (see p. 44) gives a brief overview of the impurities found in rainwater collection systems (Mosley 2005).

Table 2 Rainwater Harvesting Systems Contaminants (Mosley 2005)

Pollutant	Cause	Hazard
Dust and Ash	The dirt and vegetation around the site	Moderate: Can be reduced by cleaning the roof and gutter regularly and flushing the water out once.
Pathogenic Bacteria	Bird and animal excreta on the roof and attached to dust	Moderate: Make sure that the bacteria present in dust or in bird faeces is minimalised by first flushing.
Heavy Metals	Materials from the dust or rooftops from urban and industrialised areas	Low: Unless downwind from an industry or manufacturing processes such as metal smelting and/or those that create strong acid rain.
Other inorganic contaminants (salt from sea spray)	Spray from the sea, certain industrial discharges in air, use of inappropriate tank and/or rooftop surface	Low: Unless very close vicinity to the ocean or downwind from a large industry.
Mosquito Larvae	Eggs laid by mosquitoes in stagnant water	Moderate: Screen the inlet/entrance to the tank; make sure there are no gaps.

One of the biggest challenges regarding indigenous RWH knowledge is the integration of new technology with traditional methods. Locals who are accustomed to these systems are not willing to abandon them for new machinery and techniques. Including locals in the planning and developing of these new techniques, as well as respecting their insights, will make them more likely to actively and continually develop and improve their RWH systems with modern technology (Behailu, Pietilä & Katko 2016).

Conclusion

Ten indigenous RWH techniques from the many that are a part of TEK were discussed. These techniques (categorised into micro-catchment and macro-catchment and flood-water methods) have been developed over centuries as efficient measures for adaptation in areas susceptible to climate change. RWH has provided sustainable measures for irrigation, as well as domestic needs. Two case studies of traditional RWH systems were presented. To cope with issues such as water scarcity, integrated rice-fish farming in the Eastern Himalayas of India and bamboo drip irrigation in the North-Eastern Hills of India are still successfully practiced.

Indigenous RWH techniques from different geographical areas are influenced by the region's biophysical factors such as layout, soil type and distance from other water sources. Many traditional techniques being used today show one of the most important advantages of RWH, the adaptability to different conditions.

If reinstated and developed, RWH technologies could secure the water and food conditions of poorer, developing nations as well as climatically susceptible regions of the world. RWH systems can also contribute to an increase in agriculture potential in dry regions. However, this can only be possible if the progress focuses on using a holistic approach instead of the conventional one-dimensional way.

There is a continuous need to provide information and raise awareness for sustainable usage of water resources. Integrating the poorest people will provide water security for future generations. To improve agriculture and natural resource management, it is worthwhile to have farmers with in-depth knowledge on traditional RWH systems and on how to implement these systems on-site. It is important to come up with models and methodologies that promote indigenous knowledge.

Picture Credits

Figure 1 (p. 35) Categorisation of Different Traditional Water Harvesting Systems
Based on Oweis, Hachum & Bruggeman (2004).

Figure 2 (p. 37) (a) A Wooden Mesh to Sieve Debris, (b) Fenced Pond, (c) Preserving Ponds from Silt by Constructing Outside Terraces, and (d) Basins to Collect Silt Coming in through the Flood
'(A) Wooden mesh to filter debris coming to the pond, (B) fenced pond, (C) outside terracing to protect silt from side of the pond, and (D) stilling basin that settles silt coming in with flood before entering the pond' <https://journals.sagepub.com/doi/full/10.1177/2158244016682292>by Behailu, Pietilä & Katko is licensed under CC BY 3.0, <https://creativecommons.org/licenses/by/3.0>.

Figure 3 (p. 39) Ecological Regions of India
Based on Agarwal & Narain (1997).

Figure 4 (p. 40) Rice-Fish Field
'Combined cultivation of rice and tilapia fish aquaculture in a paddy field. Yogyakarta' <https://commons.wikimedia.org/wiki/File:Mina_padi_java_Pj_IMG-20150313-WA0004.jpg> by Kembangraps is licensed under CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0/>.

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