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PERSPECTIVE

A 'debt' based approach to land degradation as an indicator of global change

Earth's life support systems require a healthy biosphere with diverse ecosystems. Degradation of these ecosystems and the soils that support their functioning is a threat to human activity and wildlife. About 95% of our food is produced on land. This led Warren Buffet, the 'oracle of Omaha' and famed investor, to opine that land is a more desirable investment than gold (Buffet, 2018), which is supported by recent economic analysis suggesting returns on investment in soil health may run into the trillions of US$ (Schindler, 2020). With growing populations and affluence, agriculture will need to considerably expand its capacity to meet demand (Hunter et al., 2017). At the same time, the most productive soils are already in use (Ramankutty et al., 2008). Currently (2018), FAO estimates ~12% of land is cultivated and ~25% used as meadow or pasture, and only ~21% of world soils are without major soil constraints for cultivation (Bot et al., 2000). This nexus brings the issue of land into sharp policy focus; more so given an estimated third of land was already degraded at the beginning of the 1990s (Oldeman et al., 1991) and an estimated 1.3 billion people lived on degraded land in 2010 (Barbier & Hochard, 2018), and both numbers keep growing. The challenge and opportunity for policy makers is now to solve land scarcity issues by halting and reversing global land degradation, to meet the increasing global demand for agriculture, provide food security and mitigate the environmental impact that follows land degradation, such as biodiversity loss and climate change (Smith et al., 2016).

Major global initiatives recognize the prescience of the issue. Most prominently, the United Nations (U.N.) sustainable development goals (SDGs) have land degradation neutrality by 2030 as a target (indicator 15.3.1; Sachs et al., 2019). Yet, what exactly is land degradation remains an unresolved issue. To date, indicators of degradation have tended to focus on either above- or below-ground characteristics of the biosphere. Here we propose a way to synthesize these approaches combining vegetation and soil indicators into a consistent framework for assessing land degradation as an environmental 'debt'. Single indicators can give a limited lens through which we see an issue and underestimate the level of debt, whereas our combined approach reveals a broader lens for land degradation through global change, in particular, identifying hot-spots for the different kinds of land degradation. We propose that this approach advances our ability to assess degradation and should serve to provide important measures by which success in reversing it can be better quantified. Some years ago, Gibbs and Salmon (2015) already raised this issue, by comparing maps of the world's degraded lands using different approaches, including expert opinion on soil status (e.g. GLASOD), satellite observation of plant productivity (e.g. GLADA), biophysical models (e.g. potential vegetative productivity) and remote sensing classifications of land abandonment. As to be expected, there are many regions in the world that are degraded, or are being degraded, according to some measure but not another.

The United Nations is a good example of an organization using multiple definitions (see discussion in Supporting Information). The different definitions provide valuable, but divergent, spatial assessments of land degradation. It is apparent, that combining them would build upon their individual strengths and compensate their individual limitations. We demonstrate how this can be achieved using a natural resource 'debt' approach to capture global change. In particular, what we propose:

1. Combining the current SDG indicators—land use, carbon stocks above- and below-ground—with globally modelled soil erosion by water using the Global Soil Erosion Modelling platform approach already used by IPCC,
2. Capturing land degradation more comprehensively, as status and trend, and
3. Building on the idea of a 'land, soil and carbon debt', defined as the difference in each land degradation indicator's current value and what it would be without human intervention, or in a native condition. This utilizes recent advances in remote sensing, machine learning, and computational resources, and can now be implemented in a straightforward manner at the global scale. This considerably extends, for example, the utility of the 15.3.1 indicators in an important way: It lets us distinguish between the natural and the man-made change. As a framework, it can also, easily be augmented to include additional physical processes, such as phosphorus depletion, acidification, diffuse contamination, and others.

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See also Commentary on this article by Zhao et al., 27, 5411–5413.

[Correction added on 20 October 2021, after first online publication: The copyright line was changed.]

