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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 Historical documents, starting from ancient records to data from the mid-twentieth century and numerous literature reviews form an extensive assortment of examples that show how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

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development of different conservation practices in Lesotho; and Mather (1982) discussed the changing perception of soil erosion in New Zealand. However, the analysis of contemporary descriptions and observations on soil erosion is problematic. The sources need very critical analysis because they were often created in the context of personal interests or political issues instead of being based on scientific facts (Showers, 2005; Lane, 2009). In addition, it is often unclear if the writer has credibility and if the description documents a genuine observation of a uniquely disturbed site or the wider conditions accurately. Frequently they describe extreme events that may be exaggerated while the more subtle and continuous processes of sheet wash are neglected. The philosophical background and the level of knowledge of the person producing the source have to be considered and whether the writers' document observed events, created narratives, or simply presented vague assumptions. Also, the description of the areas and periods are often imprecise and linkages to geomorphic evidence need careful consideration. Finally, documentary records about soil erosion are not common and often are deeply buried in archived files and rarely indexed with respect to soil erosion. Consequently, the spatial–temporal linkage between geomorphic evidence and historical descriptions is often very difficult and requires extensive research.

Hence, this paper gives an overview about the current knowledge on human-induced soil erosion by water in humid and semihumid areas since the beginning of agriculture. The data has been derived from geomorphological and geoarcheological evidence like erosional forms and surfaces as well as colluvial, alluvial, and lacustrine sediments in Europe, Africa, America, Asia, Australia, New Zealand, and Easter Island. Historical descriptions, essays, reports, rules, poems, figures, and other sources about observed soil erosion processes, eroded landscapes, or soil protection strategies will be presented to provide examples on how contemporary travelers, farmers, land owners, land surveyors, researchers, and policy makers may have perceived soil erosion from the middle of the first millennium BCE until the mid-twentieth century CE. In this context, the paper also summarizes examples on the early developments of soil conservation. Depending on the previous research and because of the availability of historical records or their dearth, the presented citations encompass areas or sites particularly in central Europe, ancient Greece and Rome, southern Africa (Lesotho and Malawi), China (Loess Plateau), and eastern North America.

The presented material is based upon studies from many additionally cited authors and the reader is also referred to these works for expanded discussions in the research areas they address. Owing to the limitations of a journal-length paper, most of the historical records are presented in the original language and translated in the online supplement as excerpts only. As far as possible, the mentioned locations have been given in Fig. 1 and as Google Earth placemarks (pm) in the supplementary materials.

2. Europe

2.1. Geomorphic evidence and causes of past soil erosion in Europe

The anthropogenic transformation of European landscapes varies widely for different regions, and the widespread occurrence of past soil erosion has been examined. In the area of Mediterranean Europe, land use has significantly modified the landscapes directly and indirectly since the Neolithic (Glacken, 1976; McNeill, 1992; Shipley and Salmon, 1996; Brandt and Thornes, 2002; Grove and Rackham, 2003; Hughes, 2011), and research on the effects of past land use on the environment and on soil erosion has a long tradition (Judson, 1963; Vita-Finzi, 1969; Hughes and Thirgood, 1982; Bintliff, 2002; Butzer, 2005; Dusar et al., 2011). Mediterranean environments are particularly prone to soil erosion because of high rainfall intensities, alternation of wet and dry periods, low average annual precipitation, the fragility of many soils (low organic matter content, poor nutrient content), the presence of steep slopes, and the long history of landscape transformation, including deforestation, forest fires, frequent land use changes, and cultivation in extreme topographic and climatic conditions (Wainwright and Thornes, 2004; García-Ruiz, 2010; García-Ruiz et al., 2013). Most studies assume that soil erosion started or accelerated after the removal of natural woodlands since at least the Bronze Age. Based on geomorphological, pedological, paleoecological, and geoarcheological studies, important phases of soil erosion have been detected for the Bronze Age and/or the Classical period, for example in Greece (van Andel et al., 1990; Lespez, 2003; Fuchs et al., 2004; Bintliff, 2005), Cyprus (Fall et al., 2012), Turkey (Brückner et al., 2005), Italy (Marchetti, 2002; Eppes et al., 2008; Piccarreta et al., 2011, 2012; Pelle et al., 2013), southwestern France (Bertran, 2004), and Spain (Cerdà, 2008; García-Ruiz, 2010). Grove and Rackham (2003, p. 311), however, argued against past land use by ancient civilizations having been the main cause for soil erosion because the chronology of alluvial sediments does not regularly correspond with the rise or decline of past land use. Instead, episodes of abnormal weather conditions and local deluges may be contributory factors. However, the causes of soil erosion in the Mediterranean landscape are very complex and only individual multicausal explanations are appropriate to elucidate landscape changes (Bintliff, 2002).

In contrast to the Mediterranean, soil erosion north of the Alps is more strongly associated with land use in the more humid parts of Europe (e.g., Stehlík, 1981; Starkel, 1987; Bell, 1992; Dearing, 1994; Howard et al., 2003; Lang and Bork, 2006). For central Europe, several comprehensive overviews combining studies on hillslope erosion, gully erosion, and floodplain development have been published in Bork et al. (1998), Lang and Bork (2006), Hoffmann et al. (2007), Dotterweich (2008), Dreibrodt et al. (2010), or Notebaert and Verstraeten (2010). For example in Germany, the observed variability of soil erosion in

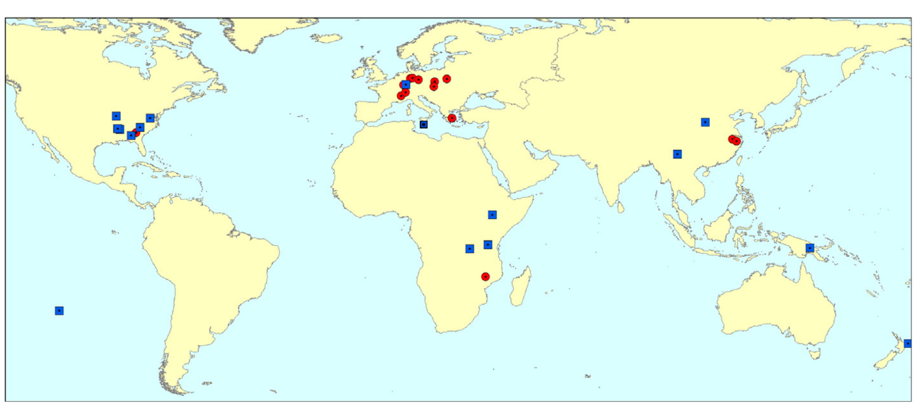

Fig. 1. Location of selected case studies that are mentioned in historical records (red) or which show geomorphic evidence (blue) on past soil erosion and soil conservation (cf. Google place marks in the online supplements).

small catchments reflects, to a large extent, the varying intensity of population pressure and agricultural land use. Already the manipulation of forest vegetation by fire through sedentary Mesolithic hunter and gatherer groups may have created open areas and enabled intensive soil erosion at a local scale (Dotterweich et al., in press-a). The effects of agriculture are illustrated by the pronounced increase of soil erosion, particularly at the onset of and during the Neolithic period (ca. 5500–2200 BCE in southern and central Germany). Further peaks occurred perhaps at the end of the Bronze Age (~1000 BCE) and at the end of the Roman times (~200/300 CE). Distinctively low levels in soil erosion have been detected for the early Bronze Age (ca. 2000–1600 BCE), the Migration Period (around 400/500–700 CE), and early Middle Ages (ca. 700–1000 BCE) (Dotterweich, 2008). Seemingly, centennial-scale climate change affected the observed variability by modifying the threshold conditions for erosion. The most remarkable phase of human-induced soil erosion took place in the first half of the fourteenth century CE, a phase of climate deterioration with increasingly frequent extreme precipitation events and very intensive land use (Fig. 2). The second well-known intense soil erosion phase with severe gullying developed in the mid-eighteenth to early nineteenth centuries CE (Fig. 2). Historical records document extreme precipitation events during these two phases, implying a strong influence of climatic extremes on geomorphological processes. However, certain phases of the record remain unexplained. For example, within the Roman Provinces, geomorphic indications suggesting low intensities of soil erosion can be found at sites with clear proof of intensive land use while at other sites with little evidence of relentless land use, often outside of the Roman Empire, high rates of soil erosion were detected (Dotterweich and Dreibrodt, 2011). Regarding the latter, continuous soil erosion did not appear to be too high at the respective localities. Instead, the occurrence of single erosion events seems to have been the dominant cause (Dotterweich and Dreibrodt, 2011). However, the last phase of accelerated soil erosion has taken place since the mid-nineteenth century. Sheet erosion was at a low intensity until the mid-twentieth century. Since then, the introduction of mechanized agriculture and the enlargement of fields triggered increased runoff and soil erosion once more. Today, many areas that were highly affected by hillslope erosion or gullying in the past are under forest and stabilized (Dotterweich, 2008).

In the more marginal areas of northern Europe past soil erosion has also had dramatic effects. In Iceland for example, where occupation began in 874 CE, soils became very vulnerable to erosion after deforestation and intensive grazing. Regulations on preventing overgrazing were already in place from around 1200 CE onward, and adaptive soil management practices had a positive effect causing a decline of soil erosion in the fifteenth century. However, the limited cultural knowledge of changing and rapidly fluctuating environmental conditions hindered appropriate regulation of grazing on a long-term time scale (Simpson et al., 2001; McGovern et al., 2007). Today, a large proportion of the formerly usable grazing areas in Iceland are severely eroded (Arnalds et al., 2001).

The most common geomorphic legacies revealing attempts to prevent soil erosion on hillslopes in Europe are terraces that were formed by tillage or construction. They are very common throughout Europe's farmland areas and particularly impressive in the case of vineyards (Petit et al., 2012). Some terraces in Mediterranean Europe have probably been constructed as early as the Bronze Age (Grove and Rackham, 2003, p. 112). A recent review about their properties, development, best management practices, and conservation of terraced soils in Mediterranean Europe has been presented by Stanchi et al. (2012).

2.2. Historical descriptions of soil erosion in ancient Greece

The ancient Greek philosopher—scientists were excellent observers of nature and had already gained a clear understanding of soils (Brevik and Hartemink, 2010). The first descriptions that refer to the planting of olive and fig trees in the region of Attica (pm 2-1) date back to the sixth century BCE. Plutarch, a Greek historian, wrote the history of the lawmaker Solon who gave instructions on the planting of trees on the hillsides of Attica around 75 CE (Plutarch—Solon 23,6. 24,1; cited in Perrin, 1914, cf. excerpt in Suppl. 1.1). For the same time and area, Dio Chrysostom mentions in his discourses (written in the first century CE) that during the leadership of Peisistratus (who ruled in Athens for several decades until his death in 527 BCE) people stayed on the land and became farmers. Peisistratus also gave the order to reclaim bare land by planting olive trees (Dio Chrysostom orat 25,2, cited in Cohoon, 1939, 326f.; cf. excerpt in Suppl. 1.2). According to these descriptions Attica was already devoid of woodland and possibly highly degraded by soil erosion in the mid-first century BCE. However, it is speculative if Solon or Peisistratus perceived soil erosion and if their orders were declared to prevent further degradation.

About 100 years later, the first detailed description about soil erosion was given by Plato, who lived 427 to 347 BCE. He describes the processes and effects of land use and soil erosion in the historic area of the Attica peninsula in his Critias (cf. Suppl. 1.3). However, this image of the degraded landscape of Attica is striking and has often been cited as an early perception of environmental degradation. McNeill (1992, p. 72) assumes that Plato apparently had Hymettus (pm 2-2) in mind, which was covered in garrigue back then and still is now. Commentators

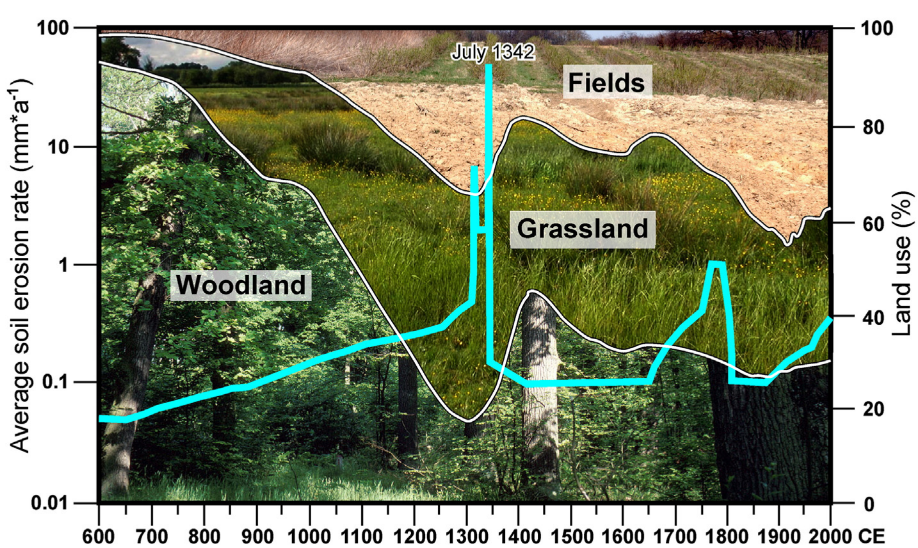

Fig. 2. Soil erosion and land use change in central Europe since 800 CE (adapted from Bork et al., 1998).

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remarking on the Classical age tend to interpret this description as an exaggeration, and it is not clear if it is history, mythology, or poetry (Williams, 2003, p. 96). In addition, the translation and its interpretation have been criticized because they are influenced by contemporary thoughts on erosion rather than interpreted in the context of the time it was written (Rackham, 1996; Grove and Rackham, 2003, p. 288).

However, the Greeks did not test theories or conduct experiments, and Greek agriculturists never developed techniques to prevent soil erosion (Brevik and Hartemink, 2010). Originally, the Greeks were pastoral people and they used the lowlands for grazing while the uplands were covered with woodland (Zangger, 1992). With the population increasing, they started to expand cultivation from the productive valley soils to the hillsides (Troeh et al., 2004). In the Bronze Age, soil erosion became a serious problem in ancient Greece. The eroded material was transported downhill and accumulated on footslopes and floodplains or built up deltas (Zangger, 1992; Bintliff, 2005). More than 1 m of soil was washed downslope from the surface of extensively used areas, and in some places the bedrock became exposed. Also, severe gullying took place and the footslopes were covered with unproductive erosion debris (Troeh et al., 2004). Today, the plains are filled with fertile alluvium often 5–10 m thick while most Greek mountains are barren—with little or no soil cover left. In very remote areas of Greece, some places still have been more or less continuously under forest and barely affected by agriculture. In these areas, mature soils similar to a Terra Rossa, which is usually 20–100 cm thick, cover the limestone upland and provide a fertile soil (Zangger, 1992). According to these findings we can suggest that the "bare and treeless" situation at the time of Solon and Peisistratus as well as the description from Plato were true. The latter describes the already heavily degraded environment of the first half of the first millennium BCE (which had been caused by deforestation and soil erosion) a couple of centuries earlier in the Bronze Age.

2.3. Historical descriptions of soil erosion during Roman Times

In Roman Times, many ancient philosopher–scientists and writers like M. Porcius Cato, M. Terentius Varro, L. Iunius Moderatus Columella, Rutilius Taurus Aemilianus Palladius, Plinius the Elder, and Vergilius Maro recognized the importance of soil fertility and/or gave comprehensive practical instructions on how to manage and fertilize the soil (Winiwarter, 2006a; Brevik and Hartemink, 2010; Emberger, 2012). Compared to the large amount of such documents being available, little evidence is seen that the Romans recognized the problem of soil erosion, even soil erosion had been a serious issue in many areas of the Roman Empire (Butzer, 2005; Dusar et al., 2011). The polymath Marcus Terentius Varro, who lived from 116–27 BCE, wrote in his "De re rustica" (a comprehensive textbook in three volumes) about all aspects of agriculture. In the first volume he gives instructions on how to manage the soil during the year. He suggests that it is not profitable to plant violet beds on a farm because they have to be planted on the ridges of a ridge-and-furrow field. Under such conditions, irrigation and heavy rains wash the soil away and make the ground poorer (Book I, 35,1, cited in Hooper and Ash, 1936; cf. Suppl. 1.4). About 100 years later, Columella, who lived from 4 CE to around 70 CE, also recognized the problem of soil erosion in the context of farming. In his book "On agriculture" he suggests that on irrigated fields the water should not flow too fast over the field in order to retain the soil: *for in loose soil it is not wise to let in too heavy a flow of water before the ground is packed and bound together by vegetation, because the force of the water washes away the soil and, by exposing the roots, does not allow the grass to gain a foothold* (Book II. xvii. 5, cited in Forster and Heffner, 1941, vol. I, pp. 210f.; cf. Suppl. 1.5). In the context of planting vineyards, he suggested methods to protect the soil and enhance water infiltration (Book V. x. 5, cited in Forster and Heffner, 1941, vol. II, pp. 88f.; cf. Suppl. 1.5). Columella also observed the process of soil erosion and sedimentation in the landscape. In the context of selecting suitable soil for vineyards he wrote: […] *that the bases of mountains, which have received the soil that washes down from their summits, or even valley lands that have been formed by the soil deposits of rivers and floods, are especially suited for vineyards* […] (Book III. xi. 8, cited in Forster and Heffner, 1941, vol. I, pp. 304f.).

