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Spatial assessments for the mapping and monitoring of soil organic carbon: Using stakeholder engagement processes

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Abstract
Land degradation impacts the health and livelihoods of about 1.5 billion people worldwide. Given that the state of the environment and food security are strongly interlinked in tropical landscapes, the increasing need for land for food production, urbanization and other uses pose several threats to sustainability in the long term. There is increasing recognition that more integrated approaches to ecosystem health assessments are needed to meet the targets of the 2030 Agenda, including SDG 15.3. In addition to systematic and reliable biophysical and socio- economic assessments, stakeholder engagement with evidence is crucial. This paper demonstrated the integration of land and soil health maps with socio-economic datasets into an online, open-access the Resilience Diagnostic and Decision Support Tool using the SHARED approach in Kenya. This highlights the utility spatial assessments of SOC for monitoring of LDN compliance, understanding the drivers of SOC dynamics, and inclusion in stakeholder decision-making. The main objectives of this paper were to: 1) demonstrate the application of a systematic approach for land health assessments, including spatial mapping of soil organic carbon; 2) demonstrate the operationalization of interdisciplinary framework for assessing ecosystem health; and 3) showcase the application of evidence-based tools for stakeholder engagement using the SHARED approach.

Keywords: soil organic carbon, stakeholder engagement, remote sensing

Introduction, scope and main objectives

The 2030 Agenda, including multi-lateral environmental agreements and the Sustainable Development Goals (SDGs), has set the stage for greater appreciation and understanding of the complex nature and interaction among issues facing society. SDG 15 calls for the protection, restoration and promotion of sustainable use of terrestrial ecosystems, sustainably managed forests combatting desertification, halting and reversing land degradation and halting biodiversity loss. At their core, Land Degradation Neutrality (LDN) and SDG 15 necessitate healthy ecosystem function and resilient landscapes which underpin healthy economies and societal well-being. Because these aspects are intrinsically inter-related, decisions around soil and land cannot be taken in isolation. Achieving the associated targets, requires a) a robust evidence base for measuring and monitoring land health indices and associated land management practices; b) local and policy level awareness of the importance of land health in supporting multiple sectors; c) local capacity to implement the monitoring and assessments of these indicators; and d) mechanisms for integrated, cross-sectoral coordination and inclusive, multi-stakeholder collaboration for prioritizing actions to achieve impact.

Many assessments of land health suffer from (i) disagreements about the definition of land degradation/ land health; (ii) a conundrum of indicators that are often not feasible to measure and hence operationalize, and (iii) a lack of rigorous science-based analytical frameworks. Indicators are critical when assessing environmental conditions and progress made towards the mitigation or avoidance of land degradation, but they are also important to effectively communicate information both to stakeholders such as farmers or advisory services, and to policy makers. Indicators for assessment and monitoring of land health should be a) science based; b) readily measurable (quantifiable); c) rapid; d) based on field assessment across multiple scales (plot, field, landscape, region) and e) representative of the complex processes of land degradation in landscapes. Furthermore, there is a critical need for efforts to operationalize monitoring frameworks for assessment of land health, including robust analytical frameworks that explicitly incorporate scale dependencies.

The Land Degradation Surveillance Framework (LDSF) is an example of a method that has been applied in a number of projects in the global tropics to provide more rigorous, science-based, assessments of land degradation risk and status, as well as soil health (Vågen et al. 2013c). An important indicator of soil health is soil organic carbon (SOC), and field datasets collected using the LDSF have been used to provide spatially explicit assessments of land degradation processes such as soil erosion and SOC, among other soil properties across landscapes (Vågen et al. 2016; Vågen et al. 2012; Winowiecki et al. 2016a; Winowiecki et al. 2016b). These assessments can be used to inform spatially explicit land and soil health monitoring systems, which are critical in order for countries to avoid land degradation, or to restore already degraded ecosystems. Combining systematic data collection efforts with rigorous analytical frameworks, evidence-based approaches have the opportunity to engage stakeholders with interactive online user-friendly platforms to inform national and international policy makers.

Within this context, the engagement of stakeholders becomes an important element to prioritize investment strategies for accelerating sustainable development goals. The Stakeholder Approach to Risk-informed and Evidence-based Decision-making (SHARED) emerged in response to this need and was developed around a number of key factors, steps and principles, including: a) advancing a holistic or systems view to raise awareness on the integrated nature of environmental, social, cultural and economic dimensions and causal relationships; b) establishing a clear understanding of the influencing factors of human and group decision making including stakeholder analysis; c) facilitating different government sectors and multi-stakeholder platforms of diverse societal sectors; d) collectively articulating mutually agreed, desired sustainable development outcomes and indicators building upon fundamental ecosystem services and nested within national and global goals, e) generating evidence and experience and tailoring tools in a readily consumable way problem solving and options identification, f) testing options based on collectively defined criteria, including risks and potential synergies and g) designing option implementation with monitoring and evaluation and co-learning feedback into the process.