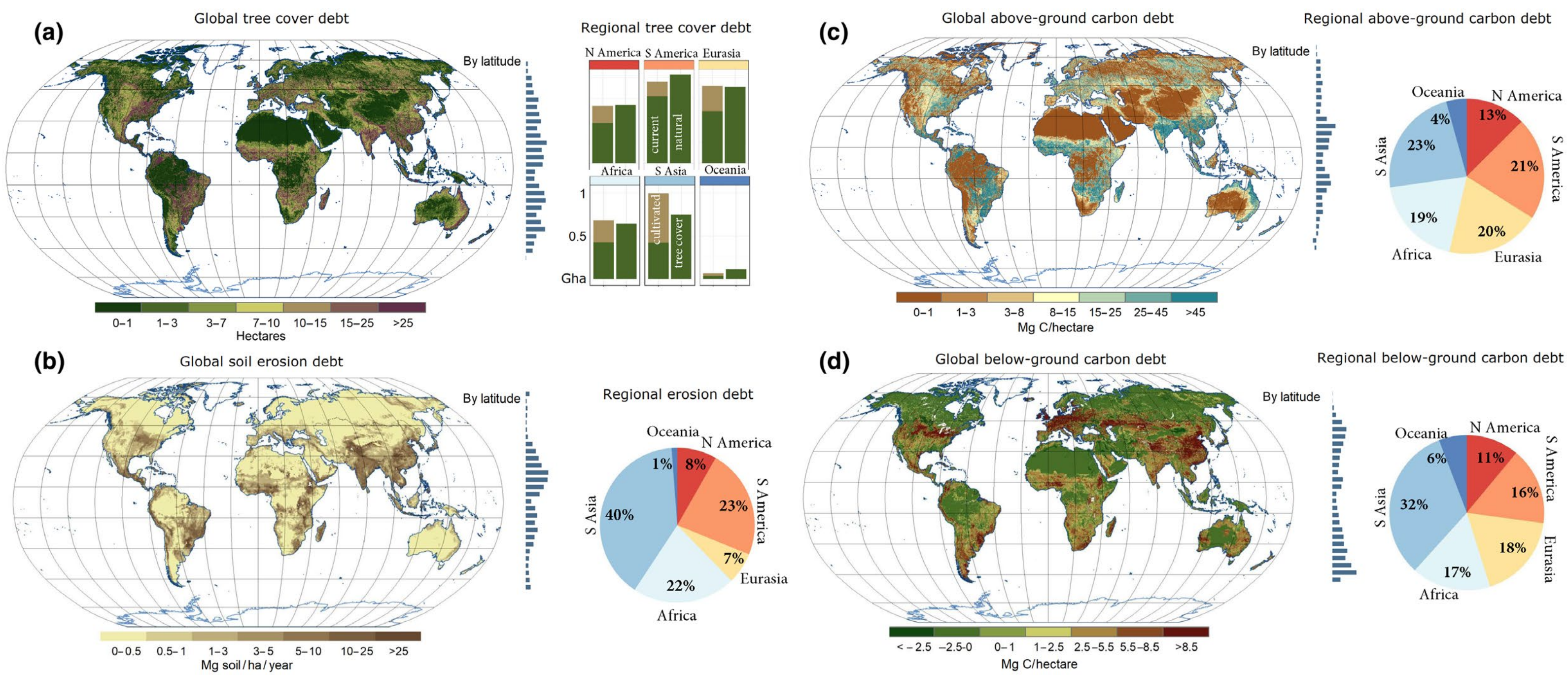

FIGURE 1 Global Land degradation as 'debts'. (a), the difference between natural forest potential and actual tree cover globally, and aggregated by latitude and by world region (see Figure S1), (b), the difference between natural soil erosion and actual soil erosion globally, and aggregated by latitude and by world region, (c), the difference between natural above-ground carbon and actual above-ground carbon globally, and aggregated by latitude and by world region, (d), the difference between natural below-ground carbon and current below-ground (0–30 cm) carbon globally, and aggregated by latitude and by world region. Regarding our global tree cover debt, naturally, there could be 4.6 Gha of tree cover but currently there are only 3.2 Gha, so our global tree cover debt is 1.4 Gha (correspondingly, if we define forests as areas with >10% tree cover, naturally there could be 8.8 Gha, currently there are 5.9 Gha, and the implied forest debt is then 2.9 Gha; a). The natural rate of soil erosion would be 10 Gt per year, but currently, it is 36 Gt. Thus, our global soil erosion debt is 26 Gt – and rising (b). The above-ground biomass would naturally be 871 Gt C, but currently, it is only is 601 Gt C (c). This means our global above-ground carbon debt is 270 Gt C. Below-ground, naturally, there would be 899 Gt C, but currently, there are only 863 Gt C, which means our global below-ground carbon debt is 36 Gt C (d). The maps (a)–(d), and maps of each indicator's current and natural condition can be found in high resolution in the Supporting Information (Figures S2–S6) [Colour figure can be viewed at wileyonlinelibrary.com]