Another indication pointing to an awareness of soil erosion during Roman Times could be derived from contemporary jurisprudence (Milde, 1950; Fischer, 1996; Jaillette and Merola, 2008). As early as 451/450 BCE, the law of the Twelve Tables constituted that the owner of a property is responsible for damage on a neighboring property caused by rainwater runoff (Crawford, 1996, Tabula VII, 8, pp. 673ff.). The Twelve Tables formed the heart of the legal system of the early Roman Republic, which was still dominated by peasant structures at that time. The problems of damage through rainwater and runoff were also discussed by several Roman scholars and jurists like Cicero, Trebatius, or Quintus Mucius in the following centuries (Griffin et al., 2002, p. 61ff.). The historical importance of this problem also became evident in the jurisprudence of the Corpus Iuris Civilis, a great collection of Roman law. The Digesta (or Pandectae) is a compilation of juristic literature from the middle of the first century BCE to around 230 CE commissioned by the emperor Justinian I between 530 and 533 CE (Mommsen et al., 1985). Particularly, the "actio aque pluviae arcendae", which also refers to the Twelve Tables, is very extensive and addresses runoff on farmland properties and the subsequent damage to neighboring land (Digest 39.3.1, cited in Mommsen et al., 1985, cf. Suppl. 1.6). The Digest conveys a very detailed definition on runoff loaded with sediments (e.g. *[…] body of water is regarded as being swollen by rain if it changes color when it increases in quantity* (Digest 39.3.1.16, cf. Suppl. 1.6)). It discusses the accelerated generation of runoff caused by man-made constructions or land management (e.g. dripping from eaves, ditches, dams) and the effects caused by natural events (e.g. violent storms). Possible damage includes sediment deposits and gullying (*water has hollowed out a site*) on the neighboring field (Digest 39.3.2.7, cf. Suppl. 1.6). Milde (1950) pointed out that the described actions of the Digesta were extensively used and must have had a definite practical implication in soil conservation during Roman Times. It represents the origin of the rules of modern civil law with regard to the runoff of surface water (Milde, 1950).

2.4. Historical records of soil erosion in central Europe

In central Europe, which extends from central France, Belgium, the Netherlands, and Germany, to Poland, the Czech Republic, and Slovakia, research on historical documents to analyze the perception of climate and environmental degradation has a long tradition. Particularly, in the context of historical climatology thousands of citations have been collected (e.g., Weikinn, 1958–1963; Deutsch, 1999; Pfister, 2001; Pfister et al., 2002; Brázdil et al., 2005; Glaser et al., 2005; Glaser, 2008). Most of the historical records are related to heavy precipitation events, floods, and the damage they caused; sometimes sediment aggradation in rivers and the destruction of crops in valley bottoms or on hillslopes are also mentioned. We can assume that in medieval times farmers perceived soil erosion after extreme precipitation events but only minute traces of documentary evidence were recorded by contemporary historians or scholars. Even extreme gullying events, as occurred in the first half of the fourteenth century, were demoted by the damage of the related floods because the destruction along the rivers was much more apparent than soil erosion in the fields.

As a result, records with explicit descriptions of soil erosion are rare or poorly preserved. Extensive case studies on historical records about soil erosion in the area between central France and western Germany were carried out by Jean Vogt (e.g. Vogt, 1953, 1958, 1960, 1970) and Gerhard Hard (e.g. Hard, 1963a,b, 1968, 1970), and for central Europe in general by Bork et al. (1998). According to these compilations, the earliest known records that point indirectly to soil erosion are from the late thirteenth century CE. At this time floods occurred and soil erosion damaged fields in Kerpen in Silesia (today Kierpień in south

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Fig. 3. Memorial stone at the St. Blasien church in Hannoversch Münden (pm 2-4) which documents the largest flood in central Europe between July nineteenth and 21st, 1342 CE. Translation: In the year of the Lord 1342, on the 24th July, a flood occurred on the Weser and Fulda Rivers, and the great height of the water touched the lower rim of this ashlar stone (picture taken on 15.07.2000 by the author).

Poland; pm 2-3) and exemption from taxes was agreed for the monastery in Leubus (today Lubiąż) (Thoma, 1894, p. 68). In the first half of the fourteenth century CE, climate deterioration triggered an increase in extreme weather events, and large floods took place throughout central Europe. Particularly between 19 and 21 July 1342 CE, extensive floods struck all over Germany as a result of extreme precipitation events (Fig. 3, pm 2-4). These events may have caused the most severe destruction by a flood that ever occurred in the history of central Europe. Some of the records related to this flood also provide some indirect evidence on soil erosion. Phrases like: *water spout from everywhere, even from the top of the mountains, yet that water covered areas, where it was unusual; but* [water] *bursted from hidden streams, down the mountains;* and *springs and streams spilled out of the ground* (cf. Suppl. 2.1) confirm extreme amounts of runoff. The water flowed along dry depressions or newly developed gullies. The effects of soil erosion and decline of soil fertility in the first half of the fourteenth century might have triggered starvation, and a massive decline in population occurred even before the European-wide pandemic disease, namely the Black Death, in the years 1347–1351 CE (Bork et al., 1998, p. 238).

The degradation of soils and the rapid decline in population caused a decrease in land use intensity, and a widespread regeneration of woodland occurred in the following decades. During the second half of the fourteenth century CE, the percentage of forest increased from around 20% to over 40% while the proportion of cultivated fields declined by the same amount (Fig. 2). Forests regrew particularly on steeper slopes and wasted areas, but erosive legacies might have still been visible in the landscape. Some miniatures from the fifteenth and sixteenth centuries show corrugated landscapes, but it is not clear if these paintings allegorize real landscape elements or if they simply mirror the imagination of the artists. A prominent example is the book of hours "Les Tres Riches Heures du Duc de Berry" first commissioned around 1410 CE (Fig. 4). The paintings were created between 1416 and 1485 and illustrate different farming activities in a figurative landscape of the Savoy in France (pm 2-5) (Longnon and Cazelle, 1969). The fissures in the landscape could be related to the karstic landscape or gullies caused by soil erosion.

Fig. 4. 'Les Tres Riches Heures du Duc de Berry' which includes figurative landscape paintings of the Savoy in France (pm 2-5) (Longnon and Cazelle, 1969). The fissures in the landscape could be related to the karstic landscape or to gullies caused by soil erosion. Left: folio 48 recto, annunciation to the herdsmen; right: folio 88 recto, request for safeguard; both miniatures were painted by Jean Colombe (1467–1529 CE).

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In the following centuries the intensity of land use was influenced by warfare, particularly during the Thirty Years' War (1618–1648), and by epidemics. Historical records show a small number of extreme precipitation events in the following centuries and they reveal little evidence for soil erosion until the eighteenth century. One example has been preserved from Kazimierz Dolny (pm 2-6), a small town in southeast Poland that became very prosperous during the fifteenth to sixteenth centuries. At that time, the city functioned as a port and a trading post between the Vistula River and an important trading route for grain and timber running to the city of Lublin via the Nałęczów Plateau (Teodorowicz-Czerepińska, 1981). The mid-sixteenth to mid-seventeenth centuries had been called "a golden age" for Kazimierz Dolny, but the massive deforestation of the loess-covered Nałęczów Plateau triggered devastating flash floods and gullying. Frequent and intensive gully erosion at the end of the sixteenth century can be inferred from a resolution of the Sejm (parliament) from 1601, which states that taxes have to be increased to pay for the repair of two bridges on the Grodarz creek, "*that every year the rapid water from hills breaks and siltate*" (in Polish: *które co rok woda z gór gwałtowna psuje i muli* (cited in Rutkowski, 1965)). In May 1633, massive flash floods were reported for Kazimierz Dolny. The event of 1644 was captured in a poem (Montusiewicz, 1991), e.g.: *Where once there were high hills, now there are deep valleys*. (cf. Suppl. 2.2 for a full translation of the poem). The sale of one-third of all estates could be related to the devastation of crops by the downpour and a subsequent lack of funds (Teodorowicz-Czerepińska, 1981). The origins of the current dense gully network on the Nałęczów Plateau, which partly exceeds 10 km/km^2 (Maruszczak, 1973), with gullies up to 40 m wide and 20 m deep can be traced back to the massive soil erosion in the sixteenth and seventeenth centuries (Fig. 5) (Dotterweich et al., 2012b). Similarly, in western Slovakia, a local chronicle describes soil erosion and gullying around the village of Bukovec (pm 2-7) in the Myjava hill land between the end of the sixteenth century and 1730 CE (Dotterweich et al., in press-b) (cf. Suppl. 2.3). The geomorphic legacies of these soil erosion events are visible even today (Dotterweich et al., in press-b).

Geomorphic investigations show that soil erosion and gullying increased in the eighteenth century. A rising number of reports on floods and environmental degradation are also evident in the historical records. The records confirm the observation of rapid formation of gullies by runoff and soil erosion (Suppl. 2.4). Some records also give very detailed information about the causes of soil erosion and their socioeconomic consequences, e.g. in the year 1791: *The inhabitants of Althornbach* [village in southwest Germany (pm 2-8)] *have become very poor and ruined because of the gullying of their fields — as a result, many people left their country* (Hard, 1976, p. 225) (cf. Suppl. 2.4). A very impressive example is the cadastral survey of the Heyliedgraben in the Eichsfeld region in Germany from 1768. It shows a very detailed situation of dissected furrows between the fields and the deep incision of a former road (Fig. 6, pm 2-9). The map was produced in the context of a legal action because the farmers were not able to farm their degraded land and hence could not pay their tithe (Hempel, 1957).

2.5. The advent of early research on soil erosion and soil conservation in central Europe with a focus on Germany

The agricultural knowledge in medieval central Europe was based on traditions, and only scholars may have had access to documents that described farming practices. The first treatises on agriculture after the essays by Roman writers appeared in the thirteenth century and were mostly written in Latin although hand-copied manuscripts were also translated into other languages. In the following centuries further agricultural treatises show a development in agricultural knowledge, although it was still based on the sophisticated knowledge from antiquity (Winiwarter, 2006a,c).

Until the end of the eighteenth century, no records showed an interest in the nature of soil erosion and soil conservation by scholars. A sole exception could be the work of Leonardo da Vinci, who lived from 1452 to 1519 CE. He was fascinated by water and its power and examined the motion of waves and currents. He observed the landscape of the South Tyrolean Dolomites in northern Italy and southern Switzerland and postulated the principle of (geological) erosion. For example, in the Arundel Codex (written between 1478 and 1518 CE), he wrote: *Here are the rivers which carry the eroded ground earth from the hills* […] (folio 42v, cited in Fumagalli, 1938, p. 195). On the same folio he noticed that the river Gießbach (Switzerland, pm 2-10) *brought so much earth and stones and along his riverbed, that the river course changed*. (Fumagalli, 1938, p. 201). In addition, the properties of water, rocks, and fossils have been elaborately described in the Codex Atlanticus (written between 1480 and 1518 CE) and in the Codex Leicester (1506–1508 CE).

Fig. 5. Gully system at Kazimierz Dolny, SE-Poland (pm 2-6). The main incision took place episodically in the sixteenth and seventeenth centuries (Dotterweich et al., 2012b) (picture taken on 21.04.2009 by the author).

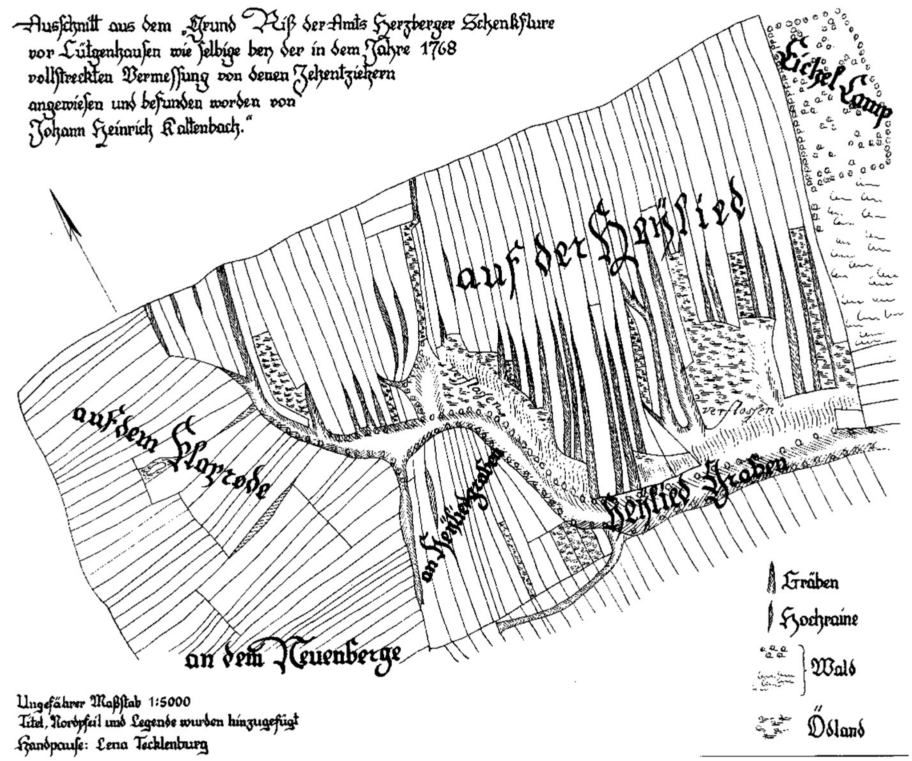

Fig. 6. Survey of the gullied areas in the Heyliedgraben (Eichsfeld, Germany) in 1768 CE (pm 2-9). The parallel gullies have a length of up to 120 m and a depth of up to 10 m. They dissected the furrows between the field ridges which had an original length of about 400 m and a spacing of about 20 m. Title: Grund Riß der Amts Herzberger Schenkflure vor Lütgenhausen wie selbige bey der in dem Jahre 1768 vollstreckten Vermessung von denen Zehentziehern angewiesen und befunden worden von Johann Heinrich Kaltenbach (cited and modified by Hempel, 1957, Karte IV).

The interest in soil erosion and soil conservation awakened at the end of the eighteenth century. A scholar in the Alsace region (eastern France) wrote: *They do not recognize that the hills used to be covered in woodland and that the trees' roots bind the soil and soak up water, thereby preventing flooding as well as gullying* (Vogt, 1960, p. 203) (cf. Suppl. 2.4).

An important scholar in agriculture at the turn of the eighteenth to nineteenth centuries was Albrecht Daniel Thaer (1752–1828), a renowned agronomist and the inventor of agronomy in Germany. He wrote a textbook about agriculture in England to enhance agricultural practices in Germany (Thaer, 1798) (cf. Suppl. 2.5). He warned about the construction and management of field plots in the direction of the slopes because runoff may wash down fertilizer and soil (Suppl. 2.5.2). Instead, he suggested that the individual plots should run along the contours and for contour plowing to be practiced. Together with Samuel Deane in North America (cf. Section 5.2), Thaer was one of the first scholars who suggested contour plowing to avoid soil erosion. However, his suggestion to construct ditches along the slopes to discharge the water during heavy rainfalls could be very counterproductive because it enhances gullying. Furthermore, Thaer continued that most of the farmers were not willing to construct and maintain such a field system. He wrote: *Construction of a draining ditch in the appropriate direction was impossible, because no one was prepared to sacrifice enough of his land and nobody wanted their field to be cut in two.* (Suppl. 2.5.8).

About one decade later, Thaer advocated more elaborate methods to prevent soil erosion in his second book “Grundsätze der rationellen Landwirtschaft (*Principles of Economic Agriculture*)” (Thaer, 1811). He provided detailed descriptions on the process of soil erosion, promoted contour plowing methods, gave instructions on how to divide fields into separate plots, and how to dig draining ditches (Suppl. 2.6). Thaer was also aware of the loss of nutrients and water. To collect the runoff he recommended the construction of interception ditches at the lower end of the drainage ditches and gave detailed instructions on how to build them (Thaer, 1811, p. 91).

At the same time, Johann Anton Schmitt, a professor for forestry at the University of Vienna, warned that total clearcuts of wooded plots in mountainous areas in Austria should be stopped to avoid runoff and the loss of soil by erosion after heavy precipitation events or snowmelts. He also realized that the loss of soil may hinder reforestation (Schmitt, 1810, p. 83).

In 1815, the “Königliche Societät der Wissenschaften zu Göttingen” in Germany announced a competition with the question: “*In mountainous areas, which are the most appropriate means to prevent the arable land from running off at prevalent deluges without fostering erosion within steep ditches too much?*” (Archiv der Akademie der Wissenschaften in Göttingen Scient. 196, Vol. VIII, Fasz. 94, Nr. 13/14, cited in Hempel, 1957, p. 13). In total, 11 essays were submitted that represent an extensive collection about the perception of soil erosion and possible methods to prevent it in the early nineteenth century. Several useful methods to inhibit soil erosion were suggested like the construction of terraces, contour plowing, creation of grassy bands along contour lines, planting of bushes, and changes in field structures. Other less suitable methods were also suggested like the construction of ridge-and-furrow fields, and the construction of draining ditches (Hempel, 1957, p. 13).

The winner of the competition was Friedrich Heusinger (1792–1883), a preacher from Römhild in Thuringia. He was an excellent observer of soil erosion and had a clear understanding of its characteristics. In his essay he gave extensive descriptions on the causes, processes, and consequences of soil erosion (Heusinger, 1815). For example, he referred to the protective effects of vegetation and the negative impacts of clearcuts to the soil. He discussed the problems of siltation in valleys and the long-term effects of soil erosion to soil fertility. Heusinger also saw the disadvantages of ridge-and-furrow systems, which triggered linear runoff and gullying. He described and discussed the futile efforts to stop soil erosion and gullying with control structures (cf. Suppl. 2.7). Bork et al. (1998, p. 263) pointed out that the essay of

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Heusinger was the first significant textbook about soil conservation in Germany. About 10 years later it was published in an extended edition (Heusinger, 1826). Both essays also contain detailed sketches on how to construct terraces and runoff ditches (Fig. 7).

Carl Sprengel (1787–1859) was a professor of agronomy in Germany. In his textbook about land reclamation, published in 1838, he was also aware of the problems of soil erosion, and he described a method of how to trap suspended and colluvial sediments on the footslopes: *Often dams or embankments have to be built to divert the melt- or rainwater from the mountains around meadows and fields. It is important to ensure the water flowing slowly to a place from where it can be drained into a stream or river via ditches.* Furthermore, he gave detailed instructions on how to build and manage such a system. He suggested that *The accumulated soil has to be dug out as soon as the troughs have filled up. The sediment can be used to fertilise the fields and meadows* (Sprengel 1838, p. 57) (cf. Suppl. 2.8). A contemporary report of this time described that the method of carrying the sediments back to the fields is very common in the regions of Thuringia and Saxonia. According to Schmalz (1820, pp. 149–160) this method was a specific type of land management in the region around Altenburg (Thuringia pm 2-11) and it seemed to be not very sustainable because it caused an exorbitant amount of soil removal and additional soil degradation. However, the practice to carry the deposited sediments back is still common today, particularly in areas with specialized cultivation (Fig. 8, pm 2-12).

