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Invited review article

The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—A global synopsis

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ABSTRACT

This paper presents a global synopsis about the geomorphic evidence of soil erosion in humid and semihumid areas since the beginning of agriculture. Historical documents, starting from ancient records to data from the mid-twentieth century and numerous literature reviews form an extensive assortment of examples that show how soil erosion has been perceived previously by scholars, land surveyors, farmers, land owners, researchers, and policy makers. Examples have been selected from ancient Greek and Roman Times and from central Europe, southern Africa, North America, the Chinese Loess Plateau, Australia, New Zealand, and Easter Island. Furthermore, a comprehensive collection on the development of soil erosion research and soil conservation has been provided, with a particular focus on Germany and the USA.

Geomorphic evidence shows that most of the agriculturally used slopes in the Old and New Worlds had already been affected by soil erosion in earlier, prehistoric times. Early descriptions of soil erosion are often very vague. With regard to the Roman Times, geomorphic evidence shows seemingly opposing results, ranging from massive devastation to landscapes remaining stable for centuries. Unfortunately, historical documentation is lacking. In the following centuries, historical records become more frequent and more precise and observations on extreme soil erosion events are prominent. Sometimes they can be clearly linked to geomorphic evidence in the field. The advent of professional soil conservation took place in the late eighteenth century. The first extensive essay on soil conservation known to the Western world was published in Germany in 1815. The rise of professional soil conservation occurred in the late nineteenth and early twentieth centuries. Soil remediation and flood prevention programs were initiated, but the long-term success of these actions remains controversial. In recent years, increasing interest is to recover any traditional knowledge of soil management in order to incorporate it into modern soil conservation strategies. The study shows that local and regional variations in natural settings, cultural traditions, and socioeconomic conditions played a major role for the dynamics and the rates of soil erosion on a long-term perspective. Geomorphic evidence and historical sources can often complement each other, but there should be also an awareness of new pitfalls when using them together.

1. Introduction

Since the beginning of agriculture in the Neolithic, many phases of agricultural expansions but also regressions occurred in connection with associated land clearances and reforestation in different areas worldwide (Williams, 2003; Ellis et al., 2013). Early agriculture emerged independently in many diverse regions on most of the continents at various times during the Holocene. It spread out from cultural centers like Mesopotamia in the Middle East, the Yangtze and Huang He in China, the Indus and Ganges–Brahmaputra Rivers in South Asia, the New Guinea Highlands, Egypt in northern Africa, the Andes highlands in South America and Meso-America (James, 2013). As a result, the biodiversity, matter, and energy fluxes have been strongly transformed by human impact (Bouma et al., 1998; Messerli et al., 2000; Huntley et al., 2002; Kaplan et al., 2009). This long history of anthropogenic activity had significant implications on environmental change at different scales, from the regional hydrology (Benito et al., 2008; Macklin et al., 2010) and sediment flux (Hoffmann et al., 2007; Dotterweich, 2008) to perhaps global climate patterns (Kaplan et al., 2010).

The removal of the natural vegetation and subsequent substitution with crop cultivation created areas of bare or sparsely vegetated earth vulnerable to soil erosion. The use of hand-held hoes by ancient small-scale trade farmers often kept the surface in a rough condition still favorable for water infiltration. With the later introduction of iron tools and regular tillage operations on larger fields, soil surfaces were smoothed and compacted, encouraging surface runoff and soil erosion on hillslopes. Various forms of degraded landscapes caused by sheet

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erosion (interill), rill erosion, gullying, and piping processes became manifested in many regions under different climate conditions and with diverse land use histories (Poesen et al., 2003; Lang and Bork, 2006; Dotterweich, 2008; García-Ruiz, 2010; James, 2013). The eroded material formed new sedimentary structures including colluvial deposits on footslopes and in depressions, as well as alluvial deposits, fans, and floodplains that later became fluvial terraces (Macklin et al., 2006; Hoffmann et al., 2007; García-Ruiz, 2010). Hence, humans became a crucial agent of geomorphological change, and anthropogenic soil erosion has surpassed previous natural denudation rates (Messerli et al., 2000; Wilkinson, 2005). However, natural soil erosion also occurred as an effect of a decline in vegetation caused by climatic shifts to dryer conditions with episodic extreme precipitation events. Such changes are particularly evident for example in the northern part of the Loess Plateau in China (Li et al., 2010) or in some areas of the Mediterranean (Piccarreta et al., 2012). They are often difficult to distinguish from human-induced processes, particularly if both occur simultaneously.

Lal (2003) estimated that the area of land affected by soil erosion through water today is about 1094 million ha at a global scale, of which 751 million ha are severely eroded. Pimentel et al. (1995) assessed that about 12 million ha of arable land are destroyed and abandoned annually because of nonsustainable farming practices. To create larger farms and fields, farmers have removed the grassy edges, shelterbelts, and hedgerows that had protected the soil from erosion during the previous 50 years. Soil erosion depletes soil fertility, degrades soil structure, reduces the effective rooting depth, and disturbs the foundations of all natural processes. The decline or vanishing of numerous civilizations around the world has been closely linked with the degradation of their resources, particularly deforestation, accelerated soil erosion, and the decline of crop yields (Marsh, 1864; Lowdermilk, 1953; Brown, 1981; Dregne, 1982; Mieth and Bork, 2003; Diamond, 2006; Montgomery, 2007). Such processes can also occur separately or in combination with other factors like urbanization, epidemics, rebellion or war (Williams, 2003). However, continuous physical degradation of a landscape and the decline of local and regional resources will ultimately decrease socioecological resilience. Such fragile systems are highly vulnerable to small internal and external impacts. In the context of soil erosion, repeated moderate or single extreme events forced by climate change may have affected the productivity of the land so much that agricultural usage had to be ceased. On a local to regional scale, this may occur surprisingly fast. Especially punctuated events may trigger catastrophic changes, forcing premature land use abandonment (Dotterweich and Dreibrodt, 2011). On the other hand, humans created strategies to prevent further degradation or to mitigate environmental problems. Hence, an awareness of the impact of land use on soil characteristics in the past and an understanding of the long-term processes of soil erosion are essential for a better insight into long-term human–environment interactions in general (Dearing et al., 2006). Moreover, the past holds suggestions and ideas about sustainable strategies to protect and restore the soil. It is therefore crucial to evaluate current soil conservation strategies under changing climatic conditions and increasing land use pressure.

