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Sustainable management of tropical small island ecosystems for the optimization of soil natural capital and ecosystem services: a case of a Caribbean soil ecosystem—Aripo savannas Trinidad

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Abstract
Purpose The unsustainable use of soil natural capital and ecosystem services is of global concern due to damage and losses on a worldwide scale. This situation is further compounded in small island developing states (SIDS), such as the Caribbean, where rapid population growth coupled with limited land space accelerates the rate of degradation of soil natural capital. The Aripo savanna is the largest surviving natural savanna in Trinidad with economic and scientific importance. Presently, there are many different land uses and land covers competing for space to the detriment of soil ecosystem services in this savanna. An ecosystem framework approach is needed to guide the development of adaptation strategies to improve the resilience of soil ecosystem for the provisioning of services, especially in the face of climate change.
Materials and methods We reviewed the existing literature on soil ecosystem management in SIDS with particular emphasis on Aripo savanna and attempted to provide a better understanding of soil processes by developing frameworks for assessing tropical small island soil ecosystem services and soil health.
Results and discussion In tropical island states, poor soil quality has been associated with indiscriminant land use, creating short-term economic viability. Short-term economic viability is characterized by poor practices, negatively impacting on soil and thus limiting its ability to perform ecosystem services. To improve the resilience of a society, an ecosystem-framework approach becomes necessary. Soil ecosystem health, however, cannot be represented solely by specific land use(s)/land cover(s) (LULC) but by critical descriptors that influence soil quality.
Conclusions This review highlights the importance of an ecosystem framework approach for the sustainable management and optimization of soil natural capital and ecosystem services in the Caribbean SIDS.

Keywords Ecosystem services · Small island developing states · Soil natural capital · Sustainability

1 Introduction

The UN's sustainable development goals (UN 2015) targets the preservation and sustainable management of terrestrial ecosystems to shift the world onto a more sustainable and resilient path. In light of this, sustainable use of ecosystem services cannot be achieved without understanding the issues imperative to the reversal of land degradation and halting biodiversity loss (Harrington 2016). The concept of sustainable ecosystem management does not primarily focus on economic deliverables but intergenerational sustainability as a precondition (Harrington 2016). In addition to economic considerations, a sustainable ecosystem management approach considers the needs of present and future generations by conserving components of nature directly used to yield human well-being (Boyd and Banzhaf 2007). These components of nature are otherwise referred to as ecosystem services.

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A major global problem is the unsustainable use of natural resources resulting in the potential loss of ecosystem goods and services. Considerable damage and losses to natural resources, including soils, has taken place on a worldwide scale. Understanding processes that lead to improvements in the use and management of ecosystems is critical for achieving sustainability. Small island developing states (SIDS) are especially vulnerable to ecosystem degradation as they are increasingly confronted with the consequences of unsustainable management of their limited natural resources (Scheffer et al. 2003). According to these authors, maintaining resilience is key to the sustainable management of ecosystems. However, because natural resilience is low in SIDS (Pelling and Uitto 2001), it is increasingly challenging to balance economic gains with environmental goals.

Understanding the complexity of sustainable ecosystem management requires knowledge about the relationships among specific components as outlined in the ecological framework suggested by Ostrom (2009) (Fig. 1). The Ostrom ecological framework provides an understanding of a complex whole and how component parts are related. The framework is comprised of four core components (resource systems, resource units, governance systems, and users) under which lies second-level variables (e.g., size of resource system, mobility of a resource unit, level of governance, user's knowledge of resource system), which together links social, economic, and political relationships with the ecosystem. Having a framework for analyzing the interactions and outcomes of sustainable management is beneficial for conducting and analyzing field work, for providing common and relevant variables for a single focal social-ecological system, and for organizing similar sustainable ecosystem studies (Ostrom 2009). A modified framework (Dominati et al. 2010) to reflect soil conditions of a small island ecosystem is important to characterize soil stocks, foster data accumulation, and link land use/land cover to soil natural capital.