In the following decades several short essays about soil erosion and soil conservation were published in agricultural journals that became increasingly popular in the nineteenth century (Ehrenberg, 1915, pp. 168–170, 1951). For example, Löll (1878) wrote an essay about the processes of soil erosion and their effect on soil exhaustion on the basis of observations gained over several decades. He was probably the first who also analyzed the peasants' perception of soil erosion in Germany (cf. Suppl. 2.9). Johann Georg Kohl (1808–1878), a German geographer who traveled much through North America, Europe, and Russia was probably the first in Germany who offered a scientific description on the process of soil erosion and gullying. With the example of a gully system on the Krim Peninsula he explained the process of linear runoff from field furrows or pathways and the development of headcut retreatment (Fig. 9) (Kohl, 1841, pp. 63–71).

Stadtler (1880) also advocated the construction of draining ditches in the field. He pointed out that the runoff can be seen as "liquid gold" because of the suspended sediments and soil. Just as Carl Sprengel had already recommended several decades earlier, Stadler suggested directing the drainage ditches onto the lower parts of the field for fertilizing.

Ewald Wollny (1846–1901 CE) was one of the first researchers who carried out fundamental scientific investigations relating to soil and water conservation in Germany (Baver, 1939; Böhm, 1996). He constructed wooden plots with a surface of 80 × 80 cm and a depth of 25 cm for his experiments on runoff and soil erosion (Fig. 10). On one side they had a gutter and a bottle to collect the runoff (Wollny, 1890). Between 1881 and 1882 he placed these plots outside under field conditions with different substrates, and vegetation (grass, peas, and bare earth) and at altered aspects and slope angles. He was able to show that grassland reduces soil erosion significantly while an increasing slope led to accelerated runoff and soil erosion. With regard to the vegetation cover, he recognized that vegetation on the surface, particularly grassland, reduces runoff and cleans the water from particles. The root network fixes the soil and hinders soil erosion. Based on

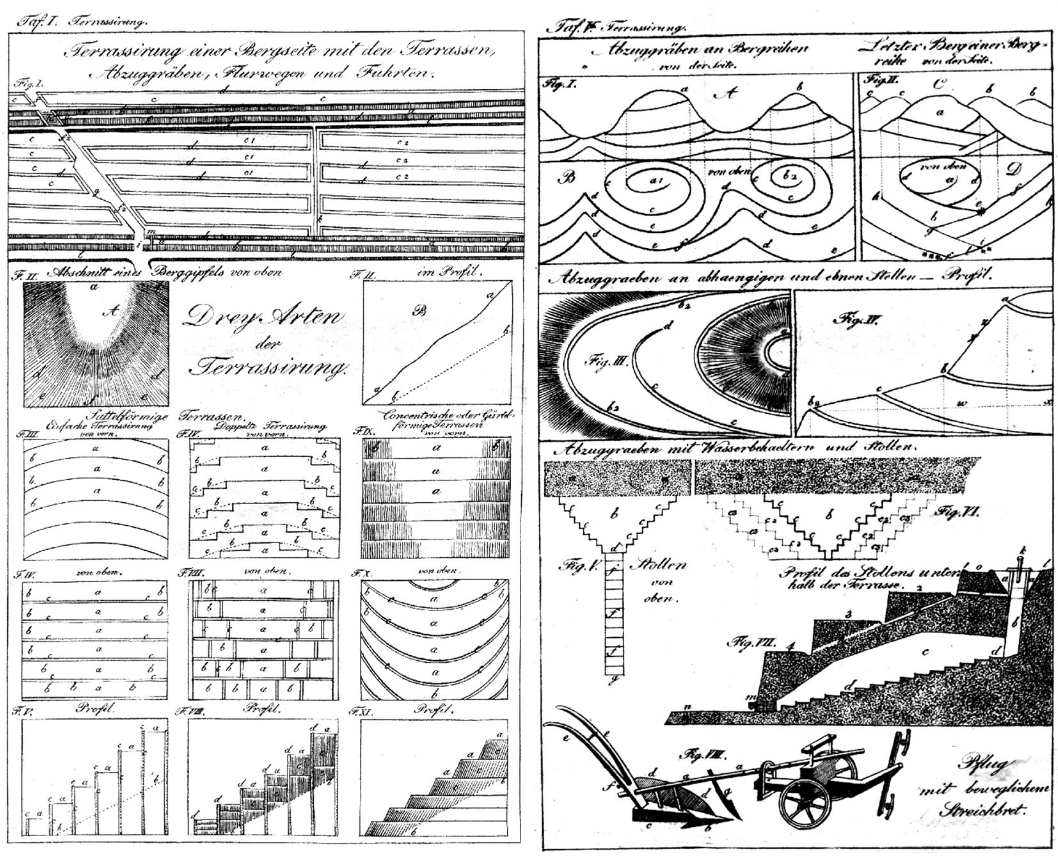

Fig. 7. Examples of soil conservation techniques to prevent soil erosion as suggested by Friedrich Heusinger (Heusinger, 1826) in his second essay. Left side: At the top it shows a terrace system including runoff ditches viewed from above; below this, different kinds of terraces are shown from different views (top, front and in profile). The drawings at the top of the right-hand side show the direction of the runoff ditches on a hill from the side and from above. The middle part shows the construction of an underground storage reservoir to collect and drain water. At the bottom, it shows a mouldboard plough modified for contour plowing.

Fig. 8. A severe local thunderstorm with a precipitation of 49 mm in 2 h occurred near Deidesheim on 08.07.2005. After this event a wine-grower carries the eroded and accumulated soil back to his vineyard (pm 2-12). (picture taken on 09.07.2005 by the author).

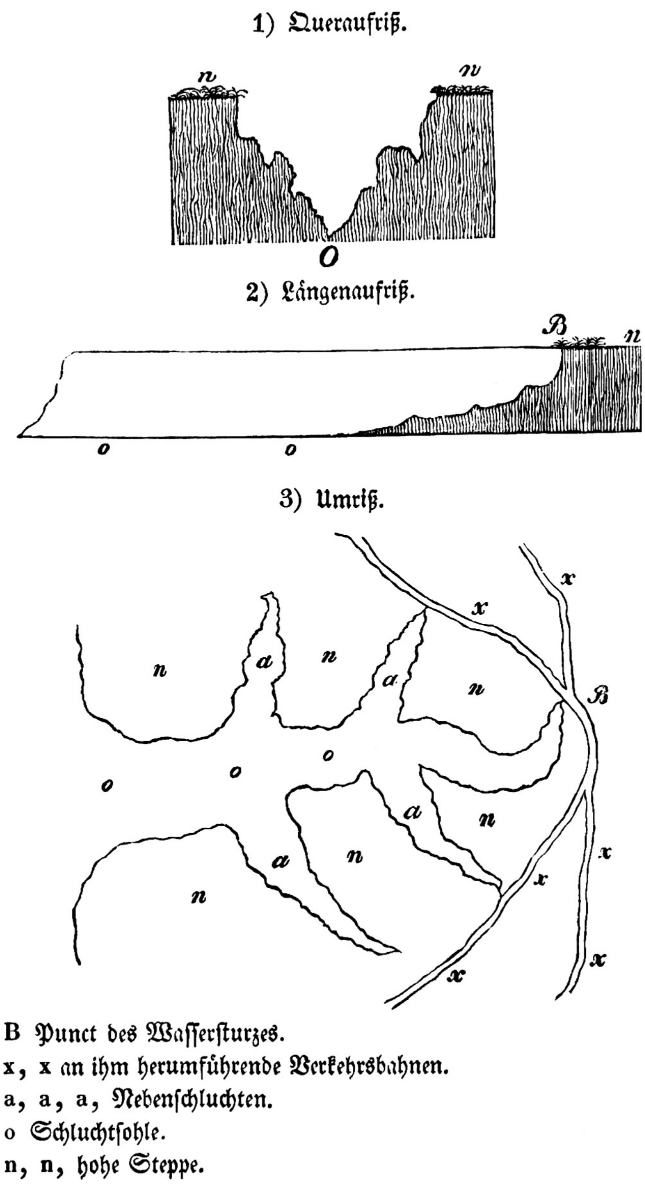

Fig. 9. Gully system on the Crimean peninsula published in (Kohl, 1841, p. 69). Key: 1) cross Section; 2) longitudinal Section; 3) map; B: point of the water breach; x, x pathways passing around (the gully); a, a, a, tributary gullies; o bottom of the gully; n, n, high steppe.

this data, he concluded that tree cover in forests prevents runoff and soil erosion very efficiently. The canopy reduces the precipitation intensity, the litter hinders runoff, and the roots fix the soil. Furthermore, he asserted that formerly forested soils are highly vulnerable to soil erosion after clearcuts (Wollny, 1895). At the same time, Hazard (1900) also made also some field measurements of soil erosion. He observed that the particle size distribution in the soil changes as an effect of soil erosion. Furthermore, he warned that the ongoing removal of lynchets, contour parallel field ridges, and terraces would trigger runoff and soil erosion (Ehrenberg, 1915, pp. 168–170).

In the following decades there was little attention focused on the research of soil erosion in Germany. Paul Ehrenberg (1875–1956), who was a renowned scientist in agricultural chemistry, pointed out that little research had been done to understand the processes of soil erosion (Ehrenberg, 1915, p. 170). Similar to many other countries, this situation changed in the 1930s with an international awareness of the serious soil degradation and the subsequent promotion of soil conservation in the USA. In 1939, the German Soil Science Society founded the new section "Soil erosion" chaired by the soil scientist Hans Kuron (1904–1963) (Breburda and Richter, 1998; Schmidt et al., 2010). In the following years a large number of papers were published, and more textbooks about soil erosion in Germany were written in the 1950s e.g. by Schultze (1952).

3. Africa

3.1. Geomorphic evidences of past soil erosion and soil conservation in Africa

Agriculture in Africa has a long tradition and diverse history. Unlike the land use evolution in western Asia or the Mediterranean, the earliest

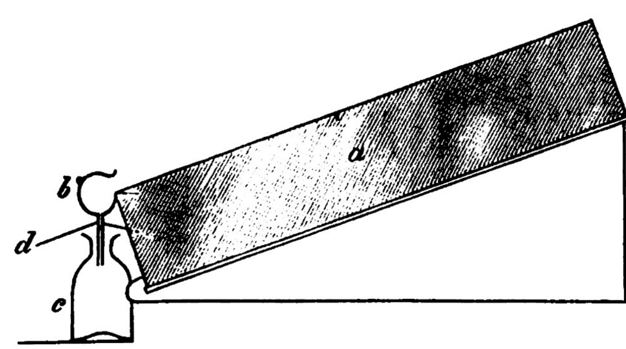

Fig. 10. Soil erosion plot as described in Wollny (1890, p. 317). His measurements were probably the first scientific experiments on soil erosion.

food producers were mobile pastoralists and not agriculturalists (Neumann, 2005). They lived in the Sahara and Sahel region about 4500 BCE. In Egypt, agricultural crops were already cultivated around the sixth millennium BCE, but spread into other areas of Africa including the central African rainforests only much later. The first pieces of evidence in the Sahara and Sahel region date to around 1800 BCE, and for the rest of the continent from around the middle of the first millennium BCE onward (Neumann, 2005). In regions with rainfed agriculture, traditional soil management (small fields, mulching, and nontillage) and the farming of valley bottoms and gentle slopes hindered runoff and soil erosion (Showers, 2005, 2006b), but there are also examples that traditional mound and ridging systems accelerated soil erosion in formerly forested areas of West Africa (Nye and Greenland, 1960). In the highlands of Tanzania, the intensification of agriculture accelerated soil erosion and gullying in the Mahala Mountains at around 500 CE (pm 3-1) (Msaky et al., 2005) and at around 1000 CE in the Irangi Hills (pm 3-2) (Eriksson et al., 2001; Lane, 2009). In the latter case, erosion was also triggered by woodland clearings to produce fuel for iron smelting. Human-induced soil erosion in the Ethiopian and Eritrean highlands dates back to 5000 BP (Nyssen et al., 2004). Extensive studies about past soil erosion in northern Ethiopia show that, particularly in the last century, extreme soil erosion and gullying occurred as an effect of woodland removal and agriculture (Nyssen et al., 2006, 2010). In southern Africa, geomorphic and historical studies of past soil erosion have mainly been carried out in the Karoo (Boardman et al., 2003; Mighall et al., 2012), the KwaZulu-Natal province (Watson, 1996; Watson and Ramokgopa, 1997; Rienks et al., 2000; Foster et al., 2007), Swartland (Meadows, 2003), Lesotho (Showers, 2005), and Malawi (Mulwafu, 2011). An early compilation of studies relating to the soil erosion history of southern Africa has been edited by (Dardis and Moon, 1988, pp. 187–320).

The studies show that soil erosion and gullying accelerated soon after the European arrival in the nineteenth century. A second phase was primarily triggered by an increase in grazing between the 1930s and the 1960s. Already in the early twentieth century an extensive overview (with many photographs) about the causes and processes of soil erosion, including instructions for soil erosion prevention and land reclamation in South Africa, was presented by Torrance (1919). Today, land degradation is still a major concern in South Africa, and the awareness of the problem and attitudes toward it have changed little over the past century. Soil erosion is viewed as a result of overpopulation, overgrazing, and poor agricultural practices (Critchley and Netshikovhela, 1998).

Agricultural terracing was not widespread in Africa, but the construction of stone terraces, often built along contour lines, has a long tradition particularly in Ethiopia and Tanzania (Showers, 2006b) where the oldest has been dated to about 2450 BCE (Sandor, 2006). In contrast to other terracing systems on hillslopes throughout the world, such structures were also often built to last just for the planting season to control soil erosion, although some did last for as long as 20 years. A prominent example of this type of soil conservation is the "Living Terraces" in Ethiopia, a system in which the terraces were constructed completely new each year before crop cultivation (Watson, 2009) (Fig. 11, pm 3-3).

In general, despite some examples of prehistorical soil erosion, no evidence is available for the development of large badland areas having been induced by agriculture before the arrival of the Europeans (Showers, 2006b). With the introduction of European agriculture and land management practices—including large scale deforestation, monocultures, overgrazing, and deep plowing—soil erosion accelerated and many areas throughout Africa were largely devastated by soil erosion leading to a rapid decline of soil fertility and land abandonment (Showers, 2006b). The first soil conservation programs began to be implemented in the 1930s. Over the last few years, several papers have been published on the history of soil erosion and soil conservation for different areas in Africa (e.g. Beinart, 1984; Showers, 1989; Showers and Malahleha, 1992; Beinart, 2003; Meadows and Hoffman, 2003; Showers, 2005, 2006b; Lane, 2009; McGregor et al., 2009; Lane, 2010). Some of them also include oral and written accounts on the perception of soil erosion and practices in the transitional phase between the African and European land use period. The following sections focus on Lesotho and Malawi because this region has been highly degraded by soil erosion since the introduction of European farming methods around 150—250 years ago (Meadows and Hoffman, 2003), and extensive analyses of historical sources were carried out regarding the perception of soil erosion and soil conservation.

3.2. Geomorphic and historic legacies of past soil erosion and soil conservation, an example from Lesotho

An investigation on past soil erosion and soil conservation with extensive analyses of historical sources for Lesotho has been presented by Showers (1989, 2005) and Showers and Malahleha (1992). Agriculture in this area began relatively late with the arrival of the Basotho (Sesotho-speaking people in Lesoto) around 1600 CE. The farmers

Fig. 11. Newly constructed 'Living Terrace' near Konso (pm 3-3) in the highlands of southern Ethiopia (picture taken on 30.12.2009, courtesy of H.-R. Bork).

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lived in small villages in a relatively small area with a large mountain range. The small cultivated fields were located predominantly in valleys and managed with wooden hoes providing few opportunities for soil erosion. In the first half of the nineteenth century European settlers arrived and brought new crops and new soil management techniques, which triggered soil erosion in this area. The native people were subsequently displaced to steeper areas that are more vulnerable to soil erosion (Showers, 2005). Description about soil erosion came from travelers, mission stations, agricultural experimental stations, farms, plantations, and ranches (Showers, 2006b). According to Showers (2005), an early mention of accelerated soil erosion with a specific site description is from the 1880s. *At the sight of the deep ravines which traverse Basutoland in every direction and which continue to grow from year to year, progressively draining and desiccating the most fertile parts, one of our Christians remarked the other day: Naha ea tsofala, the land is aging* (Duvoisin, cited in Germond, 1938, p. 410). Possible causes and specific locations of soil erosion were mentioned by people who visited the mission stations in the lowlands 1882–1883 (Showers, 2005, p. 139). For example, H. Kruger wrote: *We lost our direction in this labyrinth and instead of remaining on the heights, eventually tumbled down a pile of fallen boulders of every dimension into a ravine. Some three hundred metres below it opens out into a wide cultivated vale* […] *Behind the station of Barea the children of the first missionary generation remember how they used to jump over a little brook which separated the garden from a plantation of willows and poplars; today there exists at the same place a ravine thirty-six to forty-five feet wide* (Kruger, 1888, cited in Germond, 1938, p. 408). Showers (2005, p. 141) pointed out that, according to the historical records, gully erosion was essentially unknown in the 1830s but that it had developed along roads and on some mission stations by the early 1890s. Reports in the early twentieth century show a mixture of general statements and specific site descriptions (Showers, 2005). In a record of 1908, the Basutoland was described as having *numerous, vast and unsightly scars upon the surface*, and in 1909 it was mentioned that *almost everywhere certain gardens are in danger* by soil erosion. The Colonial Annual Report of 1911/12 stated that soil erosion *has been gradually getting worse and worse*, and the resident commissioner asserted in a speech that *your country is being washed away* (all cited in Showers, 2005, p. 141). In the following decades, many other reports or speeches warned about the dramatic effects of soil erosion. Some of them link their negative effects on intense livestock farming, agriculture, and economy, but actions to prevent soil erosion were still rare in the 1930s (Showers, 2005).

However, during the 1920s the first experimental stations were established, and systematic and sustained investigations on soil erosion were carried out. In the 1930s and 1940s the official concern about soil erosion increased and many professional publications and research papers were produced. Programs for farmers to prevent soil erosion or to mitigate its consequences were also established (Showers, 2006b, p. 158). However, they often failed, and according to interviews, rural farmers were critical of certain professional conservation structures because they seemed to have favored soil erosion instead of preventing it (Showers, 2005).

