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Spatial assessment of land degradation through key ecosystem services: The role of globally available data

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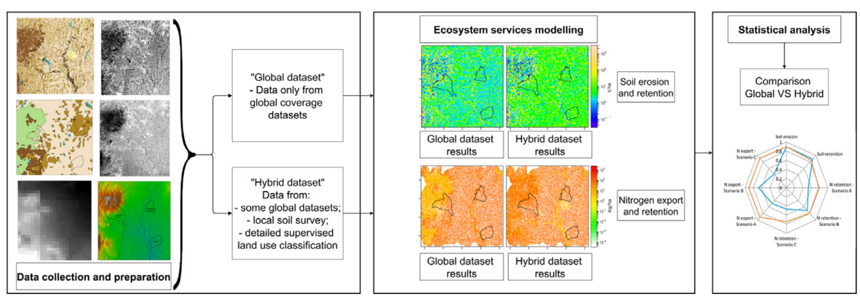
HIGHLIGHTS

- Modelling ESS in data-poor areas is often faced with lack of local spatial data.
- Global dataset introduced inaccuracy in ecosystem services modelling.
- Ecosystem services assessments are useful to infer land degradation risk hazard.
- Integration of local and global data to model ESS is a valuable option to map ESS.

GRAPHICAL ABSTRACT



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ABSTRACT

Land degradation is a serious issue especially in dry and developing countries leading to ecosystem services (ESS) degradation due to soil functions' depletion. Reliably mapping land degradation spatial distribution is therefore important for policy decisions. The main objectives of this paper were to infer land degradation through ESS assessment and compare the modelling results obtained using different sets of data. We modelled important physical processes (sediment erosion and nutrient export) and the equivalent ecosystem services (sediment and nutrient retention) to infer land degradation in an area in the Ethiopian Great Rift Valley. To model soil erosion/retention capability, and nitrogen export/retention capability, two datasets were used: a 'global' dataset derived from existing global-coverage data and a hybrid dataset where global data were integrated with data from local surveys. The results showed that ESS assessments can be used to infer land degradation and identify priority areas for interventions. The comparison between the modelling results of the two different input datasets showed that caution is necessary if only global-coverage data are used at a local scale. In remote and data-poor areas, an approach that integrates global data with targeted local sampling campaigns might be a good compromise to use ecosystem services in decision-making.

1. Introduction

Land and soil degradation are a widespread problem, especially in dry and developing countries. More than half of the global agricultural land is degraded (UNCCD, 2014). Overall, land degradation leads to degradation of ecosystem services (ESS) because it causes depletion of soil

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fertility through loss of soil functions such as nutrient recycling, sediment retention, and carbon sequestration, with a consequent reduction in food production (Bronick and Lal, 2005; Daily et al., 1997; Lal, 2009, 2015).

Land degradation affects about 1.5 billion people worldwide (Bai et al., 2013; UNCCD, 2012) by i) decreasing the capacity of ecosystems to provide goods and meet users' demands (Lal, 1997; Reed et al., 2015); ii) reducing ecosystem services flow to society (MEA, 2005; UNCCD Secretariat, 2013); and iii) threatening the biological and economic resilience capacity of the socio-ecosystems and the populations who depend upon them (MEA, 2005; Reed and Stringer, 2015; Sutton et al., 2016).

The Millennium Ecosystem Assessment (MEA, 2005) reports that approximately 60% of the evaluated ecosystem services have been degraded or used unsustainably, particularly to increase the supply of food. Land and ecosystem services degradation exacerbates poverty in developing countries, but it also influences human well-being in developed countries (Bai et al., 2008, 2013; MEA, 2005). Africa is particularly harmed by land degradation (ELD Initiative and UNEP, 2015; Oldeman, 1992) and Sub-Saharan Africa accounts for the highest share of the total global cost of land degradation worldwide (Nkonya et al., 2016). Among the Sub-Saharan developing countries, Ethiopia has been affected by severe degradation for many years and the degradation of its natural resources has been going on for centuries (Hurni et al., 2010).

In Ethiopia, land degradation is a serious problem because of the country's heavy reliance on natural resources. The agricultural sector, which accounts for over 50% of the Ethiopian GDP, provides livelihoods for over 85% of its population (Berry, 2003; Shiferaw and Holden, 1999). Rapid population growth is often indicated as the major and indirect driver of land degradation (Girmay et al., 2008; Hurni, 1993; Meseret, 2016; Nyssen et al., 2004) because it leads to several pressures such as deforestation, overgrazing, and overexploitation of natural resources (Desta et al., 2000; Grepperud, 1996; Hurni et al., 2005). Deforestation might provide more land for provisioning services, in particular crop production. However, in this study we focused on the negative impacts of deforestation that lead to depletion of key ecosystem services (e.g. nutrient cycling, sediment retention, climate regulation, carbon storage) and to land degradation exacerbation.

Most Ethiopian studies on land degradation (Amsalu and Mengaw, 2014; Berry, 2003; Desta et al., 2000; FAO, 1986; Feoli et al., 2002; Gashaw et al., 2014; Girmay et al., 2008; Hagos et al., 2002; Hurni, 1993; Hurni et al., 2015; Nyssen et al., 2004; Taddese, 2001; Tefera et al., 2002) point out that this is a complex issue due to the interactions between natural factors, management aspects, and socio-economic and political factors.