The most common challenges to the management of ecosystems for SIDS include their increasing demands for food as a result of rapid population growth and accelerating degradation of natural resources. The high dependence on marine resources which lead to overexploitation by foreign fleets as well as local markets is often left unchecked depleting inshore and reef fisheries. Degraded soils, contaminated water supplies, and saline water intrusion are affecting agricultural productivity and freshwater resources (Atwell et al. 2016). Other factors, such as geographic isolation, limited land resources, natural disasters, low economic diversification, and exposure to external and global changes in climate, contribute to the poor ecosystem management currently taking place in most SIDS (FAO 2014).

Soil natural capital can be defined as stocks of mass and energy and their organization (entropy),which can be evaluated in terms of their quantity, quality, and value (Table 1) (Robinson et al. 2009). The stocks of mass can be broken down into three phases: (1) solid phase, which is made up of inorganic (e.g., sand, silt, clay) and organic (e.g., organic matter, carbon content, and biomass) materials; (2) liquid phase, which comprises soil water content (e.g., volumetric, gravimetric); and (3) gas phase, which comprises soil air (e.g., soil gas PDF, air-filled porosity). The stocks of energy comprise of soil thermal energy (e.g., °C, soil temperature PDF). For soils to maintain capacity to provide sufficient stocks for future generations, soil management becomes important. However, unsustainable soil management in the form of over cultivation, water abstraction, under-fertilization, over-fertilization, careless use of biocides, failure to maintain soil organic matter levels, and loss of natural vegetation can have the effect of increasing soil erosion, salinization, desertification, and decreasing soil fertility (Wuddivira and Atwell 2012).

In SIDS, as found in the Caribbean (Fig. 2), there is limited land space and as a result, a limited amount of soil stocks. Efforts

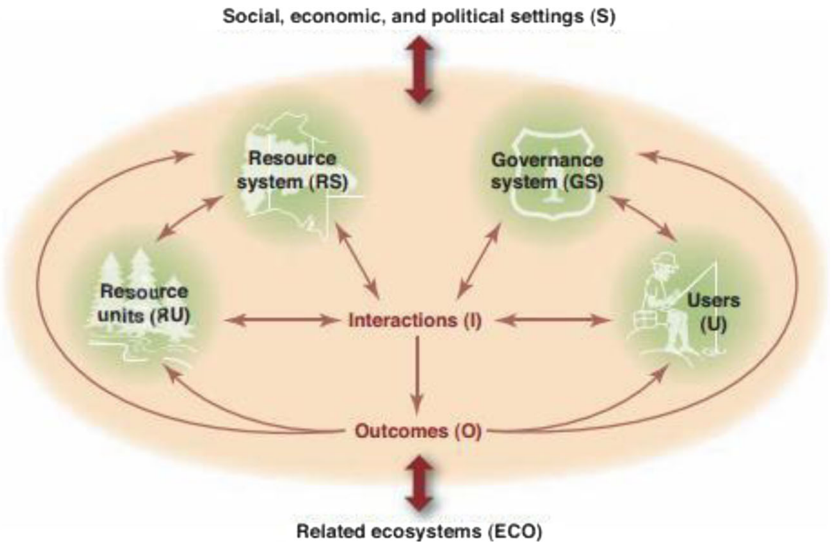


Fig. 1 Major components of an ecosystem framework for analyzing social-ecological systems. Original source: Ostrom (2009)

Table 1 A summary of soil natural capital and its quantity and quality aspects (Original source: Robinson et al. 2009)