3.3. Early historical oral traditions and written records of soil erosion and soil conservation, an example from southern Malawi

Mulwafu (2011) examined the impact of state intervention on the peasant economy in the highlands of southern Malawi with specific emphasis on the Shire Highlands districts of Zomba, Chiradzulu, and Thyolo (pm 3-4). The investigation of Mulwafu (2011) shows that, during the pre-colonial period, the semisedentary Africans had a very good knowledge about soil fertility and soil management. They used many different local conservation practices such as general tilling before planting, raised mounds, mixed cropping, and planting protective grasses to prevent runoff and soil erosion. According to oral traditions, they were aware that undertaking conservation helped to prevent soil erosion, improved soil fertility and therefore increased yields. Elders knew of different strategies like placing grass or tree branches on the top of the outer ridge or planting sugar cane or other plants and fruits on the outer ridge of their gardens. In addition, various types of grasses were used for livestock feeding. In hilly areas, the plantations were set along the contour lines. Peasants only used basic tools like hoes and axes and non-labor-intensive practices. In some areas, stone walls were built across the slopes in order to prevent runoff and soil erosion. One other method was to divert a stream from its natural course above a garden. The water was sometimes directed into a furrow and/or stored in a pond behind an earthen dam to irrigate the fields (Mulwafu, 2011, pp. 33–35). This type of soil and water management was widely used until a significant population increase caused by immigration of different African groups and European settlers in the late nineteenth century CE occurred. Various social and power relations competed against the traditional systems. Slash-and-burn practices and shifting cultivation became more popular on the scarce land resulting in an increase of soil erosion and environmental degradation. In the early colonial period, African production systems and conservation practices increasingly came under attack from colonial state officials and some missionaries who sought to control access to land and labor resources. The Colonists did not realize the intrinsic causes of land degradation and the historic practices; instead they believed that Africans had no idea of manuring and effective management of land resources. The European idea of soil conservation was to settle permanently in a certain area with careful manuring allowing a constant rise of crop yields. Soon after a declaration in the 1890s CE, a series of restrictive measures were introduced resulting in increasing rates of deforestation, wildlife depletion, and soil erosion (Mulwafu, 2011, p. 51). A report on soil erosion on private estates from 1930 indicates that sheet and gully erosion had been taking place to an alarming degree (Haviland, 1930). After the 1930s, the colonial state began to realize the importance of soil erosion control, but state interventions bifurcated between rural and private lands. Harsh conservation campaigns were spread over the rural areas, while on the mainly European-owned private estates they came much later and were not adequately enforced. On the whole, estate owners did not use many methods to control soil erosion. But in the early 1940s, with the help of well-educated soil conservationists, there was a new focus on what might be called integrated land use management in modern terminology. This was the birth of Malawi's modern soil conservation network (Mulwafu, 2011, p. 72).

4. Asia

4.1. Geomorphic evidence and causes of past soil erosion in Asia

Many countries in Asia have experienced and suffered from soil erosion since the beginning of agriculture. A few millennia after the development of land cultivation in Mesopotamia by the Sumerians around 10,000 BCE, agriculture spread into China and India (Troeh et al., 2004). Severe soil erosion damage was generally caused by deforestation and land exploitation as well as by extreme population pressure and climate change (e.g., Lowdermilk, 1953; Brown, 2001). For example, Wasson (2006) gave an overview about the exploitation and conservation of soil in South Asia with a focus on India over the last 3000 years. He was able to show a causality chain between growing populations, deforestation, soil erosion, floods, and land abandonment similar to the theory of "Himalayan Environmental Degradation" (Ives and Messerli, 1989). Integrative studies of multiple archives in the Lake Erhai catchment in SW China (pm 4-1) provided a system–theoretical understanding of climate–human–environment interactions over the past 3000 years (Dearing et al., 2008). The relationship between soil erosion and land degradation starts from a nondegraded steady state through a transition period leading to the modern degraded steady state. Such an approach also includes the capacity to show possible future trajectories of landscape recovery (Dearing, 2008).

Agricultural terracing for irrigation and to prevent soil erosion originated in the Middle East about 6000 BCE and spread in all directions (Sandor, 2006). A secondary center developed in Indochina (Spencer and Hale, 1961; Gregor, 1970). A very successful example of achieving soil conservation has been demonstrated in the highlands of Papua New Guinea (pm 4-2; here, Papua New Guinea is geographically counted to southeast Asia and not to Australia because of the similar land use history). On this island, an elaborated traditional soil management system with living fences, gridded field plots, and compost mounds allowed sustainable agriculture on fairly steep slopes over centuries (Humphreys and Brookfield, 1991). However, despite the long history of cultivation studies, concentrating on the perception of soil erosion in historical times is rare. Here, the focus will be on China for which the most comprehensive studies on past soil erosion are available.

4.2. Geomorphic legacies on past soil erosion and conservation on the loess plateau in China

The agricultural and anthropogenic soil erosion history in China covers a time span of more than 7000 years. The ancestors of the Chinese cleared forests, terraced hill slopes for irrigation and soil conservation, and partitioned the valley floors into fields. Particularly the Loess Plateau, which is situated in the middle reach of the Yellow Rivers is well known to the world because of severe soil erosion incising deeply into the immensely thick deposits. The first scattered villages with Neolithic rice farmers appeared on the alluvial plains of central China about 7000 to 5000 BCE (Liu, 2004; Rosen, 2008; Li et al., 2010). A slight climatic cooling that occurred from 2500 BCE to 700 CE was accompanied by deforestation and other vegetation changes that are partly attributed to cultivation. At this time, the Loess Plateau was relatively flat and not yet dissected and human-accelerated soil erosion was a fairly local phenomenon. The Yellow River and many of its tributaries had clear water and carried very little sediment. Generally, it was known as Da He or Great River before the seventh century CE. However, during the Tang Dynasty (618 to 907 CE), the name Yellow River appears in the historic documents that points toward a high sediment concentration (Ren and Zhu, 1994). During this period, historic documents and sediment deposits show an increase in magnitude and frequency in the flood regime with severe destruction of the protective dykes that flanked the Yellow River. These floods were mainly caused by clearances, farming, and associated soil erosion of the fragile loess uplands in the river's middle and upper course (Elvin, 1993; Ren and Zhu, 1994; Wang et al., 2006). The correlation between an increasing population and soil erosion is clear (Wang et al., 2006). This trend of rapid sediment aggradation continued during the early Song Dynasty (CE 960 to 1279) parallel to the economic prosperity and rapid destruction of forests (Xu, 2003). The increase in population had already led to a shortage of wood for fuel in the central eastern area by the eleventh century CE (Elvin, 2004, p. 20). The following centuries were dominated by warfare with socioeconomic impacts to nomadic minorities who were assimilated by the Han Chinese. This cultural assimilation and social development generated additional forest clearances and accelerated soil erosion. During the following centuries, the sediment load of the Yellow River was generally high, which indicates severe soil erosion in its catchment. Particularly during the Ming period (1368–1644), the whole of the central reaches of the Huang River Valley began to undergo extreme deforestation accompanied by an expansion of agriculture, in some cases at the expense of grazing land. Even the Yinshan Range to the north of the Loess Plateau, for which records suggest that it was still forested during the Mongol Yuan dynasty, began to suffer as the Mongols encouraged Han-Chinese agriculturalists to settle in the area. All this deforestation was to have a serious impact on the Huang River as flooding became increasingly more common and silt loads reached new heights during the time of the Ming dynasty (Edmonds, 1994, p. 25).

Deforestation was not the only factor for accelerated soil erosion after the first millennium CE; changes in climate also played an important role, particularly variations in the amount of precipitation (Ren and Zhu, 1994). The last phase of human-induced accelerated soil erosion took place during the 1930s, 1950s, and the later part of the 1960s, which has led to the famous Loess Plateau experiencing some of the most severe soil erosion recorded anywhere in the world (He et al., 2006). The current landscape was formed by climate and human impact, and today, more than 70% of the Loess Plateau is dissected by gullies. An average gully density of about 3–5 km^2 exists in 30–50% of the whole area (He et al., 2004). The footslopes, valley bottoms, and river deltas are covered with sediment up to several decameters. Because of the high vulnerability of the soils to erosion, soil conservation strategies like hillslope terracing have a long tradition in China. Some hillslope terraces date back around 3000 BCE (Sandor, 2006). For example, charcoal deposited in the lowermost sediments in a terrace in the Shaanxi region (Fig. 12, pm 4-3) was dated to 4750 cal. BP (Bork et al., 2006). The recent implementation of soil and water conservation measures like terracing, reforesting, and dam constructions (Ping et al., 2012; Zhou et al., 2013) has decreased the Yellow River's sediment load by 25% since the 1980s (He et al., 2006).

4.3. Historical descriptions on soil erosion, related floods, and soil conservation in China until the twentieth century

Most of the research on the environmental history of soil erosion in China is related to deforestation, floods, sediment aggradation in rivers and their related damages (e.g. Elvin, 1993, 2004; Edmonds, 1994; Fang and Xie, 1994; Elvin and Liu, 1998; Osborne, 1998). Similar to the situation at many other sites, surveys on historical documents focusing on hillslope erosion and gullying are rare.

One of the oldest published records concerning environmental protection measures in general comes from Guanzi (also called Guanzhong) who lived in the seventh century BCE. He advocated that forests, rivers, and marshes were a resource that should be protected. Guanzi further noted fire prevention and strict conventions on tree cutting as important aspects of environmental protection. He also linked environmental protection and development: *In spring if the government does not prohibit [cutting] than hundreds will not grow. In summer if the government does not prohibit (cutting) than the crops will not succeed* (cited in Edmonds, 1994, p. 25).

The probably oldest record on soil erosion in China was documented by Wen Tao during the Warring States era (403–221 BCE). He suggested that the Chinese had an understanding of the relationship between deforestation and soil erosion in the Eastern Zhou Dynasty: *The rulers enjoy themselves degrading famous mountain spots. This blocks the great rivers which overflow around the famous mountains. Therefore, great floods come more often, harming the people and causing the crops not to grow* (cited in Edmonds, 1994, p. 24). In the mid-first millennium BCE, iron axes became available and woodland exploitation rose in the Sichuan region. In the third century CE, Zuo Si wrote a rhapsodic description on the Min River basin in the region of Chengdu, the capital of the Sichuan region at the end of the early imperial period. The main passage of Zuo's poem describes an environment that is busily exploited but still not yet spoiled. For the southern hinterland of Chengdu of the Min River basin, he depicted a humid world with a great variety of trees: *Valleys hug one like arms;* [natural?] *gullies close round like mouths. Crests, straight-ridged or circling are tangled and twisting, Interposing their rocks and deflecting the clouds, The dense forests a haze under bluish-green mists, The lone summits imposing, rising uplifted* (cited in Elvin, 2004, p. 60).

About 500 years later, Liu Zongyuan, a philosopher and essayist who lived around the eight to ninth centuries CE, captured the processes of deforestation and the consequences of runoff, soil erosion, and the creation of gullies very metaphorically in a poem (Elvin, 2004, p. 19) (cf. Suppl. 1.7). According to the history of the Song Dynasty, scholars had a good knowledge of the close relationship between deforestation and soil erosion and they were also aware of the environmental

Fig. 12. This terrace in the Zhongzuimao catchment near Yangyuangou (Shaanxi region) in China (pm 4-3) has a height of about 8 m. Deposited charcoal at the base of the terrace dates back to around 4750 BP (Bork et al., 2006) (picture taken in Sept. 2003, courtesy of H.-R. Bork).

consequences of filling in lakes to create additional crop land (Edmonds, 1994, p. 25). Such relationships are recorded, for example, as a river burst its banks in Tanzhou and flooded several provinces in November 971 CE. In 972 CE, the emperor gave an order for local people to plant 50 trees per year (Toqto'a and Alutu, 1343) (cf. Suppl. 1.8). About 1020 AD, the Prime Minister (Wu Chong) suggested leaving thousands of hectares of fertile lands fallow because of the ongoing floods. A discussion about the primary reason responsible for frequent flooding events, the rapid siltation of river beds, was also recorded. Such silting-up processes and discussions about the disadvantages (destruction of crops) and advantages (delivery of nutrients) have been recorded repeatedly in different volumes of the book about the History of Song (Toqto'a and Alutu, 1343). Also, in younger historical texts discussions about growing trees to prevent rivers from flooding are mentioned frequently, but explicit descriptions on soil erosion in the uplands are missing.

In the context of maintaining the Bai Canal (a part of the Zheng-bai irrigation system of the Shaanxi province), a dam across the river was erected each year to manage the water level in the tenth century. In the fifteenth century a feeder tunnel was built to renew the system. Overflow tunnels and grille-like barriers were constructed across the gullies to let water through but block the debris, and the canal was roofed at key points to let gully runoff flow over it. This avoided silting up and damage by natural hazards such as floods of the Jing River and debris flows carrying rocks down the gullies (Elvin, 2004, p. 123).

The gazetteer for the Prefecture of Ningxia (in the Northwest) reported in 1780 CE that *there is little soil in the mountains, but numerous stones*. *The trees all grow in crevices in the rocks*. This suggests soil erosion, though it also seems that there existed still some good cover on the west-facing slopes (Elvin, 2004, p. 28).

Intensive environmental degradation including soil erosion has been described for the Yangzi and Han River drainage basin. For example, in the catchment of the South Lake in the Yuhang district (present day Yuhang Zhen in the lower Yangzi catchment) (pm 4-4) the owners of the hilly districts in the Yangzi valley invited the shack people (or shed people) from the southeastern provinces, where land was in short supply, to serve as their labor force for the production of goods in the first half of the eighteenth century. They deforested the hillsides and planted maize, sweet potatoes, and peanuts. As recently as the 1720s CE, deforestation had spread everywhere in the northwestern Zhejiang province. During the Taiping Rebellion (1850 to 1864 CE), a further forced influx of shed people occurred and the hilly slopes were intensively tilled causing continual soil erosion (Yoshinobu, 1998, p. 163). In this context, Mei Boyan (who lived from 1786 to 1856 CE), wrote an account on how these seminomadic groups farmed in the hills south of the Yangzi: *When the late Dong Wenke was governor of Anhui province* [in the East] *he wrote a memorial … on the opening up the mountains by the shed people … they had let the riches in several hundred mou* [~7% of a hectare] *or so of mountains run to waste* (Zengliang, 1968) cited in Elvin (2004, pp. 22f.). The account continues with a detailed description about the observed effects of deforestation and the processes and effects of soil erosion to the soil fertility and river system by the local people at *Xuancheng* (Anhui, Ningguo prefecture, pm 4-5) (cited in Osborne, 1998, pp. 218f.) (cf. Suppl. 1.9). A note from You Xian Zhi in 1874 CE describes the sediment aggradation in the lower Xiang River: *Mud, sand, and gravel are piling higher and higher. Many of the tributary creeks are silted up and the water no longer flows. Many of the fields are dry.* The massive clear-cuts led to more frequent flooding and drying up of the Xiang River (Edmonds, 1994, p. 33).

By the early nineteenth century, deforestation was so immense that it led to a shortage of timber, bamboo, and fuel, which initiated a feedback of further destruction, soil erosion, silting of waterways, and floods (Osborne, 1998, p. 216). A contemporary report written by Fang Chun describes the dimension of reclamation and the effects of soil erosion by heavy rains on the Huizhou's periphery (pm 4-6) (Chun, 1827) (cited in Osborne, 1998, pp. 216ff.) (cf. Suppl. 1.10). Osborne (1998) highlights that other contemporary authors also had a clear understanding of the impact that highland reclamation had on the ecology of the region, like loss of water retention capacity, drop of the water table, soil erosion, sedimentation, and floods in the early nineteenth century. Exemplary citations are: *The soil is exhausted so that not even an inch of grass will grow*; *Roving people reclaimed the mountains and planted maize. Several years later the soil was loosened, causing flooding, and submerging fields and irrigation ditches. The mountain fell into disuse*;

Rich land became stones and bones, there were mudslides and erosion, and fields that produced rice were covered with sand and gravel. Innumerable ones have been eaten up and are gone (Osborne, 1998, p. 219).

These observations of environmental degradation and possible solutions led to a controversial discussion as early as the mid-eighteenth century. Environmentally sound policies were devised to address these dilemmas, but no realistic way was found to solve the tradeoffs between ecology and economy. Such failures allowed further environmental degradation to take place. However, in the mid-eighteenth century, a first set of regulations was already being enforced in the lowlands. Some decades later, Governor Ruan Yuan prohibited further highland reclamation by outsiders throughout Zhejiang in 1802. A few years further on, an imperial edict banned such reclamations in Anhui, and a general policy was enacted for the whole lower Yangzi region (Osborne, 1998). Osborne (1998, p. 226) concluded that these regulatory measures predominately failed because the implementation was undermined by the basic contradiction of the state's reliance on elite management. As a result no promotion to replace maize with staple food took place and investments in tree crops and perennials enhancing the rural people's livelihood were not supported.

5. North America

5.1. Land use history and geomorphic evidence of past soil erosion in North America

In North America, agriculture began with the domestication of squash (*Cucurbita pepo*) and other wild plants at various locations by Native Americans about 3000 years BCE (Swanton, 1949; Steponaitis, 1986; Peacock, 1998). The imprint of land use on the environment was low until the agricultural expansion of maize (*Zea mays*) and beans (*Phaseolus vulgaris*) about 1000 CE. Subsequently, population densities, deforestation, and land use intensities grew and social hierarchies emerged within the agricultural limits between the Mississippi River and the mid-Atlantic to southern New England, and to some areas in the southwest (Doolittle, 2001; Delcourt and Delcourt, 2004; James, 2011). In some places, urban centers developed until their decline in the middle of the last millennium (Fritz, 1990; Peacock, 1998; Delcourt and Delcourt, 2004). Cahokia (pm 5-1) is the most prominent example, a major center of Mississippian culture in the east. The population at Cahokia peaked around 1300 CE at ~25,000 people for an area of 300 km^2 (Delcourt and Delcourt, 2004). About 200 years later it had almost been abandoned, prior to European contact. Deforestation and subsequent agriculture by Native Americans had triggered accelerated soil erosion and siltation of rivers (Stinchcomb et al., 2011), but it is unknown if soil erosion was a dominant driving force for the decline in population. Between 1500 and 1800 CE, the decimation of indigenous peoples by diseases introduced by Europeans allowed woodlands to regenerate and was a relatively undisturbed period environmentally, with geomorphic stability and soil development (James, 2011). In the semiarid southwestern USA, gully (arroyo) formation has been discussed intensely as a main factor leading to the abandonment of southern Utah and northern Arizona by Anasazi groups (Bryan, 1925; Leopold, 1976; Hereford et al., 1995). Terracing was an important strategy for soil conservation and prevention of soil erosion in these semiarid area (Doolittle, 2001).