During the last few decades, the potential to use erosional landforms and soil-sediment structures for the reconstruction of past soil erosion and to use colluviation in order to assess human impact and climate change has been recognized by an increasing number of studies. The majority of these studies focus on alluvial sediments on floodplains in different environmental settings (e.g., Trimble, 1974; Knox, 2006; Leigh and Webb, 2006; Leigh, 2008; Walter and Merritts, 2008; Macklin et al., 2010; Notebaert and Verstraeten, 2010; Hoffmann et al., 2011). These studies show processes and timings of geomorphologically significant floods, river terrace aggradation, and channel change as a consequence of land use and climate change. However, while river sediments reflect regional trends in land use changes, human-induced erosional landforms and soil sediment structures along slopes and gully forms allow characterization of sediment fluxes in coupled slope-channel systems at a high spatial and temporal resolution (Dotterweich, 2008). This has been demonstrated for instance in western Europe (Bertran, 2004; Larue, 2005; Lespez et al., 2008; Brown, 2009), the Caucasian region (Borisov et al., 2012), Meso-America (Beach et al., 2006b), the USA (Barnhardt, 1988; Waters and Haynes, 2001), China (Rosen, 2008; Wu et al., 2008), Mongolia (Lehmkuhl et al., 2011), or Australia (Prosser and Winchester, 1996; Beavis et al., 1999; Whitford et al., 2010).

The long-term feedback of such erosion and sedimentation processes to an ecosystem, including socioeconomic aspects and human behavior, has also received attention in geomorphology and soil science recently (Bork et al., 1998; Bintliff, 2002; Butzer, 2005; Dotterweich, 2008). For example, historical studies in Germany show that during the first half of the fourteenth century CE, many villages had been abandoned as an ultimate consequence of a combination of sociocultural processes, crop failures, and soil degradation caused by soil erosion (Dotterweich, 2008). The price of food had increased significantly for several consecutive years in the first half of the fourteenth century CE because of shortages, which had been a consequence of soil degradation and economic mismanagement (Fraser, 2010). These unfavorable socioeconomic, nutritional, and health situations might have prepared the ground for starvation and diseases. In the eighteenth to early nineteenth centuries CE, soil erosion and crop failures led to major migrations overseas. Soil erosion appears to have been one factor in a complex causality spiral leading to socioeconomic instability and land use changes (Dotterweich and Dreibrodt, 2011).

From a historical perspective, several studies and overviews about soil management knowledge in historical times have been published (Winiwarter, 2000; McNeill and Winiwarter, 2004; McNeill and Winiwarter, 2006; Winiwarter, 2006b,c; Brevik and Hartemink, 2010; Winiwarter, 2010; Emberger, 2012). They show that long before the introduction of scientific research, subsistence farmers had a good practical knowledge of how to manage soils sustainably. Soil conservation strategies have often been embedded in many traditional soil management systems. For example, agricultural terracing is one of the main techniques to prevent soil erosion that had emerged already 4000 years ago (maybe over 6000 years) to control soil erosion (McNeill and Winiwarter, 2004; Sandor, 2006). However, knowing whether a particular terrace was primarily created to protect the soil, for irrigation or for other purposes is often difficult.

Historical studies that focus on human-induced soil erosion by water are also available. For example, on a global scale, Lowdermilk (1953), Dale and Carter (1955), McNeill (2001), McNeill and Winiwarter (2004), and Montgomery (2007) have summarized the history of past soil erosion and soil management over the last millennia. Mosley (2010) gave a general overview about soil management, soil degradation, and soil protection strategies in different cultures and periods, and Brevik and Hartemink (2010) presented examples on the perception of soil erosion in historical times in the context of a precise understanding of soil and the birth and development of soil science. Additionally, numerous case studies and regional overviews refer to historical descriptions on past soil erosion. Several of them will be cited later in this paper. Some of the literature and textbooks about the research history of soil science, geomorphology, or soil conservation also provide summaries on historical soil erosion and soil conservation (e.g., Ehrenberg, 1915; Giesecke, 1929; Bennett, 1939; Jacks and Whyte, 1939; Mickey, 1945; Mückenhausen, 1949; Faulkner, 1953; Howard, 1953; Dale and Carter, 1955; Richter and Sperling, 1976; El-Swaify et al., 1982; Krupenikov, 1992; Pimentel, 1993; Hudson, 1995; Yaalon and Berkowicz, 1997; Richter, 1998; Troeh et al., 2004; Warkentin, 2006; Orme, 2013).

Studies focusing on the perception of soil erosion in historical times in the context of geomorphic evidence are still rare. For example, Showers (2006a) presented an extensive case study on the perception of soil erosion since the early nineteenth century, including the