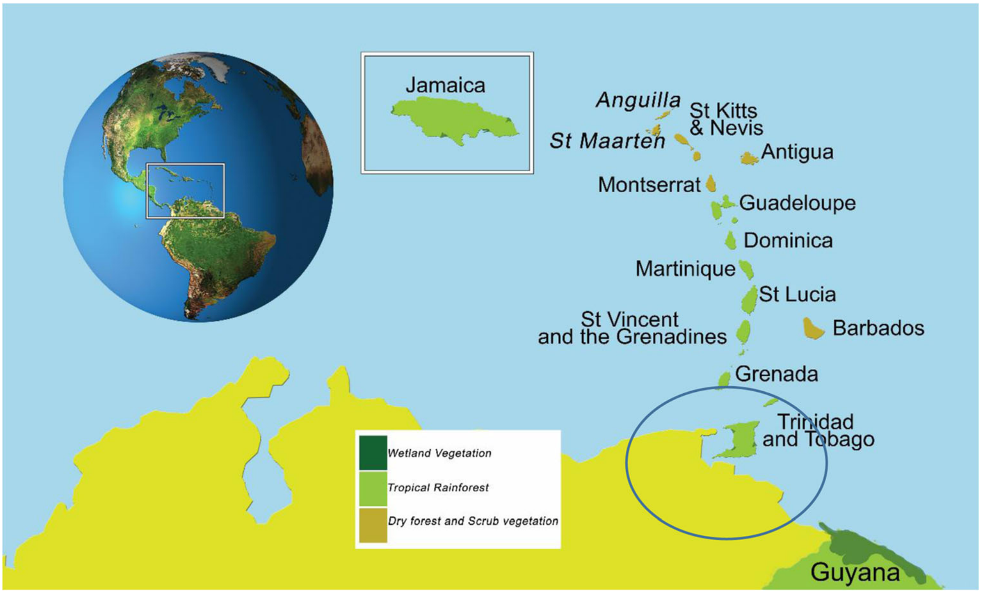
Mass	
Solid	Inorganic material
Quantity	Sand, silt, clay
Quality	% Mineral type, cation exchange capacity (CEC), surface area
	Organic material
Quantity	Organic matter %, carbon content, biomass
Quality	Chemical composition (e.g., C/N/S ratio; hydrophobic/hydrophilic behavior); surface area; CEC; heavy metal content
Liquid	Soil water content
Quantity	Volumetric water content, gravimetric water content, soil moisture storage, soil moisture probability density function (PDF)
Quality	pH, Eh, Electrical conductivity, sodium adsorption ratio, chemical composition/constituents (e.g., nutrient content), temperature
Gas	Soil air
Quantity	Air-filled porosity, soil gas PDF
Quality	e.g., O_2, CO_2, NO_x, H_2S, CH_4
Energy	
Thermal energy	Soil temperature
Quantity	°C, temperature PDF
Quality	–
Organization/entropy	
Physicochemical structure	Soil physicochemical organization
Quantity	Aggregate %, clay%, organo-mineral complexes (OMC) %,
Quality	Aggregate and OMC stability, hydraulic conductivity, permeability, bulk density
Biotic structure	Biological population organization
Quality	Biodiversity, biological activity, presence/absence harmful or useful organisms
Spatiotemporal structure	Hierarchical patches and gradients
Quantity	Landscape metrics, spatial statistics, geophysical information, parametrization
Quality	Connectivity, feedback processes, critical threshold levels

to use the soil sustainably is therefore of utmost importance as land management often suffers from poor decision-making due to undervaluing the services provided by the soil. Poor land management decisions in the Caribbean are due to decisions emanating from paucity of scientific data (Lambin 1997). Additionally, weak policies, policies due to political exigencies, and inadequate surveillance and monitoring for the enforcement of ecosystem regulations, among others, encourage poor land decision-making in the Caribbean.