In the first half of the seventeenth century CE, colonialists started to displace the Native Americans and settled the landscape in New England and the mid-Atlantic coast colonies. Within a few centuries, large areas of the southeast had been deforested for timber and fuel or to gain fields for agriculture. In contrast to the Native Americans, European farmers had much larger fields and they used oxen and horses to pull iron plows, which stirred the soil more deeply and more continuously. The European style of farming produced bare surfaces and soil compaction or intensively grazed grasslands that triggered accelerated runoff and soil erosion. This triggered widespread soil erosion and increasing sediment yields to rivers, thus resulting in floodplain accretions of 0.5 to 2.0 m within 200 years (Happ, 1945, 1968; Trimble, 1974; Gregory, 2006; Knox, 2006; Walter and Merritts, 2008). The historic impact of timber exploitation and agricultural cultivation left clear evidence of hillslope erosion, gullying, and badland formation in the uplands and along the bluffs (Ashe, 1909; Bennett, 1939; Ireland et al., 1939; Smith, 1983; Grissinger and Murphey, 1984; Phillips, 1993; Magilligan and Stamp, 1997; Hyatt and Gilbert, 2000; Ambers et al., 2006). As a result, soil fertility began to decline. The first proposals suggesting to preserve forests to prevent soil erosion appeared in the 1790s (Cronon, 2003). Comprehensive overviews for the European period of land use and soil erosion in North America have been given for example by Miller et al. (1985). More recently, James (2011) also included the prehistorical period. The following sections present early descriptions and the development of soil erosion and soil conservation research in the western and southwestern parts of the USA. A particular focus will be given on the northern part of the State of Mississippi.

5.2. Early descriptions of soil erosion and soil conservation methods in the USA

The earliest descriptions of soil erosion and soil conservation in the USA came mainly from colonial writers, farmers, or naturalists. They noticed the massive amount of clearings and their effects on the environment, such as negative changes in microclimate, reduced water-holding capacity, accelerated runoff, increase of floods, and soil exhaustion as early as the eighteenth century (Cronon, 2003, p. 122; Montgomery, 2007).

A extensive compilation about some of their lives and work with respect to the perception of soil erosion and suggested techniques to prevent it has already been assembled by McDonald (1941) and is summarized here.

5.2.1. John Bartram (1699–1777)

The first written records are available from John Bartram, an early American botanist, horticulturist, and explorer. He had an intensive correspondence on agriculture with Jared Eliot, who was a famous farmer and physician. In the mid-eighteenth century, Bartram mentioned the situation of rich soils and their degradation by soil erosion in the area of the New England and the mid-Atlantic coast colonies. Over a period of 20 years, he observed gullying and erosion changing a black and very fertile soil into an area with coarse sand in Pennsylvania, East Jersey, and York: *above 20 years past when the woods was not pastured and full of high weeds and the ground light then the rain sunk much more into the earth and did not wash and tear up the surface (as now).* […] *but now the rains most of it off on the surface is colected into the hollows which it wears to the sand and clay which it bears away with the swift current down to brooks and rivers whose banks it overflows* (Eliot et al., 1934, p. 204). Bartram also described examples from floods of the Hudson River near Albany that were rich in sediments and how sediments fertilized the floodplains of the river. On a branch of the Susquehana River, he observed soils *like a rotten dung hill* and their destruction and erosion caused by farming and soil erosion (cf. Suppl. 3.1).

5.2.2. Jared Eliot (1685–1763)

Jared Eliot had similar ideas. He believed that fine sediment was washed from the hills and left sterile soils behind while the valleys were choked with fine material. In this context, Eliot warned about the depletion of nutrients in the soil caused by nonmanuring of the fields (Eliot et al., 1934, p. 29) (cf. Suppl. 3.2). Only few farmers made efforts to save manure from the farmyards, and land had become so poor that Eliot said: *it would raise turnips no larger than buttons. Such land needed dung*. This, however, could not be purchased for *love or money*. Eliot, while recommending manuring, warned against the use of manure on sloping lands, where it would be washed away by rain (cf. McDonald, 1941, p. 4). Eliot also developed a soil-building program

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and recommended the digging of ditches and holes to drain water and trap sediment. Eliot considered the problem of restoring the original texture of the soil so that eroded lands would again become productive. Sediments that were deposited in swampy depressions should be deposited back on the worn hillsides, while sand could be used as a soil amendment to meliorate swampy areas (Eliot et al., 1934, p. 156) (cf. Suppl. 3.3). McDonald (1941) pointed out, that Eliot's ideas had not been adopted by the famers. Soil conservation and manuring, however, were difficult as long as land remained unenclosed. Even a provident farmer, using an unenclosed farm, could not conserve the manure of his stock for the benefit of either his tilled fields or pastures. Eliot also advocated additional soil conservation methods to improve pastures on depleted or exhausted land. Besides animal and calcareous manures, he employed red clover (*Trifolium pratense*), timothy (*Phleum pretense*), and various wild grasses. When Eliot's work was completed, soil conservation was still at a fairly elementary stage. However, his work constituted the beginning of literature in the colonies on agriculture in general and on erosion control in particular, and it was frequently utilized by his successors (McDonald, 1941).

5.2.3. Samuel Deane (1733–1814)

Samuel Deane lived a generation later than Eliot and he also recognized the ill effects of erosion by water in New England. In his book he wrote *more of the fine mould would have been washed down into the hollows; and deeper channels would have been made in the soil by the running of water which are considerable inconveniences* (Deane, 1790, p. 232). Deane carried forward specific principles of plowing to prevent soil erosion as had already been recommend by Eliot. In addition, Deane suggested to plough the furrows a little bit deeper each year and proposed contour plowing to prevent gullying and hillslope erosion. The furrows should be turned into one direction so that the water drained only slowly and no soil was washed away. At first Deane advised throwing up banks of earth on the contours, but dismissed the idea in favor of ribbing, which was merely running parallel contour furrows at intervals on sloping land to prevent soil erosion. He also recommended terracing and strip cropping and the plowing of flat ridges about 9 ft wide. His book probably exerted more influence on New England's farming than any other published in the United States until then. It was repeatedly revised and published (McDonald, 1941).

5.2.4. Solomon Drown (1753–1834)

Solomon Drown also had an active interest in agriculture. He noted the progressive deterioration of the land to which he attributed increasing poverty among New England farmers. Together with his son, William Drown (1793–1874), they wrote “The Compendium of Agriculture, or the Farmer's Guide” (Drown and Drown, 1824, p. 49). They regarded the current system of tillage as the principal cause of erosion, but they also saw the constant cropping combined with bad plowing as the chief cause of soil erosion. They warned that the practice to plough up and down the hill will trigger soil erosion (Drown and Drown, 1824, p. 82) (cf. Suppl. 3.4). In the place of this destructive practice, the Drowns recommend the Butler method that was followed *by carrying a furrow down the hill only, and by inclining this furrow to the left hand, directly in proportion to the descent of the declivity—and suffering the team to re-ascend the hill without a furrow* […] *In this way, the steepest hill may be ploughed, a single furrow left open to the wash, except the last one, and the saving in the strength of the team, and in the value of the crop, which will arise from the extra goodness of the ploughing, will doubly compensate for the loss of time* (Drown and Drown, 1824, p. 49). As a further method to control soil erosion they advocated the method of “alternate husbandry” which would today be called crop rotation (Drown and Drown, 1824, p. 83).

5.2.5. John Taylor (1753–1824)

At the same time, John Taylor had two large farms and was active in different societies such as “Promoting Agriculture in Philadelphia and Virginia”. In his essays he noted: *If inclosing, manuring, deep and horizontal ploughing, were unattended by any other advantages, that of preventing the land from washing away would in many views be a sufficient recommendation of such a system. The disaster is not terminated by the destruction of the soil, the impoverishment of individuals, and transmission of a curse to futurity. Navigation itself is becoming its victim, and in many parts of the United States, our Agriculture has arrived to the insurpassable state of imperfection, of applying its best soil to the removal of the worst farther from market* (Taylor and Adams, 1813, pp. 172–173). One of the foremost problems in southern agriculture was gully erosion and their reclamation. Taylor was probably the first who promoted methods to prevent gullying by using his system of “soil renovation”. He wrote: *The effect of manuring and enclosing united in stopping gullies and curing galls, is an hundred fold greater, than the most ingenious mechanical contrivance. Land filled with roots, covered with litter, aided by buried bushes forming covered drains, protected against the wounds of swine and hoofs, and replenished sex-ennially with the coarse manure of the farm and stable yards will not wash* (Taylor and Adams, 1813, pp. 224–225) (full citation see Suppl. 3.5).

5.2.6. John Lorrain (1764–1819)

John Lorrain was one of the few men of the mid-Atlantic coast States who actively tried to solve the erosion problem. To him soil wastage was an *insatiable monster, like Arron's serpent, swallows all the rest* (Lorrain, 1825, p. 518). He judged careless furrowing and plowing to be a major reason for the development of gullies particularly when the furrows were too steep and too large (citation see Suppl. 3.6). To prevent soil erosion, he suggested seeding grass and using a crop rotation system which provided an adequate supply of manure. With regard to plowing, he proposed contour plowing in such a way that the water would flow through as many furrows as possible. Hence they should be deep enough to carry the water and uniformly shaped to prevent the water from concentrating at one point and breaking through the furrows in times of excessive precipitation. Lorain believed that gullies could be leveled and filled with stones (McDonald, 1941).

5.2.7. George Washington (1732–1799) and Thomas Jefferson (1743–1826)

George Washington, first president, and Thomas Jefferson, third president of the United States, were two prominent people concerned with soil conservation. They made experiments to enhance soil fertility and to minimize soil erosion on their farms and emphasized soil management methods like crop rotation, including legumes, the use of fertilizers, and the practice of deep plowing (Brooke, 1919; Bennett, 1944; Montgomery, 2007). Washington refilled gullies with garbage like fencing posts and separated large fields into smaller ones to minimize runoff. Jefferson made various soil conservation experiments on his farm in Albermarle County in Virginia (pm 5-2). Jefferson introduced the method of “Horizontal Plowing” to his fields, and in the following decades he became an important advocate of this soil conservation method (Bennett, 1944).

5.2.8. Isaac Hill (1789–1851)

Isaac Hill lived in New Hampshire when the state was going through its greatest land exploitation. He was one of the first who stated the economic aspects of soil erosion: In 1842 he commented: *We have here in New Hampshire many extensive farms once fertile, that scarcely now by their products pay for the labor employed upon them. Look at many of our hill-tops, rendered entirely barren by a long course of wasteful cultivation, united with the ordinary action of winds and rain. Do we not hear the voice of help crying to us from such grounds?* (Hill, 1842). He believed that every new country passed through a cycle of soil exploitation. All areas of the United States had either gone through this period or would do so shortly after being put under cultivation. He feared that New England might suffer the same fate as Virginia and Maryland; and when he traveled through Virginia to Delaware, he commented on the general land abandonment: *whole districts of country have been abandoned as sterile;*

and he who travels through this country in many directions would suppose the greater part of the country had never been capable of producing ordinary crops. (Hill, 1843). Just like almost every other progressive agriculturist of his time, Hill favored various methods to prevent soil erosion including protecting manure from the rain, subsoil plowing, crop rotation, and the planting of grass or trees on steep slopes (McDonald, 1941).

5.2.9. Nicholas Sorsby (mid-nineteenth century)

Nicholas Sorsby was a trained physician but a farmer by choice in Alabama and Mississippi. Sorsby defined gullies as *open water-channels, caused by rain water and care-less up and down hill plowing. They are hideous objects to the eye of a scientific and practical farmer, and should receive the condemnation of all good husbandmen. There are many ways of filling them up, but in doing so, sometimes two are made in place of one, unless it be properly done and aided by the horizontal culture. The land requires to be well graded and the direction of the water changed, and not be permitted to flow so abundantly down the gullies as before* (Sorsby, 1860, p. 24). He developed a new system of horizontal plowing to prevent soil erosion that considered variations in crop, slope, and soil type (Sorsby, 1860). This method was probably practiced neither in Europe nor in the United States until the nineteenth century. By 1850, however, it was widely practiced in the southern states, from North Carolina to Mississippi. Gullies received special treatment from Sorsby: they had to be filled by hand with shrubs, pieces of rails, turf, or other waste matter. Earth was piled up on top and the surface leveled. No gully was to be tolerated either along fence lines or old plantation roads. For larger gullies, stakes should be driven down and oak boards should be placed against them to hold back soil and water. Thereafter, the rows were curved in such a way that as little water as possible could accumulate in the old gully (Sorsby, 1860) (Fig. 13). Sorsby seemed to have been unaware that this practice might also cause new gullies rather than preventing its expansion (McDonald, 1941).

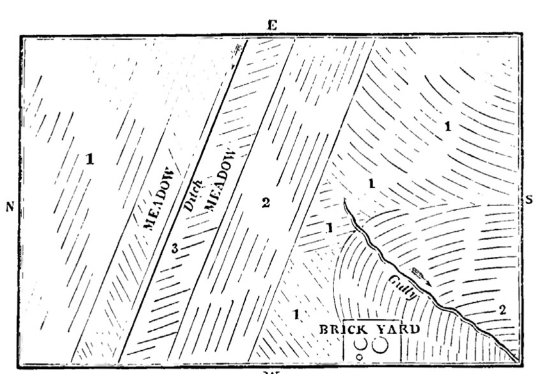
5.2.10. Edmund Ruffin (1794–1865)

Edmund Ruffin (1794–1865) had a farm in Virginia and was the most outstanding agricultural reformer of the pre-Civil War period because his essays were read by more farmers and owners of large estates than any other agricultural book of the nineteenth century (McDonald, 1941). With respect to soil erosion, he observed the ecological and economic effects of soil exhaustion and flooding. He adopted Taylor's methods of cultivation and promoted lime (marling) as a fertilizer of degraded soils. He was probably the first to carry out detailed studies on runoff and sedimentation, but he did not offer too many details on aspects preventing soil erosion on hillslopes (Ruffin, 1832). Ruffin made a big effort to build a better agrarian system, but most of his activities failed. However, Edmund Ruffin's hard toil ended the pioneering stage of the erosion-control movement in America. His work was equal to that of all his predecessors combined and his erosion-control practices provided a foundation for later developments (McDonald, 1941).

5.2.11. Charles Lyell (1797–1875)

The English geologist Charles Lyell (1797–1875) traveled to the United States and Canada in the 1840s and wrote two popular travel-and-geology books. Throughout his geological studies, he realized that freshly incised gullies provided excellent exposures for his geological and paleontological surveys. During his second visit, he also traveled through the southeastern part of the USA and reflected on their geological formation. In January 1846, he moved through the neighborhood of Milledgeville in Georgia where he wrote a detailed description about the process of gullying and made a drawing (Fig. 14, pm 5-3). He wrote: *Twenty years ago it had no existence; but when the trees of the forest were cut down, cracks three feet* […], *during the rains, a sudden rush of water* […] *caused them to deepen at their lower extremities, from whence the excavating power worked backwards* […] (Suppl. 3.7, p. 28). This drawing, which is published in his second volume of the book "A Second Visit to the United States of North America" (Lyell, 1850, p. 29) is probably one of the oldest scientific drawings of a gully. Lyell also described some other gullied sites and prepared detailed descriptions about their locations, formation processes, sizes, and ages (cf. Suppl. 3.7).

FIG. 2.—BRICK-YARD FIELD, 10 ACRES.



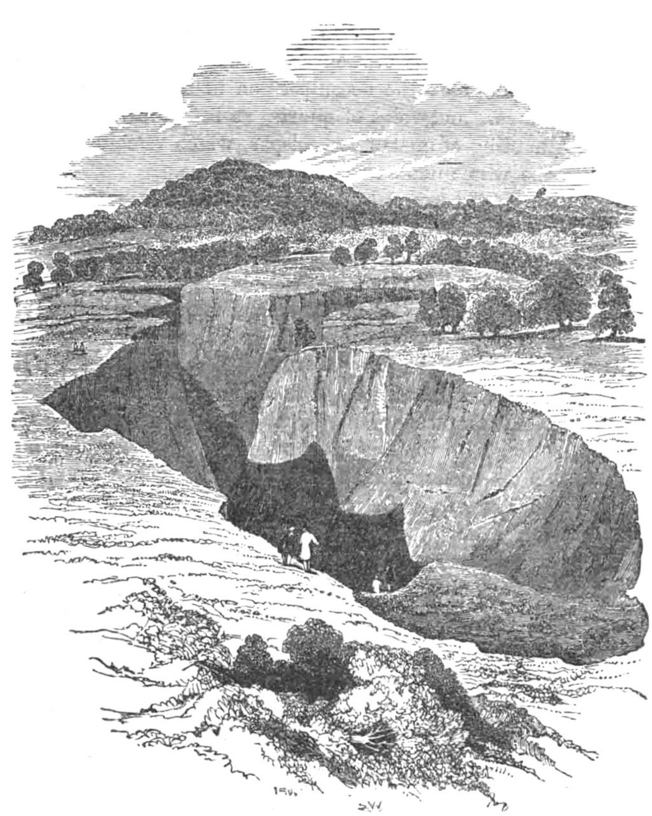
EXPLANATION OF THE FIGURE.

1. Level Method, - - - - - - - No. 1.
2. Grading Method, - - - - - - - - " 1.
3. " " - - - - - - - " 3.

The gully was stopped in two years.

Fig. 13. Sorby's plan with horizontal plowing methods for diversified erosion control on his farm in Mississippi (Sorsby, 1860).

Fig. 7.



