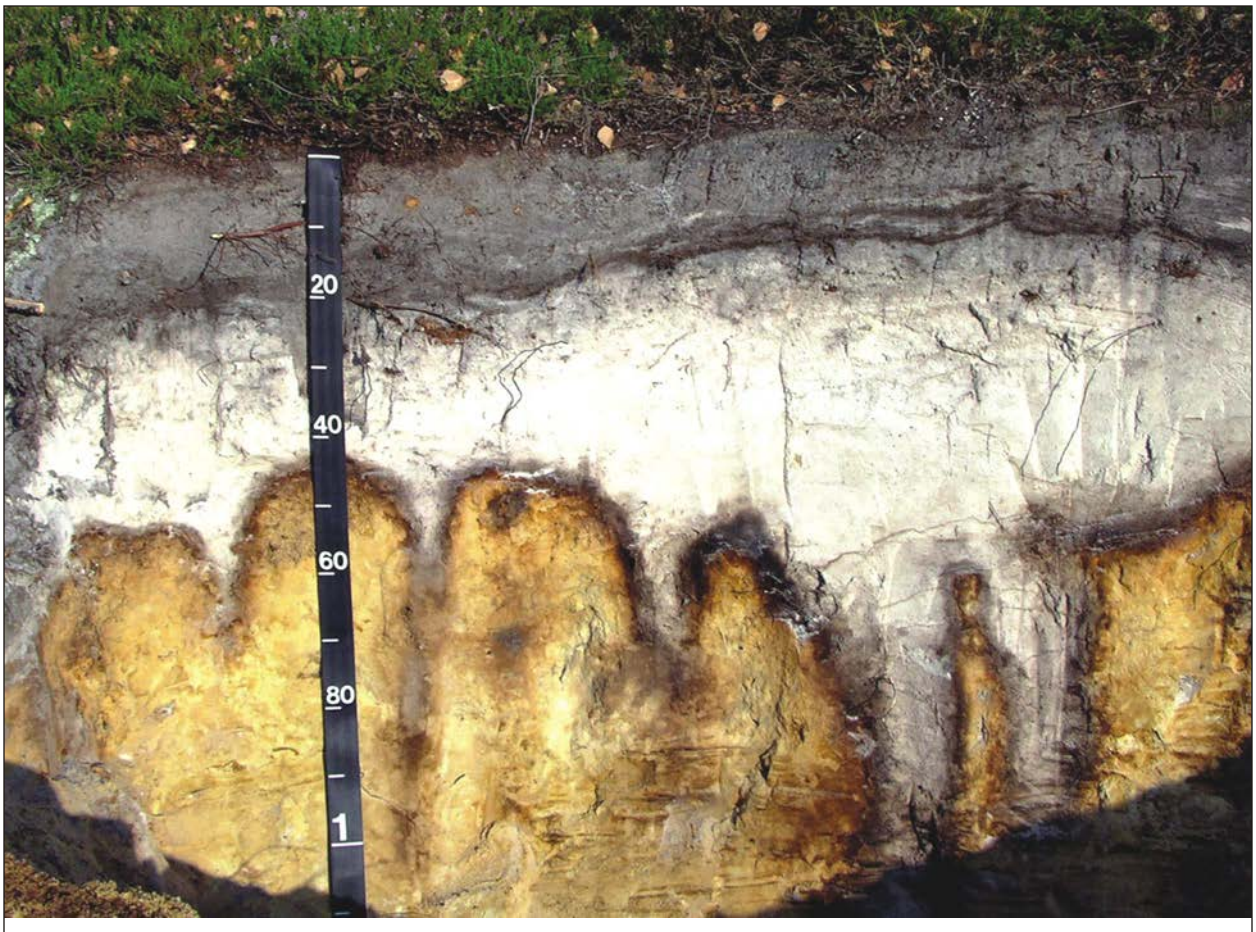


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# Soil and Sediment Chronology as a Tool to Study Long-term Natural and Human-induced Land Degradation: An Overview

Iraj Emadodin
Institute of Ecosystem Research, Ecology Centre, Christian-Albrechts University, Kiel, Germany

## ABSTRACT

The investigations of long-term natural and human-induced land degradation are important subjects in earth ecosystems researches. They involve several scientific field of studies and tools of investigation. In order to study natural and human-induced land degradation, it is necessary to use integrative approaches with respect to temporal and spatial landscape changes. The reconstruction of historical land degradation requires a chronology of enviromental events. Soils and sediments are geoindicators which preserve important information about the long-term human impact on the environment. Optically Stimulated Luminescence (OSL) and radiocarbon dating are as applied technologies and important tool for understanding time sequences and chronological order of soil and sediment. They estimate the age of organic remains which have been preserved in soil and sediment in the past. The main methodological questions related to this paper are: why soil and sediment chronology are important and how can they be applied in long-term land degradation researches.