This paper demonstrates the integration of land and soil health maps with socio-economic datasets into an online, Resilience Diagnostic and Decision Support Tool in Kenya. The main objectives of this paper were to: 1) demonstrate the application of a systematic approach for land health assessments, including spatial mapping of soil organic carbon; 2) demonstrate the operationalization of interdisciplinary framework for assessing ecosystem health; and 3) showcase the application of evidence-based tools for stakeholder engagement using the SHARED approach.

Methodology

This paper uses data from a network of Land Degradation Surveillance Framework (LDSF) (Vågen et al., 2013) sites in the global tropics. The LDSF was designed for practical and cost-effective soil and ecosystem health surveillance, and for mapping soil organic carbon (SOC) and soil erosion prevalence, in particular (Vågen et al., 2013; Vågen et al., 2012; Vågen and Winowiecki, 2013; Winowiecki et al., 2016). The framework is also designed for monitoring changes over time, and provides opportunities for targeting improved soil management and land restoration activities. Specifically, the LDSF systematically assesses several ecological metrics simultaneously at four different spatial scales (100 m^2, 1000 m^2, 1 km^2, 100 km^2), using a spatially stratified, hierarchical sampling design (Vågen et al., 2013). The LDSF also applies the latest soil infrared (IR) spectroscopy technologies in analysis of SOC and other soil properties, which are cost effective and hence allow for the scaling of soil measurements.

About 21,000 georeferenced soil samples were analyzed for SOC at the ICRAF Soil and Plant Diagnostics Lab in Nairobi, Kenya. A subset consisting of 70% of the samples were used to develop a predictive model for SOC based on remote sensing data from the MODIS platform in the current study. The accuracy of the prediction model was assessed using the remaining 30% of the samples, representing an independent validation or test dataset. The prediction model was applied to an annual composite MODIS image for 2012 and a map of SOC stocks was generated for Kenya.

ICRAF GeoScience Lab is actively developing interactive dashboards as a data-driven platform to integrate existing and new data and to provide robust data management and graphical tools to allow users to interact with these data in a meaningful way. The Landscape Portal (landscapeportal.org) is ICRAF's interactive online spatial data storage and visualization platform. It comes with a rich set of features to store, document, search and retrieve, and visualize spatial data and maps. By applying advanced data visualization and actionable data, these dashboards help facilitate communication of data and analysis between scientists and stakeholders. This will then allow for interrogation of evidence and increase the rate of discovery and help contextualize the data used. The dashboards are designed as an integrated part of the SHARED approach, which ensures that the tools developed are firmly embedded in a strong facilitation process. Recently, the created an interactive dashboard for Turkana County in Kenya, the Resilience Diagnostic and Decision Support Tool was developed.

To foster the innovation required for land health assessments, we use the Stakeholder Approach to Risk-informed and Evidence-based Decision-making (SHARED) approach to shape and embed evidence into inclusive negotiation and decision-making processes. SHARED is a comprehensive framework tailored to specific decision needs; it brings together processes, evidence and tools to shift the decision paradigm towards more inclusive, inter-sectoral and inter-institutional integration to tackle complex decisions and achieve desired outcomes. This targeted facilitation ensures cohesive communication across multiple institutions, political levels and knowledge systems to build capacity and the evidence-base as a continuously linked process, within the same development outcome pathway. At the national level, the SHARED approach has been used in collaboration with Kenya's Ministry of Environment and Natural Resources and the Ministry of Agriculture, Livestock and Fisheries to synthesise the evidence of 44 integrated crop-livestock-tree system projects to develop recommendations for climate-resilient approaches (Chesterman and Neely, 2015) and to directly inform the drafting of Kenya's National Climate Change Policy Framework (Neely, 2014).

Results

Soil organic carbon (SOC) stocks were mapped for Kenya at 500m spatial resolution (Figure 1) and used to estimate SOC stocks for the country (Minasny et al. 2017). Based on this analysis, Kenyan soils store approximately 2.4 Gt carbon (C) in topsoils at 0 to 30 cm depth, on average. The lowest estimated C stocks are found in arid and semi-arid regions of the country, as expected. Higher SOC stocks are found in sub-humid and humid parts of the country, such as in the central highlands and in western parts of the country, with the highest SOC stocks found in forest systems, such as around Mt Kenya, the Aberdares, the Mau Forest Complex and Kakamega forest. Also, wetland ecosystems are critical SOC pools in Kenya and in much of East Africa, including inland riverine and palustrine wetland systems. In the drylands, such wetland systems are critical for SOC stocks, frequently reaching between 80 and 100 $MgC\ ha^{-1}$ at 0 to 30cm depth. Other wetland systems, many of them under threat, such as around the Rift Valley lakes and lacustrine wetlands along Kenya's coast are also examples of ecosystems that are critical for C storage in the country.