Ravine on the Farm of Pomona, near Milledgeville, Georgia. January, 1846.

Excavated in the last twenty years, 55 feet deep, and 180 feet broad.

Fig. 14. A gully near Milledgeville, Georgia (pm 5-3) drawn by Charles Lyell in 1846 which is one of the oldest drawings of a gully with a scientific purpose (Lyell, 1850, p. 29).

5.3. The development of scientific soil erosion and soil conservation research in the USA

Farmers like Eliot, Taylor, Jefferson, and others covered above obviously had been concerned with soil erosion and were engaged in experimentation for the purpose of conserving soils in eastern North America. However, the interest in geomorphic legacies of soil erosion in the past became more prominent in the middle of the nineteenth century. At this time, mapping of the geology and agriculture became increasingly more important and, occasionally, descriptions on soil erosion or gully forms were made.

In the state of Mississippi, for example, an area that was settled in the early nineteenth century, three reports were published in only the first decade after 1850. No records on soil erosion and gullying were included in the first report (Wailes, 1854). Harper (1857), who produced the second report on the geology and agriculture in Mississippi, also utilized the potential of exposed gully walls for geological investigations. In his report, several drawings of gully walls are described. Unfortunately, he used them to describe the geological formations only. But the attached cross-sectional figures give a good idea about the situation (Suppl. 3.8). He also employed the township numbers to describe the locations of the investigated sites, which would be very helpful for the retrieval of information today.

The most comprehensive reports on the geology and agriculture (and soil conditions) in Mississippi were carried out by Eugen Woldemar Hilgard. He was a state geologist between 1858 and 1873 CE and later became a very famous and highly honored geologist in the whole of the USA (Slate, 1919; Amundson and Yaalon, 1995; Amundson, 2006). In his first report, he frequently provided information about hillslope erosion and gullying (cf. Suppl. 3.9). For example, he wrote about the Bluff Formation (western loess uplands in northern Mississippi): *It generally caps the hills, and also forms their talus, while on the brow of the hills, where the level breaks off, the calcareous loam of the bluff formation is generally near to, and sometimes at, the surface; the same is the case, of course, in washes and gullies on the hillsides* (Hilgard, 1860, p. 204). For the area of the east Monroe and Tombigbee valley he also described tunnel erosion: *The loam stratum is not very thick, however, and being underlaid by loose sands, it caves and washes away badly on the hillsides (on which extensive gullies are often formed), though otherwise possessing, to a considerable extent, the advantage of being underdrained by the pervious sands* (Hilgard, 1860, p. 257). Hilgard also depicted the formation of sunken roads. In general, he saw the urgent problems of soil erosion and developed several methods of how to prevent hillslope erosion and gullying. He suggested deep plowing and leveling methods as have already been described by Nicholas Sorsby (see above). Interestingly, Hilgard saw some advantages of soil erosion. He stated *the washings from the loam and sand hills often greatly improve heavy prairie soil […] but the washes must not to be allowed to penetrate into the reddish hard-pan underlying the loam, which cannot serve the soil* (Hilgard, 1860, p. 260). But finally Hilgard observed that soil erosion continued and "*the [sandy] materials thus removed cover over the fertile branch bottoms, in company with a flood of sand, which renders them useless for all time to come*" (Hilgard, 1860, p. 293) (cf. Suppl. 3.9). Such legacy sediments can be observed at many floodplain sites in the southeastern USA today (Fig. 15, pm 5-4). Hilgard also realized the physical causes of gullying and provided explanations on why some soils are more vulnerable to soil erosion than others and elucidated the process of gullying. He wrote: *It is highly important* […] *to prevent the washes from penetrating the* [shallow] *loam into the underlying sand or hardpan.* […]*, the moment the water reaches it, an undermining process will begin, which will cause the land to waste with greatly increased rapidity. Should it, on the contrary, be an impervious hardpan, as is very frequently the case, the increased mass and velocity of the water will rapidly widen its channel, casting away the sides of the gully* (Hilgard, 1860, p. 295). About 25 years later, Hilgard (1884) compiled a report on cotton production in Mississippi (cf. Suppl. 3.10). Regarding the effects of tillage he stated: *But the actual extent of the damage done by this washing and final gullying of the hillside slopes, with the final undercutting into underlying sands and the bodily descent of the upland soil into valleys, mingling with a flood of sand, which renders useless alike the hills and the valleys, must be seen to be appreciated* (Hilgard, 1884, p. 77). In this context he made detailed analyses on how cotton production indirectly provided rates of soil degradation. He summarized: *The seed-cotton product per acre of fresh land is 800 pounds; after five years' cultivation the product is 400 pounds. More than one-half such land lies turned out and cannot be reclaimed* (Hilgard, 1884, p. 111).

It is evident that in the eighteenth and nineteenth centuries farmers and later also scientists were aware of the causes and effects of soil erosion. At this time no laws or official policies existed to prevent further soil erosion, and there was no support by the state to regenerate eroded areas. McDonald (1941, p. 38) pointed out that in spite of the numerous and varied suggestions of more or less practical recommendations on soil conservation, they were barely adopted by farmers because they argued that it was impractical or an insult to their ancestors or that it was not suitable for the area. Probably to American farmers it appeared as though they had access to unlimited areas of land and it was hard to believe that fertile land could become scarce (McDonald, 1941, p. 19). As a result, in the second half of the nineteenth century, large proportions of land were already taken out of cultivation because of severe soil degradation because of the depletion of nutrients, soil erosion, and other economic issues (Usher, 1923; McDonald, 1941). At first, this took place in many areas of the initially settled colonies in New England (Cronon, 2003) but later it spread into other areas soon after land reclamation in the south and mideastern as well as in the western parts of the USA. For example, around 20,000 km^2 of formerly cultivated land was

Fig. 15. Typical situation of legacy sediment covering the dark clayey soil in a floodplain (Black Belt) near the Pontotoc Ridge (northeastern Mississippi, pm 5-4). Compared to the original soil profiles of the adjacent upland, the legacy sediments form an inverted stratum. It is a gradual accumulation of basal materials derived from lower soil horizons of the hillslopes (picture taken on 25.02.2007 by the author).

Fig. 16. Ravine which appears to have started from a wagon track trough the pasture. Four miles west of Abbeville in northern Mississippi (Lentz et al., 1929) (pm 5-5).

heavily eroded and laid idle in the uplands of the southern states at the turn of the nineteenth to twentieth centuries (Ashe, 1909).

The first political actions came in 1897 with the foundation of the "Division of Soil of the United States Department of Agriculture", and in 1899, with the "National Cooperative Soil Survey". The Division of Soil Erosion was established in 1908, and surveys brought scientific and political awareness for soil erosion and soil conservation (Harding, 1947). Several bulletins and textbooks on various aspects of soil degradation (including methods on soil conservation) were published (e.g., Fenneman, 1908; Ashe, 1909; Lowe, 1910; McGee, 1911; Davis, 1915; Torrance, 1919; Ramser, 1922; Bennett and Chapline, 1928; Crosby, 1928; Bates and Zeasman, 1930; Sinclair, 1931). In some counties very detailed "Erosion Reports" were published, partly with comprehensive information on soils, size and degradation of eroded areas, legacy sediments, farming activities, forest condition, abandoned land, and economic conditions. For example, the soil erosion report for Lafayette County in northern Mississippi shows that about 27% of the county was affected by soil erosion in 1929 and about 8.5% of the land was abandoned because of soil erosion (Lentz et al., 1929). The reports contain large assortments of high quality photographs of badlands and gullied areas (Fig. 16 (pm 5-5) and Fig. 17 (pm 5-6)).

However, despite the reports, still no or very little coordinated or systematic effort existed by farmers, institutions, or the government to address this issue. The catastrophe that had been unfolding in the State of Mississippi reached its climax with the destructive 1927 flood in the lower Mississippi River basin, caused by extreme and prolonged rainfall in the catchment. The runoff led to severe soil erosion in the uplands. While the southeast and southern central parts of the USA were devastated by water erosion and sedimentation, the southern plain states of Texas, Oklahoma, Kansas, and Colorado were devastated by wind erosion (Romkens, 2010).

5.4. The birth of modern soil erosion and soil conservation research in the USA

After the massive cumulation of extreme events in the 1930s, the need for soil conservation was nationally recognized as an urgent task; and the Soil Erosion Service was set up by the Department of Interior in 1933 and renamed Soil Conservation Service in the U.S. Department of Agriculture in 1934. Under the leadership of Hugh Hammond Bennett, who was an entrepreneur in soil conservation (Helms, 2010), a nationwide action program was initiated with many demonstration areas in several states of the USA. Many further textbooks and guides on soil conservation had been published during the following decades (Hall, 1937; Bennett, 1939; Ireland et al., 1939; Jacks and Whyte, 1939; Gottschalk, 1945; Mickey, 1945; Bennett, 1949; Woodburn, 1949; Lowdermilk, 1953; Wilken, 1987). Many different techniques were established and evaluated including strip farming, terraces, masonry structures, log and plank dams, various styles of gully plugs, sod strips in excavated channels and, finally, solid grass sods in natural depressions as well as the construction of terraces at experimental or demonstration stations (Fig. 18, pm 5-7 and Fig. 19, pm 5-8). Under the coordination of the Soil Conservation Service, the Civil Conservation Corps continued soil conservation activities beyond

Fig. 17. Silt and sand deposits in a ravine. This is an old break, now about 300–400 ft across and a mile or more long. Three miles west of Abbeville in northern Mississippi (Lentz et al., 1929) (pm 5-6).

the stations, and farmers were invited to attend conservation programs. Further activities like the planting of pine trees (mostly the fast growing loblolly pine (*Pinus taeda*)), black locust (*Robinia pseudoacacia*), or kudzu (*Pueraria montana*) were promoted (Bailey, 1946), particularly in severely eroded areas like badlands and larger gully systems. Kudzu has since become a serious problem because it is a very fast growing plant that climbs on trees, poles, and buildings. In 1970 it was officially labeled a weed. Kudzu currently covers 3 million ha throughout the eastern United States and is spreading at a rate of 50,000 ha/y (Forseth and Innis, 2004). Additionally, the subsequently established flood prevention programs also included many actions in soil conservation. Several of these programs and their associated case studies, including an evaluation of the successes or failings of these actions, were published (e.g. Wilkerson et al., 1972; Williston, 1988; Barnhardt, 1989; Pasquill, 2008). Some gullied areas or badlands were also bought by the state and utilized for recreation, nature conservation, education, and research. The Providence Canyon in Georgia (pm 5-9), which was already pointed out by Bennett (1939, figures on p. 4 and p. 66), is a prominent and well described example for the history of land use and soil erosion in the south-eastern USA (Donovan and Reinhardt, 1986; Magilligan and Stamp, 1997; Hyatt and Gilbert, 2000; Firestone et al., 2007; Sutter, 2010). The history of the development of the USDA Soil Conservation Service and its partly controversial role in the development of modern soil erosion and soil conservation research have been described in several papers and book chapters (e.g. Geiger, 1955; Johnson and Papendick, 1968; Helms and Flader, 1985; Trimble, 1985; Williston, 1988; Argabright et al., 1995, 1996; Nelson, 1997; Showers, 2005; Romkens, 2010).

6. Central and South America, and the Caribbean

In Pre-Columbian South America, an important area for early agriculture is the humid central Peruvian Andes region located at the heart of the formerly dominating Incan civilization (1440–1534 CE). The first forest clearings by their ancestors started around 5000 years ago and early evidence for farming dates back around 4000 years (Chepstow-Lusty et al., 1998). In the last decades, a second region with agricultural evidence is the Amazonian basin where unexpectedly complex regional settlement patterns and field systems dating to between 400 and 1600 CE have been revealed (Denevan, 1996, 2001; Heckenberger et al., 2003; Lombardo and Prümers, 2010). In Mesoamerica, plant domestication extended from semihumid central Mexico to humid Guatemala and dates back around 7000 years (Beach et al., 2006a; Williams, 2006). Humans arrived at the Caribbean islands around 6000 to 5000 years ago, and the introduction of agriculture has been estimated to have occurred about 2000 years ago, but this varies greatly from island to island (Beach et al., 2006a). With the exception of the Amazonian basin, the settled areas often lie on temperate highlands where the river valleys tended to be narrow. The interior-drained basins were also difficult to farm because they were poorly

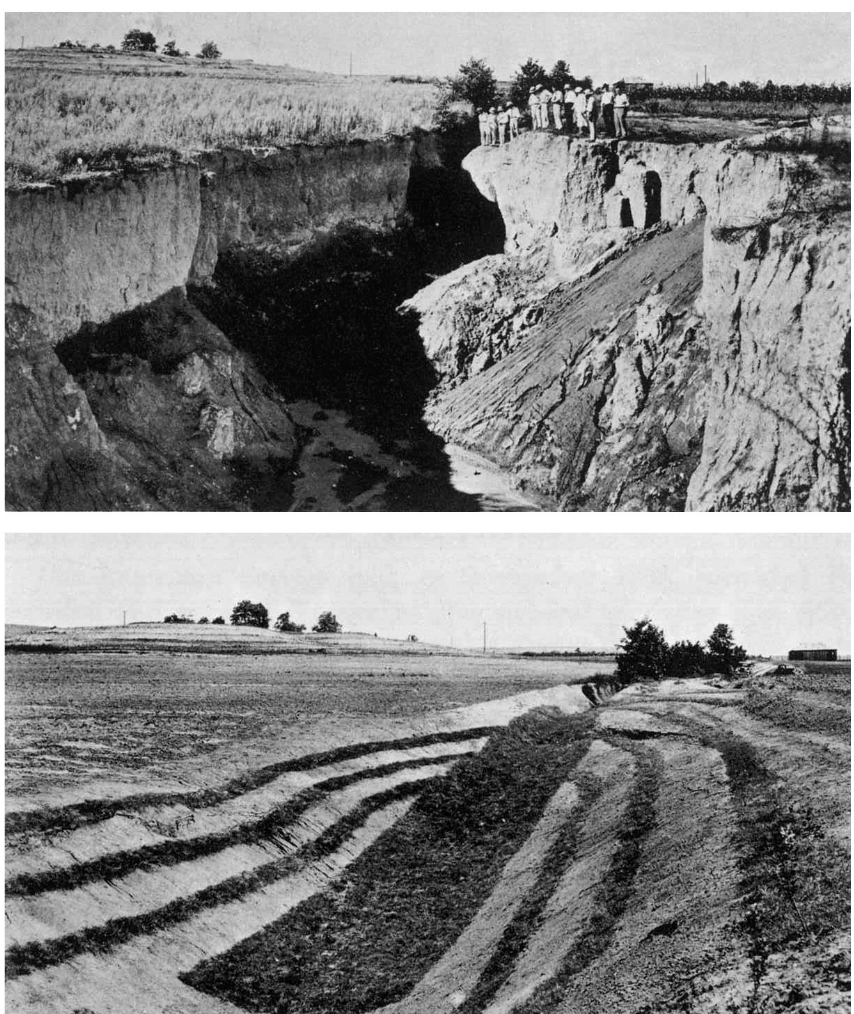


Fig. 18. A medium-sized gully on the South Tyger River Project (pm 5-7) in northwest South Carolina before and after the treatment in 1934 (Wilkerson et al., 1972, p. 18).

Fig. 19. A gully plug was set in concrete by the Civil Conservation Corps, probably in the 1930s, to prevent further gully head retreat (northern Mississippi, pm 5-8). Since then, the gully has deepened and widened. Today water slowly undercuts the plug and head retreat may occur again. The surrounding area is covered with Kudzu (picture taken on 15.02.1999 by the author).

drained and frost-prone due to cold air (Donkin, 1979). Consequently, slope cultivation has a long tradition and was enhanced by terracing to prevent soil erosion. Such an investment would have been undertaken at a local level, even by individual households (Whitmore and Turner, 2001, p. 133). Terraces in southern and central America are very old, and their construction had begun as early as 300–200 BCE in Mexico and at the latest around 200 BCE in the central Andes (Donkin, 1979; Ojha, 1997). However, terraces with ages of up to 4000 years have been found in South America (Sandor, 2006). Despite the construction of terraces and the good knowledge on soil management, geomorphological and archeological studies have shown that many areas of these ancient cultures experienced soil erosion; and several authors have proclaimed that agricultural soil exhaustion caused or triggered the collapse of ancient civilizations (cf. Beach et al. (2006a) for an elaborated discussion on soil erosion and the collapse of ancient civilizations in Mesoamerica).

In the sixteenth and seventeenth centuries, the Spanish conquest spread swiftly throughout Mesoamerica and South America, claiming land and labor. At the same time, rapid depopulation of the indigenous people took place. The Spanish reconstituted agriculture through the introduction of European technologies, but in contrast to North America they often retained the indigenous crops and cropping techniques. Ultimately, the resulting reconfigured agricultural areas were not too different from their previous state but they were modified by exchanges in biota and technology (Whitmore and Turner, 1992). However, the population explosion and the increase of grazing animals early in the sixteenth century accelerated soil erosion on agricultural lands, increased siltation, and triggered more frequent and profound flooding events. Significant losses owing to the rampant herds and the physical trampling of the fields were documented (Whitmore and Turner, 1992). Continuing until today, soil erosion has always been a serious problem, and modern soil conservation techniques are lacking or are often poorly implemented. However, some positive examples of soil conservation exist that are often connected to traditional land management systems. In Peru for example, many of the agricultural terraces have been continually used until the twentieth century. But today, socioeconomic reasons prompted the abandonment of many terraced areas, thereby increasing soil erosion after the structures collapsed (Inbar and Llerena, 2000).

With regard to historical records on the perception of soil erosion, very little research has been published that demonstrates early descriptions or soil conservation strategies by farmers before the mid-twentieth century. Probably the oldest description was recorded by Charles Darwin. During his journey through South America, he carried out analyses of the effect of 200 years of land use change on the ecosystems of Patagonia, Brazil, Tierra del Fuego, and Chile (Darwin, 1839). His observations described the devastating impact of droughts and cattle grazing on the land, desertification in Argentina, and how these factors affected erosion and sedimentation processes. Imeson (2009) remarked that his geomorphological process experiments were largely the same methods and techniques that are used today. Few case studies on environmental history include the perception of soil erosion during the early conquest period. For instance, Watts (1987) showed several examples of historical accounts of soil erosion and gullying in the West Indies. Some studies focus on the long term effects of soil erosion to soil fertility and associated economic consequences. Such a causality chain has recently been revealed for cotton production in Brazil during the mid-twentieth century (Brannstrom, 2010).