Soil erosion is strongly associated to land degradation in Ethiopia (Adugna et al., 2015; Haregeweyn et al., 2015; Tamene and Vlek, 2008) and worldwide (Lal, 1997; Oldeman, 1992; Valentin et al., 2005). In Ethiopia soil formation is reported to range from 2 to 22 tons (t) ha^{-1} yr^{-1} (FAO, 1986; Hurni, 1983), while several studies estimated soil loss by erosion in the range of 0 to 500 t ha^{-1} yr^{-1}. The large range identified depends on the high heterogeneity of the Ethiopian landscape where several aspects are involved (e.g. geomorphology, weather conditions, management practices, soil types) (Ali and Hagos, 2016; Amsalu and Mengaw, 2014; Bewket and Sterk, 2003; Bewket and Teferi, 2009; Brhane and Mekonen, 2009; FAO, 1986; Haile and Fetene, 2012; Herweg and Ludi, 1999; Hurni, 1993).

Land degradation, soil erosion, and land use also affect soil nutrient composition (Bewket and Stroosnijder, 2003; Girmay et al., 2009; Haileslassie et al., 2005; Lemenih et al., 2004), with adverse effects on the productive capacity of the land through reducing soil depth and declining soil fertility (Lal, 2015). Girmay et al. (2009) estimated sediment-associated nutrient losses by runoff of 2.1–32.8 kg ha^{-1} yr^{-1} for nitrogen (N), 0.02–0.2 kg ha^{-1} yr^{-1} for available phosphorus (P), and 0.35–5.25 kg ha^{-1} yr^{-1} for available potassium (K), with higher loss in cultivated land and lower loss in exclosures, namely areas where certain animals are excluded or biomass harvesting is controlled for management, research or restoration purposes (Aerts et al., 2009). Haileslassie et al. (2005) reported nutrient losses through soil erosion of 79 kg N ha^{-1} yr^{-1}, 15 kg P ha^{-1} yr^{-1} and 50 kg K ha^{-1} yr^{-1}. Bewket and Stroosnijder (2003) found that soil total nitrogen (N) content showed variation among land use types including differences in climatic factors, erosion and leaching intensities, soil texture, SOM content, grazing and cultivation intensity, and crop type.

Erosion and nutrient depletion are very important and widely used land degradation indicators (Chabrillat, 2006; FAO, 2003; Kairis et al., 2014; Martín-Fernández and Martínez-Núñez, 2011; Pieri et al., 1995; Syers et al., 2002). Given their association with ecosystem functions, areas where soil and nutrient retention services are low could be targets for ecosystem restoration, and this in turn has been shown to improve the level of the indicator services. For example, Mekuria and Aynekulu (2013) found an increase of 28–38% for the total soil N stocks and of 26–39% for the available P stock after the restoration of degraded grazing lands into exclosures.

Ecosystem services modelling is an important tool to identify priority areas for intervention (Duarte et al., 2016; Willemen et al., 2017) that can improve soil's functional state (Lal, 2015). Several tools and approaches have been developed to assess and map ESS, as indicated by a number of reviews (e.g. Bagstad et al., 2013; Pandeya et al., 2016; Turner et al., 2016) that highlight the high variability of ESS assessments with spatial and temporal scale. Reviews of ESS by Seppelt et al. (2011) and Vihervaara et al. (2010) found few ecosystem services studies for Africa, while Wangai et al. (2016) found an increasing number of studies. Nonetheless, studies are still relatively few and of limited scope. One of the barriers is the unavailability of high resolution local data (e.g. Liu et al., 2008). Bai et al. (2013) stressed the importance of good quality climatic, soil and land use information in order to obtain robust assessment of the benefits from ecosystem services. The absence of up-to-date land cover datasets at national level represents another challenge (Hurni et al., 2015).

The use of different datasets at different spatial scales and extents is an important topic in different disciplines and in mapping environmental properties (Grunwald et al., 2011; Malone et al., 2013, 2017; Poggio et al., 2010). In this respect, the modifiable areal unit problem (MAUP) underlines the importance of the scale problem and of the aggregation (or zoning) problem in the spatial analysis (Jelinski and Wu, 1996; Openshaw and Taylor, 1979). Therefore, the results dependency on the spatial resolution and extent was often indicated by studies on environmental factors and properties, digital soil mapping, as well as species richness and distribution (Cavazzi et al., 2013; Foddy, 2004; Rahbek, 2005; Sobieraj et al., 2004). Grêt-Regamey et al. (2014) studied the effect of scale on ESS mapping and found substantial differences between the fine and coarse resolution analyses especially when local heterogeneity, which is scale dependent, was important. This is corroborated by the results of Verhagen et al. (2016) who found that heterogeneity is often important when mapping different ecosystem services. However, to the best of our knowledge, this comparison has not yet been modelled with reference to the limitations of globally available data sets, in particular for soil and nutrient retention modelling. In this work we aimed to investigate the differences in results due to the use of globally available data sets instead of a better local alternative, and importantly, whether different management or intervention decisions would be taken. The objectives of this study were to:

- compare modelling results (soil retention and nutrient retention) obtained using different sets of data, one using only data from global datasets and the other one integrating the global data with information from a local survey, and evaluate how much the results differ at spatial level;
- evaluate the extent of land degradation assessing two ecosystem services: i) soil retention ability and ii) nutrient (nitrogen) retention ability, using a GIS (geographic information system) and remote sensing approach;