**Key words:** Land degradation, soil erosion, integrative methodology, geoindicators, geoarchives

## INTRODUCTION

Land degradation is a serious problem in many ecosystems. Land degradation may be defined as the loss of ecosystem utility or productivity and change of landscape which in many cases cannot be replaced (Barrow, 1994). Long-term human activities enable, cause and accelerate land degradation (Emadodin *et al*., 2009a; Bahrami *et al*., 2010). Land degradation is not a new problem. It is a result of long-term human interference in the environment that started from the Mesolithic and continued until Modern times (Bork, 2006). Recent high-resolution studies of the terrestrial records have shown that understanding of mechanisms behind the observed changes of the land require reliable time scales (Hajdas, 2006). The main question in order to study past land degradation is what happened in the past regarding human activity and natural processes in the environment. Soil and sediment as important geoindicators provide useful documentary references and archives to support the monitoring and interpretation of long-term land degradation and past environmental changes (Emadodin *et al*., 2010). Radiocarbon dating is widely regarded as the tool of the prehistoric and historical land degradation studies in order to estimate the age of the buried soil, alluvial and colluvial layers in order to the reconstruction of past soil and vegetation changes (Gillespie *et al*., 1992; Pessenda *et al*., 1996; Bork *et al*., 2003; Hall *et al*., 2005; Bork, 2006; Reiss *et al*., 2008; Emadodin *et al*., 2009a). $^{14}C$ is a useful isotope for dating organic remnants and therefore prehistoric natural and human-induced land degradation, detail understanding of long-term environmental changes and environmental impact assessment. It has played an important role in order to study and date past soil degradation, soil formation processes and landscape

changes. Study of cullovial layers and soil formation provide evidence of repeated phases of slope instability and gomorphodynamic stability (Rohdenburg, 1971; Daniels and Hammer, 1992; Bork *et al*., 2003; Bork, 2006; Verstraeten *et al*., 2009). In order to study long-term natural and human-induced land degradation, it is necessary to use integrative approaches with respect to temporal and spatial landscape changes. This integrated approach involves disciplines such as geomorphology, archaeology, paleohydrology, paleo-pedology, paleo-ecology and (land use) history and geoindicators such as soil parameters, sediment characteristics and land-form specifications with a special view on human activities and pressures (Emadodin *et al*., 2009b). All of disciplines which mentioned above often apply age of organic remains as chronological order.

## METHODS

**Dating techniques:** There are different dating techniques which were developed to estimate the age of soil formation processes, soil structures and sedimentation processes. The reconstruction of long-term land degradation requires a chronology of sedimentation.