7. Australia

Australia was sparsely populated before the arrival of the Europeans about 200 years ago. The aboriginal hunters and gatherers did not grow crops and had no grazing livestock. However, their influence on the environment was not to be dismissed because they used repeated burning of the vegetation to enhance their hunting efficiency (Bird et al., 2005). Studies in the Mediterranean showed that such vegetation removal accelerates soil erosion (Shakesby, 2011), but no detailed research has been carried out in this context for the pre-European period in Australia so far. Studies of archeological sites indicate an increase in sediment accumulation that coincided with the initial occupation of these camp sites (Hughes and Sullivan, 1986). However, any increase in soil erosion associated with disturbance of vegetation around these sites would have been of local extent and therefore unlikely to have had an impact at a regional scale (Scott, 2001, p. 8).

With the arrival of the Europeans and the introduction of agriculture, rapid land use changes took place and accelerated soil erosion occurred (Prosser and Winchester, 1996; Scott, 2001; Saxton et al., 2012). In addition, the fast growing wild rabbit population, after their introduction in the mid-nineteenth century, also triggered soil erosion due to the severely depleted vegetation cover (Edwards, 1993). Soil erosion by water became especially critical in southeastern Australia and Queensland. Geomorphic studies demonstrated that in the first 25 years after the arrival of sheep in the catchment of the New England Tablelands of northeast New South Wales, erosion rates increased by a factor of over 50. Then it decreased because a new drainage network equilibrium developed that reduced soil loss to a low and stable level (Gale and Haworth, 2005). In northern Australia, the erosion rate increased by between 4 and 33 times on average for agricultural lands compared to naturally vegetated areas (Lu et al., 2003). On the south coast of New South Wales, accelerated runoff led to hillslope erosion, gullying, and valley incisions (Fryirs and Brierley, 1999). A lack of substantial sediment deposition over the last 20 to 40 years is evidence for a significant drop in sediment yields in the investigated areas of New South Wales (Rustomji and Pietsch, 2007). For example, in the catchment of the

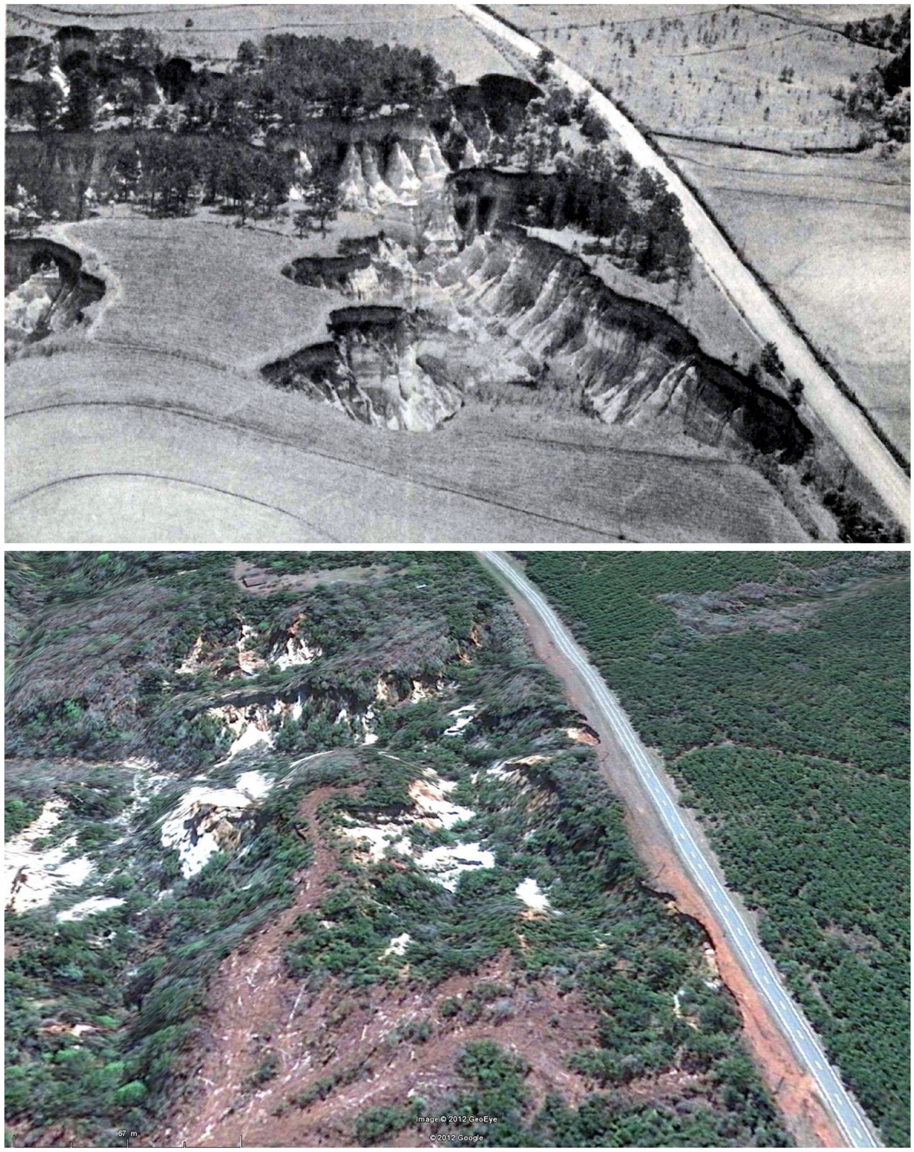


Fig. 20. The area around the Providence Canyon in Georgia (pm 5-9), was already highlighted by Bennett in the 1930s as an example of severe gullying on former farmland in SE-USA (Bennett, 1939, p. 4, reprint with permission from McGraw-Hill Higher Education). The gully system is still very active despite the implementation of a soil conservation program including the reforesting of the catchment. The Google Earth image below displays the present-day situation.

Murrumbidgee River, NSW, degradation of the vegetated valley bottoms by introduced livestock in the 1840s and 1850s triggered a massive phase of gully erosion over the next 40 to 50 years because the erosion rates in the headwater areas increased by a factor of nearly 245. Since the gully networks have reached maximum extension, sediment yields from the headwater areas declined by a factor of around 40 and are now estimated to be about six times the pre-European rates (Olley and Wasson, 2003).

With respect to historical records on the perception of soil erosion, no studies have been published so far. However, in the 1930s, after about 150 years of exploitive agriculture, scientific and governmental interest in soil erosion rose because of the severity of the problem. Concern for soil conservation in the United States during the 1930s also gave rise to a soil conservation movement in Australia as well as in New Zealand. In 1936 a special meeting of Agricultural Ministers from the States and the Commonwealth decided that each State should form a committee, in conjunction with the Council for Scientific and Industrial Research (now CSIRO), to assess the problem and make recommendations. The first report was published in 1939 with particular attention to wind erosion in the pastoral areas and the seriousness of water erosion in the cereal belt in South Australia (Soil Conservation Commitee, 1939). The outcome was "The Soil Conservation Act 1939" that defined measures to enforce soil conservation. The first extensive textbook about soil erosion and soil conservation in Australia and New Zealand was published in 1946 (Holmes, 1946).

8. New Zealand

The prehistoric land use history in New Zealand that had a profound influence on the local ecosystem began with the arrival of Polynesians (Māori) around 1280 CE (Wilmshurst et al., 2008). Paleoecological records show that both islands of New Zealand had been extensively forested before human settlement. During 500 years of prehistoric occupation, up to 40% of the forest was lost by burning (McWethy et al., 2009). Prehistoric Polynesian agriculture in New Zealand relied on non-cereal starch staples produced through a variety of *wet and dry* field-cropping methods (Kirch, 1994). At many of the occupied sites, the Māori left archeological remains that are in stratigraphic association

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with natural deposits such as dunes, alluvial deposits, shoreline sediments, and lagoon muds (McFadgen, 2007). The Māori used a variety of soil management systems including terraces and plaggen soils (McFadgen, 2007). However, very little research has been done on the soil conservation methods by the Māori and little is known if and to what extent prehistoric farming accelerated soil erosion. We can assume that the loss of forest cover on hillsides produced large amounts of sediments, but their distinction from natural mass movement processes triggered by earthquakes is difficult (personal communication, Bruce McFadgen, 2012). However, Horrocks et al. (2008) were able to show that a loss of forest cover on the steep, easily eroded mudstone soils at Anaura Bay (pm 8-1) resulted in an extremely accelerated rate of sheet erosion, carrying sediments into the valleys and onto the plain. McWethy et al. (2009) investigated sediment cores from five lakes located on the deforested eastern side of the Southern Alps that documented the local fire history of the last 1000 years and the response of vegetation and watersheds to burning. The results suggest that one or more high severity fires occurred within a few decades of initial Māori arrival, which caused the majority of the forest losses and soil erosion.

With the European arrival in the nineteenth century CE, large areas of New Zealand were quickly exploited for sheep farming. Slash-and-burn practices were used to remove thorny shrubs and to promote the growth of palatable shoots of the main tussock-grass species (O'Connor, 1982). Observations on the effects of grazing to soil erosion were already reported in 1858. Alexander Garvie, the principal assistant to the Chief Surveyor of the Province of Otago wrote: *A very great deal of mischief may be done by reckless and unseasonable burnings. A great deal of the pasture in and around the Otago Block has been much deteriorated by this cause* (Beattie, 1947). During the following decades, several reports described the problems of livestock grazing, but no evidence has been found that public servants followed these warnings (Mather, 1982). As a result, after several decades soil erosion and large gullied badlands spread over the whole of New Zealand.

The scientific and political awareness of soil erosion and soil conservation began in 1938, triggered by a number of events and circumstances. In early 1938, severe floods occurred in the Gisbome and Esk valley areas on the east coast of the North Island and resulted in the burial of extensive areas of settled farmland beneath thick deposits of silt (Hill, 1938). The fear of further, similar burial of farmland was deep-seated among sections of the farming community. Several reports highlighted the severity of soil erosion and the need of soil conservation (Mather, 1982). In 1941, the Soil Conservation Act and River Control Act in New Zealand were signed. The first textbook about soil erosion and soil conservation was published in 1946 (Holmes, 1946). Further books with a particular focus on New Zealand became available in 1947 (Cumberland, 1947) and the following years (Campbell, 1951; Anonymous, 1965). An extensive overview about the changing perception of soil erosion in New Zealand is given in Mather (1982).

9. Easter Island (Rapa Nui)

The environmental history of Easter Island (in Polynesian language, Rapa Nui) has been received by many scholars as an outstanding example of the negative effects of human-induced environmental degradation in a sensitive ecosystem and their ecological and socioeconomic effects (e.g. Diamond, 2006; de la Croix and Dottori, 2008; Good and Reuveny, 2009). Over the last few years, several studies have been carried out, focusing on the history of soil erosion and soil conservation that show a much more complex relationship than had previously been suggested (Mieth and Bork, 2005; Stevenson et al., 2006). According to stratigraphic investigations, the beginning of human settlement on Easter Island dates between 300 and 600 CE. The agriculture was characterized by sustainable land use and a traditional type of agroforestry and soil erosion was not significant. This situation changed around 1280 CE when the main endemic palm (*Jubaea spec.*) was cleared by slashing and burning to promote intensive farming on the upper slopes of the peninsula. Soil erosion occurred; and settlements and ceremonial places, which had been built one century earlier on downslope areas, were soon buried by sediments. Agriculture ceased around 1400 CE on downslope areas as the fertile soils became completely eroded (Mieth and Bork, 2005). Since ancient agriculture on Easter Island is dependent upon suitable soil conditions, the decline in soil fertility had dramatic socioeconomic consequences. A set of agricultural innovations was introduced to counteract these negative effects. These developments included the use of a surface lithic mulch (stone mulching) to facilitate water permeability, significantly reduce evaporation, and protect the soils from erosion (pm 9-1, Fig. 21). In

Fig. 21. Stone mulching at the Akahanga south coast on Easter Island as an endemic soil conservation method to prevent soil erosion (pm 9-1) (picture taken on 05.07.2009, courtesy of H.-R. Bork).

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addition, rocks were placed within gardens as protection from wind, and gardens were placed at the base of slopes that benefited from surface water runoff (Bork et al., 2004; Ladefoged et al., 2013). Gullying began with the sudden increase in the number of sheep during the early twentieth century, and the gullies are still extending on the island today. This continuous enlargement created extended badlands that generate significant problems for ecological and archeological conservation strategies (Mieth and Bork, 2005).

10. Discussion

Many of today's landscapes are a product of agriculturally induced or human-accelerated soil erosion. McNeill and Winiwarter (2004) summarized that on a global scale agriculturally induced soil erosion occurred in three main waves: the first wave began around the second millennium BCE, as a consequence of the expansion of societies based on farming who left river basins (Yellow River, Indus, Tigris–Euphrates) or lowlands and moved into areas with steeper slopes. Over the next 3000 years, rates of soil erosion increased because farmers in Eurasia, Africa, and the Americas gradually converted a moderate proportion of the world's forests into farmland or pasture. The second wave took place during the sixteenth to nineteenth centuries with the introduction of stronger and sharper plowshares, which helped to break the sod of the South American pampas, Eurasian steppe, and the North American prairies. The emigration of Europeans to the Americas, Australia, New Zealand, Siberia, South Africa, Algeria, and elsewhere accelerated the expansion of land use in semiarid and semihumid areas that are more vulnerable to soil erosion. The third wave coincided with rapid population growth after the mid-twentieth century when people started to clear rainforests and steep areas to exploit wood for timber or fuel or to expand agricultural land (McNeill and Winiwarter, 2004). However, this three-wave concept should be qualified as very general because it does not reflect the local and regional land use periods with phases of intensive soil erosion, particularly for the early history of soil erosion. Indeed, the introduction of the iron plowshares in the second wave (sixteenth to nineteenth centuries) was important to break the sod quickly in the New World, but the exploitation of this land would not have been possible without the cultural spread, including export economies, extended trade networks, navigation, etc., as well as the advent of the mechanical age (water power, saw mills, rag pumps for mining, etc.). Also the substantial clearance of forests for timber and the introduction of grazing and draft animals contributed to soil erosion, but they were largely independent from iron plowshares. Actually, the history of soil erosion evolves in a very complex manner with high variations in space and time. Local and regional variations in natural situations, cultural traditions, socioeconomic conditions, and the occurrence and the frequency of extreme precipitation events have played a major role in the dynamic and rates of soil erosion in a long-term perspective.

The anthropogenic removal of the natural woodland varied greatly geographically, in early prehistorical times and for early civilizations, such as in China, South Asia, Mesopotamia, and much of the Mediterranean. The agricultural transition began from various hearths at different times and arrived in hinterlands at different rates by various processes of diffusion, migration, or conquest. The presented summaries of the geomorphological and archeological studies show that in prehistory most of the cultivated landscapes on slopes were affected by soil erosion, but these are mostly interpreted as local phenomena. Clear evidences are given that pre-colonial agricultural societies in Africa, America, New Zealand, or on Easter Island caused soil erosion to such a degree that significant long-term consequences to soil fertility and other ecosystem services may have been brought about. However, it is often unknown if soil erosion was a dominant driving force for the decline in population. Soil protection strategies, particularly the construction of field terraces, but also very individual local strategies like the stone mulching practices on Easter Island, are evident legacies of the occurrence and awareness of soil erosion during prehistorical periods.

The earliest available historical documents that could be related to soil erosion are from Greece and China and go back about 2500 years. They describe the problem of deforestation, the effects of soil erosion, and partly also their consequences to farming. For the following two millennia, many observations of environmental degradation are documented in China, most of which are related to floods. At the end of the first millennium CE, the number of reports about floods increased for the Chinese Loess Plateau. This correlates also with accelerated soil erosion and gullying indicated by geomorphic evidence. This general correlation between historical descriptions and geomorphic signals is also apparent for the following centuries until Modern Times. However, the majority of the historical descriptions about soil erosion are assumptions and not direct observations. Also, the existing geomorphological studies are mostly very general and it is often problematic to link them with historical records.

In contrast to China, only a few historical descriptions about soil-erosion-related environmental degradations are available for the Mediterranean and the rest of Europe from the period of ancient Greece until the seventeenth century CE. The first indirect evidence came from Greece and dates back to the middle of the first millennium BCE. For Roman Times, the geomorphic evidence shows controversial results ranging from massive devastation to stable landscapes over centuries in the agricultural zones of the Roman Empire. The almost complete absence of historical records on soil erosion in Roman sources is remarkable in contrast to the vast amount of material on soil management. This contradiction plays a crucial role in the discussion about soil exhaustion versus sustainable land use during Roman Times.

Some historians are not convinced that soil degradation was an important causative factor for the general deterioration of the Roman world. They understand the areas of soil degradation around ancient Rome and Athens as solely local phenomena. Instead, large new tracts of land were converted into permanently cultivated fields throughout the second and the third centuries CE. They argued that the fertility of the soil was rarely endangered because the plows and other agricultural tools were not strong enough to cause soil degradation. Particularly Grove and Rackham (2003, p. 311) argue against human activity as being the prime cause for soil erosion in Mediterranean Europe because the misaligned or not existing correspondence between land use history and alluviation pattern. They present several examples that show a decline of alluviation, which is claimed to be a proxy for soil erosion during phases of increasing land use intensity. This contradictory behavior is particularly evident for the last hundred years and has been discussed also for alluvial plains in central Europe (e.g. Fuchs et al., 2011; Matys Grygar et al., 2011). Grove and Rackham (2003) also claimed that deforestation in the Mediterranean does not make erosion worse because trees grow again. Grazing by goats and sheep is not bad, because it renders vegetation less vulnerable to wildfires. Badlands, where erosional features dominate, are stable landscapes. They point out that the environmental situation of Mediterranean landscape in the mid-twentieth century CE was little worse than it had been at the end of the Bronze Age (cf. discussion in Williams, 2003, pp. 95–100; Hughes, 2011).