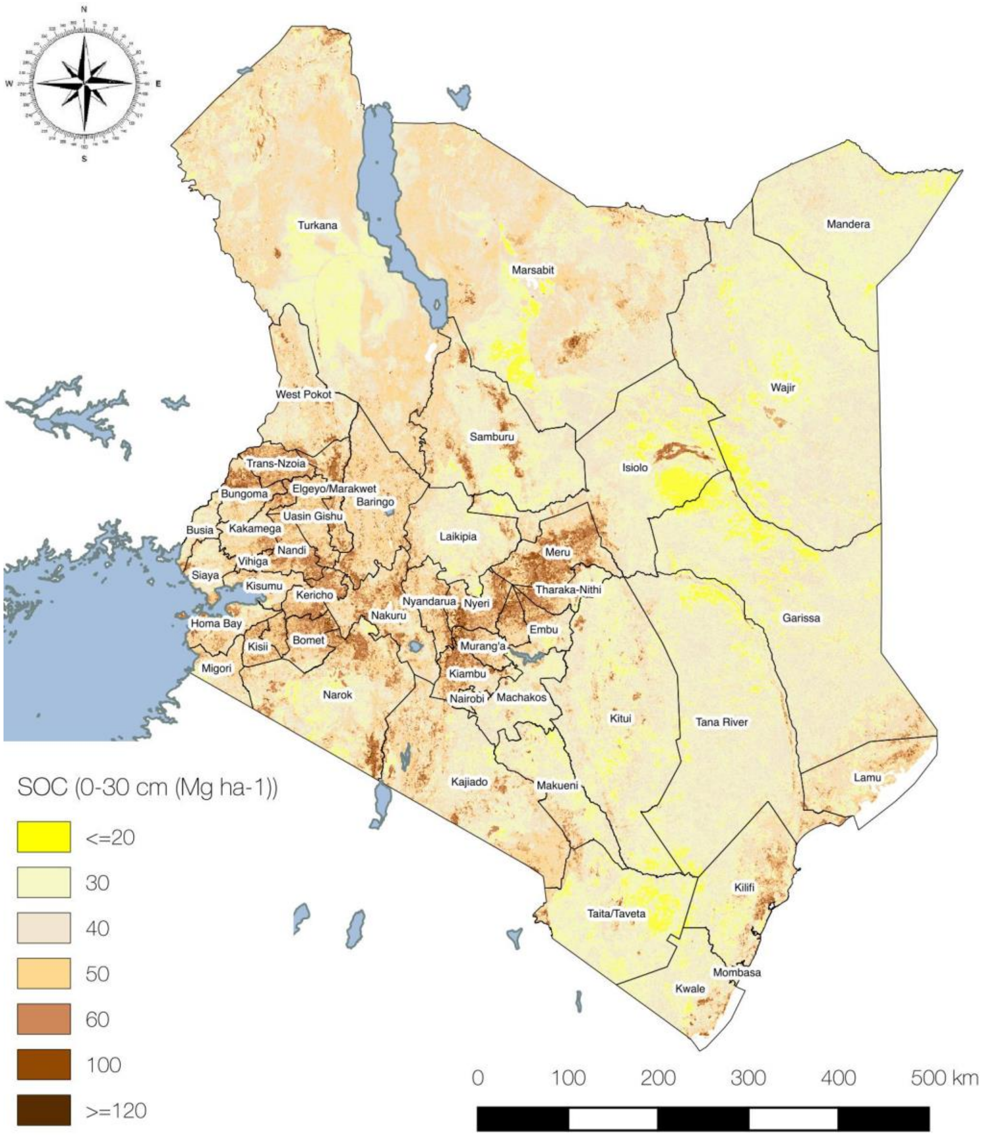

Figure 1. Soil organic carbon (SOC) stock map of Kenya at 500m resolution (for 2012).

Discussion

Through the application of systematic field and lab measurement protocols, spatial assessments of SOC can be made at multiple spatial scales with unprecedented accuracy and spatial coverage. Figure 1 shows estimated SOC stocks for Kenya for the year 2012 (Vagen et al., in prep). As is evident in this map, SOC stocks are low, particularly in degraded areas of the arid- and semi-arid (ASAL) regions of the country. Without such spatial assessments, the distribution of degraded areas and the severity of the degradation both remain poorly understood, hampering efforts to restore SOC and soil health. Further, by systematically assessing land health at scale, restoration efforts can also be scaled appropriately through assessments of the actual restoration potential of a given area.

Conclusions

Decision support tools increase the utility of soil and land health assessments by providing users with both interactive dashboards that allow them to map and interact with data and analytical tools for land health diagnostics and targeting of interventions. Through the application of open source platforms and tools, the use of evidence in land health management can also be effectively mainstreamed. In the context of the SHARED approach, this process is enhanced through structured stakeholder engagement and co-learning.

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