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A legal framework with scientific basis for applying the ‘polluter pays principle’ to soil conservation in rural watersheds in Brazil

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ABSTRACT

The “polluter pays principle” (PPP) has been looked at from the perspective of legal values and technical principles, namely of soil science, to evaluate the acceleration of soil erosion and the consequent development of degraded areas in the Uberaba River basin (area: 2419 km^2), state of Minas Gerais, Brazil. Having accomplished this goal, the study highlights the importance of PPP for the conservation of soil and development of an ecologically equilibrated environment. The diagnosis of degraded areas was based on the coupling of a Geographic Information System with soil loss, land use conflict and tolerance to soil loss models, and revealed a preoccupying situation because an extension of approximately 905 km^2 (1/3 of the basin) has been considered in advanced state of degradation potentially causing environmental damage (e.g., decline of soil fertility and hence crop production, negative impacts of soil particles export on stream and lake water quality and biodiversity of riverine ecosystems). Facing this problem, a legal framework standing on doctrinaire principles, federal laws and the Brazilian Constitution has been proposed whereby the protagonists of soil degradation are called to assume responsibility as well as the costs of repairing this negative condition. Although the study has been carried out on a specific country under pre-defined settings, the rationale behind the proposals can easily be transposed to other scenarios because the scientific methods on which soil degradation has been defined and mapped are generally applicable, while the suggested legal values are currently applied to many regions on the planet.

1. Introduction

In Brazil, the environment is legally defined as “*the set of conditions, laws, influences and interactions, of physical, chemical and biological nature, which shelters and governs life in all of its forms*” (Federal Law no. 6938, published in 31 August 1981). Thus, to effectively protect the environment, laws need to follow scientific guidelines provided as one coherent multidisciplinary framework. There is an evident interaction between legal and technical concepts, the reason why social actors are called upon to have a holistic view on the environment.

The wide-ranging view on the links between science and norms presented in the previous paragraph is fully applicable to soil science and to the legal framework ruling the use of soil. In Brazil, there is no practicable management of agricultural, livestock or integrated crop-livestock farming systems and their components without a proper consideration of laws and legislation, while there are many legal concepts transposed to laws that are appropriated from or resort to soil science principles for their practical application. In the complex interplay among soil uses and their legal constraints, the “polluter pays principle” (PPP) works as safeguard of soil conservation, because application of PPP by the authorities forces owners of rural or urban land towards the prevention, mitigation or recovery of environmental damages, namely through implementation of best management practices in their farms. The PPP underpins a major portion of regulation on pollution affecting land production and is related to environmental policy principles that require prevention and control of pollution.

Erosion is a major concern on the conservation of soil. It is a fact that erosion is a natural process related to the action of water, wind and ice on the ground surface. However, with the assistance of soil science it is possible to quantify a human-related acceleration of erosion and delineate the degraded areas derived therefrom. Among the methods offered to quantify hydric erosion rates, the most widely used is the

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Universal Soil Loss Equation (USLE) introduced by Wischmeier and Smith (1978) and revised by Renard et al. (1997). This algorithm has been used in numerous studies worldwide (e.g. Martín-Fernández and Martínez-Núñez, 2011; Valle Junior et al., 2010a), representing about one third of soil erosion assessments in Brazil (Barretto et al., 2009). Apart from conventional estimations of soil losses, the USLE has recently been used to investigate potential amplification of these losses resulting from the so-called environmental land use conflicts (Pacheco et al., 2014; Valle Junior et al., 2014a), which mean uses not conforming to land capability (the soil's natural use). However, these modeling exercises did not evolve to studies on the identification and delineation of human-related degraded areas that could be associated to the aforementioned conflicts. Using cross-tabulation tools of Geographic Information Systems (GIS), a number of studies compared images taken before and after the occurrence of specific land use changes (Abuelaish and Olmedo, 2016; Barati et al., 2015; Rysz and Janiszek, 2015), but these works were never focused on the association between changes in image characteristics and human-related soil degradation.

The development and maintenance (perpetuation) of degraded soils is highly adverse to terrestrial and freshwater ecosystems, the reason why human-related soil degradation has been classified as environmental damage (Article 3rd of Federal Law no. 6938/81). The perpetrator has a legal responsibility over the damage being forced to repair it (Number 3 of article 225th of Federal Constitution and number 1 of article 14th of Federal Law no. 6938/81).The main purpose of this paper is therefore to relate land use conflicts with human-related soil losses and environmental damages derived therefrom, while in complement the study explores the legal obligation of damage reparation by land owners in light of the polluter pays principle. The study area is located in the Uberaba River basin (Mina Gerais, Brazil), where accelerated soil losses have been documented and related to environmental land use conflicts.