Various techniques are available to date material from alluvial and colluvial layers. In recent years considerable advances have been made in the development of these techniques that specifically date the time of sedimentation. One technique is Optically Stimulated Luminescence dating (OSL dating) which has different types. Sediments everywhere contain low concentrations of uranium, thorium and potassium which produce, over geological time period, a constant flux of ionizing radiation. The ionizing radiation is absorbed and stored by surrounding sediments and with stimulation this stored dose can be evicted producing luminescence. The physical basis of the luminescence technique is described by Aitken (1998), while summaries of its application in geomorphology are provided by Stokes (1999) and Duller (2000) and the dating of alluvial and colluvial sediments by e.g., Mauz *et al*. (2003) and Fuchs *et al*. (2010). In order to understand the dynamics of the landscape changes Mauz *et al*. (2003) used an optical dating of colluvial layers which were deposited at foot slope areas and in gullies. Fuchs *et al*. (2010) stressed that the temporal information of sediment formation is essential and achievable through Optical Stimulated luminescence dating. Another technique is the estimation of ages using the radiocarbon dating methods. Radiocarbon dating is one of the most widely used in archaeology. It is also an indispensable tool to research in other fields such as geology, paleoeclogy, geophysics, pedology and environmental science. It has been applied by several researchers (Walker, 1962; Scharpenseel and Schiffmann, 1977; Ellis and Matthews, 1984; Harris *et al*., 1987; Kirch *et al*., 1991; Bork *et al*., 2003; Davidson *et al*., 2004; Hall *et al*., 2005). Radiocarbon dating, or carbon dating, is a radiometric dating method that uses the naturally occurring radioisotope $^{14}C$ to determine the age of carbonaceous materials (Plastino *et al*., 2001). Material suitable for radiocarbon dating include peat, wood, charcoal, organic mud, soil humus and calcium carbonate in molluscs and bones, inorganic carbonates can also be dated (Daniels and Hammer, 1992). With the measurement of the amount of radioactivity remaining in organic materials, the amount of $^{14}C$ in the materials can be calculated and the time of death can be determined. This radioactive time process is simple in theory, but the laboratory processes are complex. The $^{14}C$ has been a useful and efficient isotope in dating of organic remnants and thus prehistory and history of humans and it has played important role in order to study different aspects of long-term soil degradation (especially past soil erosion), soil formation processes and landscape changes. The radiocarbon method is also used in different scientific fields, such as: hydrology, oceanography and atmospheric science. In order to use this technique, charcoal, is taken from different layers of sediment. The measured age of a piece of

charcoal represents the maximum age of the sediment from which it was collected. The age of the charcoal is determined using the Accelerator Mass Spectrometry (AMS) radiocarbon method (Litherland, 1980). With the development of Accelerator Mass Spectrometry (AMS), beginning in the early 1970s, radiocarbon dating has become an increasingly useful way to measure time for archaeologists as well as scientists in other disciplines (Geyh and Schleicher, 1990). One of the most important tools to estimate the age of sediment is the identification of datable finds. In addition to charcoal, in sediments artefacts such as pottery fragments are incorporated. Therefore according to the knowledge of the production, the forms and the composition of pottery not only the age is estimated. Pottery also may contain important information about the life of past societies and cultures. Identification of key catchments and geoarchives, detailed field investigations, sampling and dating, formulation of stratigraphy (chronological order of colluvial layers and also of the sequence of events reflected in them) with regard to interdisciplinary and multidisciplinary approach provide a comprehensive method to study long-term land degradation (Bork, 2006; Emadodin, 2008). Therefore, in this method using a suitable soil and sediment dating technique is necessary.

**Interdisciplinary methodology to study long-term land degradation:** Research methods which provide data with high resolution in time and space enable interpretations and conclusions with a high precision and accuracy. Moreover, an integrative methodology can provide facilities for a better assessment, understanding and anticipation of the results. A general interdisciplinary methodology is recommended (Emadodin *et al*., 2009b). This methodology is divided into three main groups: data collection, data analysis and scientific output, each one of them can be subdivided into several important subjects. One of the most important step which has mentioned in this methodology is chrono-stratigraphical analysis (Fig. 1).