Our selection of indicators followed in principle the main ones proposed by the wider community and the United Nations. A further two criteria were also followed. First, we chose indicators that capture different dimensions of land degradation, for example, physical, chemical and biological, and both stocks and flows (consistent with United Nations natural capital accounting). Moreover, we chose indicators that differ starkly in their global distribution. Second, we restricted this study to indicators for which reliable and peer reviewed data are available and only minimal additional modelling was required. For example, we include erosion by water, but not by wind, as there is insufficient data, moreover, we include tree cover change but not grassland change. Finally, we are for now, only modelling the current land degradation debt, whereas it would, in principle, be possible to have repeated measurements to track progress and trend, and it would be interesting to add the demand side to our supply side modelling, for example, to assess how land degradation affects economic and ecological scarcity. The modular nature of our modelling approach means that all these and other dimensions can be added in future research.

A preliminary analysis for illustrative purposes reveals policy-relevant patterns in global land degradation (Figure 1). To assist interpretation, we present each indicator globally, by world regions, and by latitude. Each indicator is defined as the difference between current conditions and what it would be under native conditions, without anthropogenic land use, which we interpret as our global 'debt' in each dimension. To some extent, our indicators are intercorrelated. For example, the loss of tree cover has direct implications for the rate of soil erosion and carbon stocks above- and below-ground. However, as can be seen in Figure 1, the distributions of all four indicators differ and thus, removing any one of them would lead to a loss of information. For all four indicators we find the most land degradation in southeast Asia, where the most forest has been converted into agricultural land (a), and soil erosion (b) as well as above- (c) and below-ground (d) carbon debt are the highest. However, it can also be seen that at a more disaggregated level, sub-regional areas differ substantially in their debt profiles and this shows especially clearly in the latitudinal profiles of each map. In particular, the above- and below-ground carbon debts (c and d) are to some extent inversely distributed and the soil erosion debt is globally the most concentrated indicator (b), much of it in southeast Asia, South America and Africa, while the forest debt is globally the least concentrated indicator (a).

This shows that only by considering land degradation through this broader lens, are we able to fully capture its global distribution. If we omit soil erosion as an indicator (which it currently is for the progress assessment of SDG 15.3.1.), land degradation in southeast Asia, Africa and South America is overall underestimated. On the other hand, by only relying on soil erosion as an indicator (as is currently done by the IPCC), land degradation is underestimated in North America, Eurasia and Oceania.

Our analysis also reveals areas subject to historic degradation (e.g. arable lands in Europe and North America, the Ethiopian highlands, the Chinese plateau), and areas where degradation is a severe threat (e.g. Amazonia, Madagascar). As a result, our proposed approach both compliments, and strengthens, efforts such as the UN SDG 15.3.1 approach, providing more information to support policy development aimed at achieving land degradation neutrality and reversing it. In addition, our analysis suggests that global land use has so far decreased global tree cover by 30%, carbon stored in biomass by 20% (average for above- and below-ground carbon), and increased soil erosion almost fourfold, suggesting that our global soil erosion debt is especially large and deserving of special attention.

Our research has implications both for policy and research. For future research, our land degradation maps might be useful, for example, to understand the role of land degradation in the global distribution of agricultural yield gaps or the relationship between land degradation and socio-economic outcomes.

Policy wise, we clearly see the disadvantage of the different UN working groups operationalizing land degradation in different ways. Some ignore soil erosion and others use only soil erosion. Both approaches do not give the full picture. In addition, no current approach quantifies overall potentials but instead only measures contemporary trends and outcomes. Yet, it is valuable to understand overall capacities to inform potential action. We propose that the methodology presented improves on the efforts of the UN working groups, consolidating their efforts into a consistent and more encompassing approach. If current policy development is to learn anything from history, the very rise and fall of entire civilizations has been determined by their ability, or inability, to manage the land (Hillel, 1992). Given the global nature of the problem, reversing degradation is a clear and present societal challenge we must address for the wellbeing of future generations. A holistic assessment is a pivotal stepping stone in this direction.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data supporting the findings of this study are available within the article text and Supporting Information Appendix or are freely available at the European Soil Data Centre (ESDAC), the institutional soil data repository of the European Commission Joint Research Centre (https://esdac.jrc.ec.europa.eu/themes/global-land-degradation-debt).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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