2. Materials and methods

2.1. Study area

The Uberaba River and associated drainage network are located in the state of Minas Gerais (Brazil), in a sector of Triângulo Mineiro region, being limited by a catchment that covers an area of approximately 2419 km^2. The hydrographic basin has been shaped within the following geographic coordinates: south latitude − 19°30′37″ − 20°07′40″; west longitude − 47°39′02″ − 48°34′34″; altitude range − 522 m − 1031 m (Fig. 1). The region has distinctive weather regimes in winter and summer, being classified as Tropical by the international classification of Köppen (Cruz, 2003). While the winter season (running from October to April) is cold and dry the summer period (lasting from April to October) is hot and rainy. The mean annual temperature and precipitation are 23.2 °C and 1584.2 mm, respectively. Temperature ranges are large. In December and January maximum temperatures can reach 31.4 °C, whereas in May to July they can drop down to 13.6 °C. In the months of December and January precipitation approaches 1080 mm. This is more than 2/3 of all rainfall brought into the catchment in one year (Silva et al., 2007).

The geology of Uberaba River basin is characterized by Pre-Cambrian quartzites and micaschists of Canastra Group, which have been overlaid by Mesozoic sandstones and basalts of São Bento Group and by Upper Cretaceous sandstones and conglomerates of Bauru Group that crop out across the entire watershed (Valle Junior et al., 2010b). The sedimentary sequences have been deposited in the N/NE portion of Parana sedimentary basin. The beds and margins of water courses are usually covered by Cenozoic alluvial and colluvial deposits, respectively. The weathering of sandstones and conglomerates produced average texture latosols (Fig. 2). The nomenclature of soil types exposed in this figure is in keeping with the Brazilian system of soil classification developed by the Empresa Brasileira de Pesquisa Agropecuária (Embrapa, 1999, 2006). In the Uberaba region, soils are particularly sensitive to erosion because the preparation of land for seeding occurring in fall overlaps the period of quite erosive rainfall events (Valle Junior et al., 2012, 2013). In 2014, land use in the Uberaba River watershed was dominated by agriculture-based activities (Fig. 3). Farmlands used for crop production (mostly sugar cane) were concentrated to the south while livestock pasturing dominated to the northern part of the basin. Besides agriculture, land was occupied by remnants of native vegetation, known as Cerrado, and by a dam lake located at the catchment outlet.

2.2. Databases and software

The assessment to human-related soil degradation was based on spatial cross-tabulations and subsequent comparisons between soil losses, tolerances to soil loss and environmental land use conflicts. To execute these analyses, a database composed of geographic elements and alphanumerical data (GIS database) had to be arranged and processed in proper software. The literature sources from which database elements have been downloaded, the rationale of using those elements for the recognition of soil losses, tolerances and conflicts, the identification of data owners and a mention to the website's URL (Uniform Resource Locator), are summarized in Table 1. The GIS database was operated by the IDRISI Selva software (Eastman, 2012; http://www.clarklabs.org). In the most recent years, GIS computer packages became widely used in a vast range of environmental applications (Pacheco and Landim, 2005; Pacheco and Van der Weijden, 2012a,b; Pacheco and Van der Weijden, 2014a,b; Pacheco et al., 2013, 2015a,b; Sanches Fernandes et al., 2012; Santos et al., 2014, 2015a,b).

2.3. Soil losses

The loss of soil by sheet and rill erosion was estimated by the USLE (Universal Soil Loss Equation). This empirical algorithm has been amply used in numerous studies (Martín-Fernández and Martínez-Núñez, 2011; Wijitkosum, 2012), which followed the pioneering analysis of Wischmeier and Smith (1978) later revised in a paper by Renard et al. (1997). The applicability of the USLE to conditions beyond the area of its development (i.e. the agricultural USA east of the Rocky Mountains) has been considered in Brazil by Amorim et al. (2010). These authors compared experimental with USLE-based soil losses across various edaphoclimatic conditions and concluded that losses estimated by the USLE are systematically overestimated due to uncertainty in the assessment of various control factors (K, C and P; see descriptions below). A linear regression could be set between experimental and estimated losses, written as "*estimated loss*" = 1.146 × "*measured loss*" + 5.333 kg m^{-2}), which represents an overestimation of approximately 15%. For this reason, soil erosion data used in this study are viewed as "best estimates", not as definitive results.

The USLE produces estimates for the long-term mean annual soil loss (A), as follows:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where

A—Soil loss per unit of area per unit of time (t ha^{-1} yr^{-1});
R—Rainfall-runoff factor (MJ mm h^{-1} ha^{-1} yr^{-1});
K—Soil erodibility factor (t·h·MJ^{-1}·mm^{-1});
L—Slope length factor (dimensionless);
S—Slope steepness factor (dimensionless);
C—Cover-management factor (dimensionless);
P—Support practice factor (dimensionless).

In the GIS platform (IDRISI Selva software), the map of soil losses