However, such a conclusion neglects several issues if alluviation processes and linear correlations are considered for reconstruction soil erosion on a long-term time scale not only for Mediterranean Europe:

- Essentially, the correlation pattern of soil erosion and alluviation is nonlinear. Sediments that have been eroded are primarily stored in sinks between the slope and the floodplain. These sinks could be footslope positions, slight depressions in an undulating landscape, or terraces. Whenever one sink is filled, the material could be removed and stored repeatedly until it reaches the floodplain. This cascading effect from slope to channel causes a time lag in alluviation and depends on the magnitudes of precipitation events (Lang et al., 2003).

It is also influenced by natural and human factors including land use, field structures, and soil conservation strategies. As a result, climatic impacts are only recorded in alluvial sediments when human activities (e.g. deforestation) and rainfall thresholds for gullying are exceeded (Lang et al., 2003). Consequently, floodplains may reflect regional trends in land use changes and climate but they are not qualified as a single source to reconstruct past soil erosion.

- The construction of field terraces for irrigation or soil conservation created barriers in the landscape that can act as sinks for sediment. After abandonment, these structures are no longer maintained and may collapse. Depending on the slope gradient and the density of the protective vegetation cover, the stored sediment may be released quickly by runoff (Koulouri and Giourga, 2007). Also, the recurrent burning of scrubland to improve grassland quality may result in increased soil erosion for some months (García-Ruiz and Lana-Renault, 2011). As a result, the signal of colluviation and possible alluviation may also occur in periods of low land use intensities.
- Another uncertainty arises when ^{14}C dates or artifacts are used to date sediments that may have been relocated several times. Most of the older studies in particular did not consider this issue and hence correlated the determined ages with the age of the sediment rather than interpreting them as maximum ages.
- During the last 100 to 200 years many river systems were increasingly modified. River straightening accelerates runoff and reduces sediment deposition along floodplains significantly. Dams to store water or to produce energy collect sediments in their reservoirs instead of distributing them along the river system. The increasing implementation of soil conservation strategies may have also been reflected in reduced alluviation.
- Soil erosion and particularly gullying may also occur on pastures and in areas with high livestock pressure (Trimble and Mendel, 1995). This situation is particularly prominent in New Zealand (Mather, 1982) and Iceland (Simpson et al., 2001) but also in the Mediterranean (e.g. Fig. 22) (e.g. Gutierrez et al., 2009).
- The recovery of vegetation on eroded areas is strongly related to soil quality, which is a legacy of former land use and the amount of precedent soil erosion. Severe soil erosion may reduce soil fertility and change water fluxes so much that it impedes the recovery of woodland or shrub vegetation. This leads the system into a new equilibrium with permanent geomorphodynamic activity (Fig. 23). The uncoupling between land use and soil erosion may resist over centuries and cause the establishment or rejuvenation of gullies and badlands. The activity or stabilization of such a system is highly nonlinear and essentially irreversible within human timescales (Dearing, 2008). Such initially human-induced processes can be observed worldwide, particularly in semihumid to semiarid and subtropical areas (e.g. the Providence Canyon in Georgia, Fig. 20).

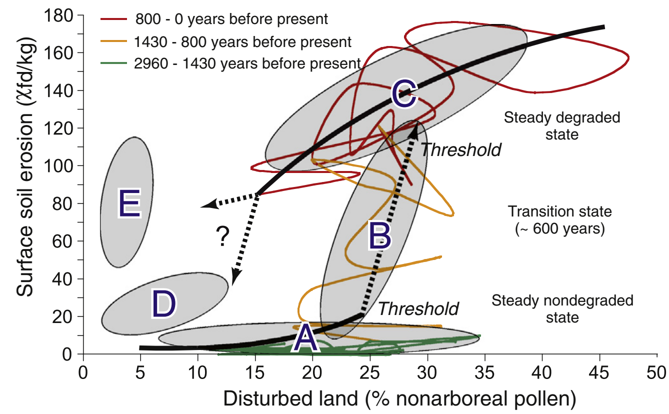

Fig. 23. Processes of coupling and uncoupling between land use (or disturbed land) and soil erosion on a long-term time scale in the Erhai lake-catchment, Yunnan, SW China, modified from Dearing (2008, Fig. 7, reprint with permission from SAGE Publications). Here, the data are used as a general example of the non-linear correspondence between land use and soil erosion on a long-term time scale. The bivariate plotting of the trajectory shows initially a situation in which changes of disturbed land do not cause soil erosion (state A). As soon as a threshold is exceeded (e.g. by changes in land use or climate), the system changes via a transitional state (state B) into a new steady state (state C) with fairly linear behavior between disturbed land and soil erosion. As soon as the land use intensity decreases soil erosion decreases as well, but on a different pathway (state D). Since soil erosion changes the natural conditions permanently (e.g. decline in soil fertility, reduced water fluxes), the system moves from state C into a new steady state (state E) with permanent geomorphodynamic activity. In state E soil erosion is very active and uncoupled from the disturbed land. Alternatively, in the case of the total loss of soil and the exposure of hard bedrock, the system may also move into a state similar to state A (modified figure, copyright: SAGE Publications).

Indeed, the Romans had a good knowledge of agriculture and little is known about the extent of deforestation and the intensity of land use in the ancient world. However, from the lack of historical evidence, one cannot necessarily conclude the absence of soil erosion and soil degradation. One aspect of this contentious discussion about the lack of historical records could lie in the very nature of soil degradation and soil erosion itself. Generally, soil erosion is a subtle process, and the negative effects often become noticeable only during longer lasting experiments or observation spans. Also in recent

Fig. 22. Agricultural terraces on Gozo (Malta) (pm 10-1). The collapse of the terrace walls on the right slope released formerly stored sediments. The hill on the left side shows still intact soils with a thickness of up to 1 m (picture taken on 02.04.2013 by the author).

history, farmers regularly recognize stones growing in the field instead of realizing a loss of soil (Löll, 1878, p. 723) (cf. Suppl. 2.9). Only during extreme soil erosion events, including rare catastrophic gullying, may soil erosion have been recognized as a soil degradation process not only by contemporary scholars but by local farmers, too. In addition, little is known if and to what extent political issues were a contributing factor to avoid the mentioning of soil erosion. The discussion about the diverse evidence for soil erosion during Roman Times should also include the variety of the natural conditions of the landscape, climate, farming practices, and soil management across the Roman Empire. Particularly the implementation of soil conservation or sustainable land use practices may be an underestimated factor (Dotterweich et al., 2012a). A possible indicator about the importance to avoid of runoff and soil erosion in the Roman Times may be derived from contemporary jurisprudence. The presented excerpts of the actio aque pluviae arcendae, which are referred to in the '12 Tables' or the Digesta could be linked to soil conservation strategies like the construction of runoff ditches, terraced fields, or stone ridges.

The first observations on floods and related soil erosion events in central Europe derive from the late Middle Ages. Particularly the extreme precipitation events and the subsequent floods in the first half of the fourteenths century are well documented in several sources. Some of them describe uniquely disturbed sites, which might be useful to link them with geomorphic evidence at a distinct locality. Also, clear evidences exist that soil erosion triggered sociopolitical and economic realignments at this time. From the seventeenth to nineteenth centuries, the number of observations about soil erosion including their negative effects on crops and nutrition increases continuously. In the seventeenth and eighteenth centuries the phenomena are often described by priests in poems or prayers. Consequently, the causes of runoff, floods, and soil erosion at this time were rather associated with a sinful behavior against god than to warn about the deforestation or unsustainable land use (Gerrard and Petley, 2013).

In the late eighteenth and the nineteenth centuries, soil erosion was increasingly observed and described by scholars and farmers. In contrast to earlier sources the descriptions now also contain comments about the causes of soil erosion and its long-term effects to the ecosystem. Citations like *The inhabitants of Althornbach have become very poor and ruined because of the gullying of their fields — as a result, many people left their country* (Hard, 1976, p. 225) can be found in reports from the late eighteenth and early nineteenth centuries. Reports like this are clear evidences that scholars and farmers alike perceived the effects of gullying. In contrast, the processes of sheet or rill erosion and particularly piping erosion were much less mentioned in such reports. This gradually changed in the nineteenth century. The agricultural essays from Albrecht Daniel Thaer or Friedrich Heusinger show that the subtle process of sheet wash was already well understood. They also gave numerous practical examples of how to prevent soil erosion. Little is known how widespread this knowledge was among peasants. The comment by Löll (1878) who got angry about farmers not understanding the process of soil erosion does not designate a general conclusion.

Obviously, most of the Europeans who moved to the colonies in America, Africa, Australia, and New Zealand were farmers with good soil knowledge. However, they had little know-how on farming and managing a soil sustainably in an absolutely different climate and ecosystem. They had to implement their practices to the new environment by trial and error. Historical documents from the colonies show that many farmers principally used their European philosophy of soil conservation which was not suitable for the new environment. Soil erosion and the rapid formation of gully systems and badlands became a widespread problem during this period.

In the eastern colonies of North America, for example, soil erosion became a serious problem already in the eighteenth century. In the late eighteenth century and in the nineteenth century, several scholars published essays on farming and most of them considered the problem of soil erosion and gave practical instructions for soil conservation. Soil erosion was so omnipresent that most reports described the situation fairly generally. Only few reports like the letters from John Bartram to Jared Eliot in the mid-eighteenth century present more detailed observations on soil erosion. However, the numerous and varied suggestions and practical recommendations on soil conservation were seemingly barely adopted, and many soils on hillslopes were highly degraded and unsalvageably lost for farming after just a few decades of land use (McDonald, 1941, p. 19).

In the twentieth century in many countries of the New World, Africa, and Eurasia, soil remediation and flood prevention programs were initiated with the aim to keep soil and water fluxes at a stable equilibrium. Particularly in the first half of the twentieth century did the rise of professional soil conservation become an increasingly important issue in the USA. At this time many reports as well as nonscientific books about global soil erosion were published, stimulating research progress with regard to soil erosion and soil conservation worldwide. Some of them, like the report of Jacks and Whyte (1939), seem to be exaggerated because they were based on assumptions rather than on scientific observations or they were of a propagandistic nature (cf. discussion in Showers, 2005). It is also unclear if all these actions in the USA since the 1930s are able to halt soil erosion in the long term. Many studies show that suspended sediment contributions to river floodplains have decreased (e.g., McCarney-Castle et al., 2010), but this also may be a legacy effect in the cascading process of the sediments. Some sources in the USA have suggested that recent erosion is as great as or even greater than that of the 1930s when the soil conservation effort was begun (Trimble and Crosson, 2000). Similarly debatable situations also occur in other regions of the world, like in southern Africa, China, or Australia.

However, the dramatic environmental degradation in the New Worlds was not a ubiquitous phenomenon. Positive examples of stable settlements exist in which European land use practices were successfully adopted or integrated into the new systems, such as in Mexico (Butzer, 1996; James, 2013). In recent years, an increasing interest occurs in the studies of pre-Columbian soil management systems because they could be used as a template for developing and evaluating current and future soil conservation strategies (e.g., Norton et al., 1998; Glaser, 2007; Lombardo et al., 2011; Sheil et al., 2012). With respect to preventing soil erosion, Wilken (1987) has already accomplished a wide-ranging study on traditional agriculture in Mexico and Central America and provided many practical examples on how to adopt this knowledge to today's farming systems. He suggested, for instance, creating different types of slope terraces. Beach and Dunning (1995) proposed that an intensive study of these old conservation methods should be undertaken so that the Mayan conservation ethic could be reintroduced to the people of the region and to others in similar circumstances around the world. Also, ancient ridge and furrow field systems in the Andes (Erickson, 1992; Denevan, 2001) have already been used as an example to reintroduce such systems today (Garaycochea, 1987; Muse and Quintero, 1987). Finally, there is an increasing interest to integrate native peasants' views in discussions about environmental conservation and sustainability (e.g. Brannstrom and Oliveira, 2000; Mulwafu, 2011, p. 207). On the other hand, the adaption and inclusion of such ancient soil management systems into modern systems may also fail if the social, institutional, or economic aspects are insufficiently considered or even ignored (Bandy, 2005).

11. Conclusion

Almost all farming-based cultures in the world, from large civilizations to peasant groups on little islands, have suffered from soil erosion by water. The amounts of soil erosion varied largely through time and space, and extreme events have left a wide variety of imprints on the landscape over millennia. Eroded hillslopes and gullies, deposited sediments in sinks like lakes, footslopes, valleys, floodplains, and river deltas are geomorphic legacies that have been linked to changes in land use and climate by many studies during the last decades. However, a standardized analysis and interpretation of these geomorphic legacies are problematic because of the variety of methodological approaches and the nonlinearity between soil erosion, climate, and land use. Cascading effects, land use structures, soil management, soil conservation strategies, and long-term system changes have produced different signals over time.

Historical records are crucial and an invaluable source to provide alternative proxies about soil erosion in the past. Direct observations of individual soil erosion events may restrict the deposition of a distinct sediment package to a certain time span. They also expand the range of alternative interpretations, particularly with respect to the long-term effects of soil erosion to ecosystem services and socioeconomic processes. However, historical records also need critical analyses regarding their origin, intention, and quality. They were often created in the context of personal interests or political issues rather than being based on scientific facts; and it is often unclear if they represent certain events, narratives, or vague assumptions. In addition, the described areas and timings are often highly ambiguous and useless for a precise connection to geomorphic evidence.

Farmers were traditionally very knowledgeable regarding soil management. The vast majority of the people were subsistence farmers who gained knowledge by experience and oral transmission over generations. The widespread occurrence of terraces and other soil protecting techniques also shows that the practice of soil conservation was imbedded in many land use traditions. However, geomorphic evidence shows that most of the cultivated slopes in the Old and the New Worlds were affected by soil erosion. For early prehistorical times, soil erosion is mostly interpreted as a local phenomenon; while in the agricultural zones of Eurasia until the seventeenth century CE, much larger areas were seriously affected and also revealed different characteristics. In addition, the evidence is clear that already pre-colonial agricultural societies in Africa, America, New Zealand, or on Easter Island also caused soil erosion.

The earliest available historical documents describing soil erosion are from Greece and China from about 2500 years ago. In the following centuries only a few historical descriptions about soil-related environmental degradation and soil erosion are available. For Roman Times, the geomorphic evidence appears to be contradictory, results ranging from massive devastation to stable landscapes over centuries in the agricultural zones of the Roman Empire. The almost complete absence of historical records on soil erosion in Roman sources is remarkable in contrast to the vast amount of material on soil management during this period. However, evidence from legal actions or from soil management strategies shows indirectly that Romans were aware of soil erosion and soil conservation.

In China, the number of reports of floods increased for the Chinese Loess Plateau during the last 1000 years. This correlates with accelerated soil erosion and gullying as indicated by geomorphic evidence. The first observations on floods and related soil erosion events in central Europe date to the late Middle Ages. Particularly the extreme precipitation events and their associated floods in the mid-fourteenth century are well documented in different sources and correspond well with the geomorphic evidence. A rapid increase of documentary evidence took place in central Europe and the eastern coast of North America in the eighteenth century and in the rest of the world in the second half of the nineteenth century. In the late eighteenth century and in the nineteenth century, soil erosion was increasingly observed and described by scholars and farmers, particularly in Europe and in the colonies of the New World. In contrast to earlier sources, the descriptions now also contain comments about the causes and long-term effects of soil erosion on the ecosystem. Furthermore, the reports present extensive practical instructions for soil conservation The first extensive essay on soil conservation known to the Western World was published in Germany in 1815. In the twentieth century, in many countries of the New World, Africa, and Eurasia, soil remediation and flood prevention programs were initiated with the aim to keep soil and water fluxes at a stable equilibrium. The long-term success of these actions remains contentious. Many studies show that suspended sediment contributions to river floodplains have decreased while soil erosion on hillslopes is still a serious problem. In contrast, historic examples of stable settlements exist where European land use practices were successfully adopted or integrated into the new systems, such as in Mexico. In recent years, an increasing interest has raised to recover the traditional knowledge of soil management in order to implement it into modern soil conservation strategies.

In general, the studies show that local and regional variations in natural situations, cultural traditions, and socioeconomic conditions played a major role in the dynamics and rates of soil erosion in a long-term perspective. The strength and frequency of heavy precipitation events have hardly been investigated yet play an important role with regard to the occurrence of runoff and soil erosion and their long-term effects on ecosystem services and socioeconomic changes. Areas with highly vulnerable soils and inadequately adapted soil management practices have been devastated by soil erosion very quickly, while other sites with less vulnerable soils and well-adapted soil management practices have been farmed over a long period very sustainably. The awareness for the need of soil conservation was dependent on the natural and sociocultural situation and was different in each culture and period. The development of effective soil conservation practices was particularly important in remote areas or on small islands where suitable soils or living space were very limited. Soil conservation techniques were obviously not developed until after severe soil erosion with deteriorations to ecosystem services and subsequent socioeconomical and political realignments had taken place. A prominent example for such a reconfiguration shows the soil erosion and conservation history on Easter Island. Inversely, it is often not clear if the rise of agricultural terraces can be associated with a preceding phase of intensive soil erosion.

Integrative studies linking geomorphic evidence with historical sources provide essential new insights into the process changes and timing of soil erosion and the long-term feedback to the environment. Apart from a few case studies, the potential to analyze long-term human–environment interactions has rarely been used from a geomorphological point of view. Particularly in regions with a long cultural history like in the Levant, Mesopotamia, India, or southeast Asia the potential to assess historical records on soil erosion should be quite significant. The assessment of earlier soil conservation strategies also provides lessons to evaluate the long-term processes to the water and matter fluxes in a managed landscape. The knowledge of long-term processes in the past is therefore an essential part for the development of modern soil conservation strategies that are sustainable in the long term under changing climatic conditions and increasing land use pressure. Geomorphic evidence and historical sources can often complement each other, but an awareness of the known and possible new pitfalls should be considered when using them together. Even if it was not possible to generate an unambiguous linkage between historical sources and geomorphic evidence for each of the case studies presented here, the article nonetheless uncovers the potential of such an integrative approach. The compilation also reveals how the issue of soil erosion and subsequent soil conservation is applicable worldwide. Therefore, this collection of different (historical) sources reveals their value to geomorphological studies on soil erosion and soil conservation and hopefully encourages further studies to utilize this promising approach.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.geomorph.2013.07.021. These data include Google maps of the most important areas described in this article.

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