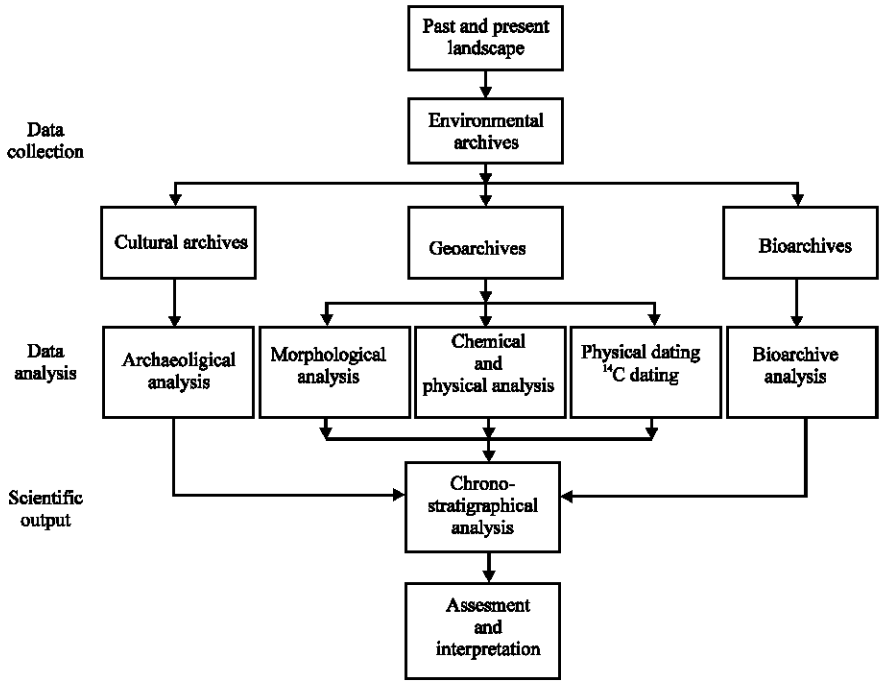


Fig. 1: Interdisciplinary methodology to study long-term land degradation (Emadodin *et al*., 2009b)

**SOME CASE STUDIES**

Based on detailed field studies, chemical soil analysis, dating methods of charcoal and pottery, as well as on written documents (cultural archives) several researchers quantified the human impact on soils during the late Holocene. According to the studies human interference in natural environment was a major cause of land degradation, especially during the late Holocene (Lang *et al*., 2003; Bork, 2006; Hoffmann *et al*., 2007; Reiss *et al*., 2008). Moreover the history of land-use changes after the 12th century showed that social and economic factors, such as war and financial support can lead to significant and rapid changes of land use (Schmitt *et al*., 2003). Bork (2006) argued that geoarchaeological, sedimentological and pedological investigations in many cases not only answer some questions about long-term human-induced land degradation but can provide new methodology that enable to qualitative and quantitative the different aspects of land degradation, too. In order to explain the results of this approach some examples are outlined as follows. Based on the stratigraphical, pedological, sedimentological and historical methods mentioned above Bork *et al*. (2003) and Lang *et al*. (2003) have carried out research in Germany. Special attention was given to a quantification, analysis and evaluation of soil erosion, which occurred during the Middle Age and Modern Times and their causes, too. Erosion enabled by agricultural activities removed most Holocene soils and changed the natural landscape significantly. They showed that soil erosion and deposition are not new processes in our environment but that humans played a dominate role in driving these processes already centuries and thousands of years ago. Comparable episodes of erosion and colluviation associated with prehistoric and historic woodland clearance and farming activities have been noted in many regions in Germany (Bork, 2006). Moreover several researchers confirm intensive human interference in environment at different areas in prehistorical and historical times using chrono-stratigraphical analysis in soil and sediments (Harvey and Renwick, 1987; Schirmer, 1988; Starkel, 1988, 1998; Bork, 1989a, b; Macklin *et al*., 1991; Bork and Lang, 2003; Reiss *et al*., 2006; Rommens *et al*., 2005; Vanwalleghem *et al*., 2005; Mieth and Bork, 2005; McNiven, 2008; Emadodin *et al*., 2009b). The main results from those investigations are summarized as follows:

- The temporal and spatial variation of soils and sediments from Mesolithic until Modern times
- Soil formation in the colluvial layers during periods of gomorphodynamic stability with a dense cover of woodland
- Hydrogeomorphic changes as a result of the changes of the topography, of drainage catchment characteristics and of sedimentation (different thickness in colluvial layers)
- The podsolization of Cambisols and Luvisols which had developed in colluvial layers earlier
- A large amount of soil displacement especially on convex middle slopes during Bronze Age, Iron Age, Middle Ages and in the Modern times
- Identify several fire pits which indicate the intensive exploitation of the woodland in the past
- An intensive change in soil fertility and quality with respect to long-term soil erosion and sedimentation (removal of soil nutrients in the topsoil by erosion and decline soil productivity)
- The compaction of surfaces by intensive human activities in farmland and subsequent reduction of the infiltration capacities and thus runoff and soil erosion in the past
- Lower transpiration rates and thus a higher groundwater recharge and water logging in valley bottoms, runoff generation and the detachment, the transport and the deposition of soil particles by heavy rainfall or by high wind velocities

## CONCLUSIONS

Soil and sediment chrono-stratigraphical analysis enable detailed interpretation of the sequence of past events therefore using the best dating techniques in order to estimate an accurate age for soil and sediment are necessary. Also they provide:

- The rate and direction of changes regarding to the past land management
- Valuable information about the past state of the environment
- The data bases to the reconstruction of long-term land degradation

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