The Aripo savanna in Trinidad (Fig. 3) is the largest surviving natural savanna in the country and is home to many endemic species of fauna and flora. It supports livelihoods through tourism and scientific research. A recent history of the Aripo savanna conducted by the Caribbean Natural Resources Institute (EMA 2007), documented the range of varying land use/land cover (LULC) activities that have taken place throughout the years. These include timber harvesting, quarrying, use as a military base, forest reserve, residential squatting, and agriculture. Local knowledge, scientific observations, and monitoring suggests that the trend of unsustainable human activities taking place in the savanna continues unabated. Some of the activities which specifically impact the soil ecosystem are:

1. Quarrying. Soil erosion, formation of sinkholes, contamination of soil and water courses (Yuan et al. 2006; Clemente et al. 2004).
2. Fires. Loss or reduction of soil structure and soil organic matter, reduced porosity, increased pH, increased hydrophobicity (water repellency) which results in decreased infiltration, increased runoff and erosion (Certini 2005).
3. Residential squatting. Dilution (by water deposit wastes) pathways of human waste into soil, increased runoff, surface water, and groundwater contamination (Ritter et al. 2002; Woltemade 2010).

Fig. 2 Location, ecological and biodiverse areas of the Caribbean highlighting Trinidad and Tobago

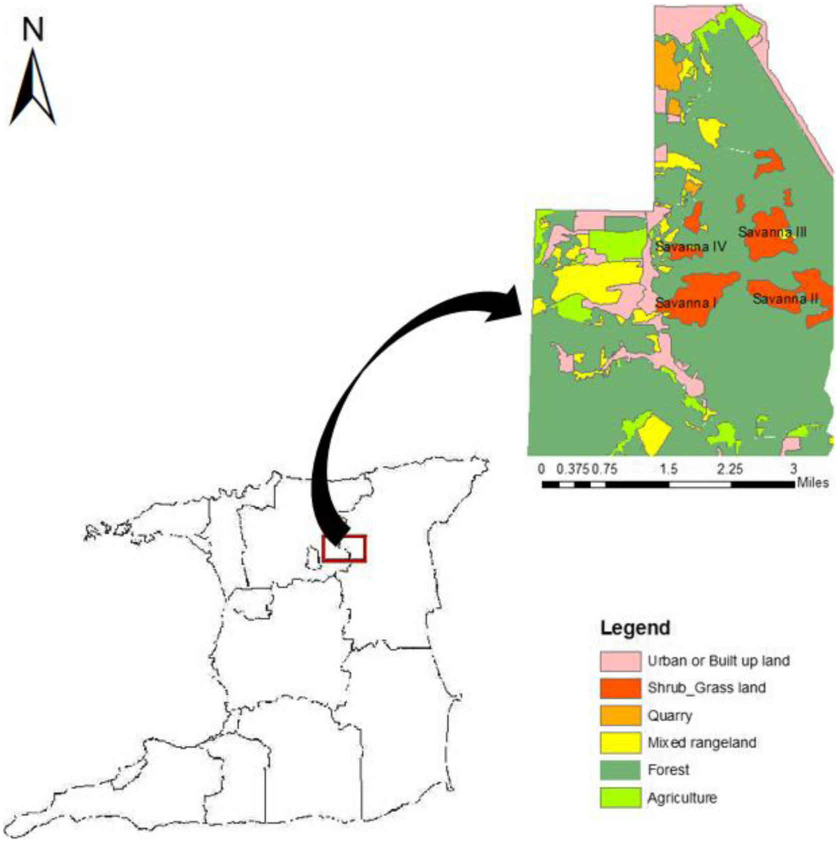


4. Agriculture. Soil contamination, erosion, and sedimentation (Carpenter et al. 1998) (Fig. 4).

Consequent to the aforementioned impacts, it is believed that the soil ecosystem has been degraded and has lost some of its value and biodiversity, limiting the ecosystem services that the savanna provides.

This review attempts to summarize the body of knowledge on soil ecosystem services focusing on SIDS of the Caribbean. The objectives were to (1) examine soil ecosystem management using the case of Aripo Savanna, (2) highlight research

Fig. 3 Map of Trinidad showing the location of the Aripo savannas and associated land uses



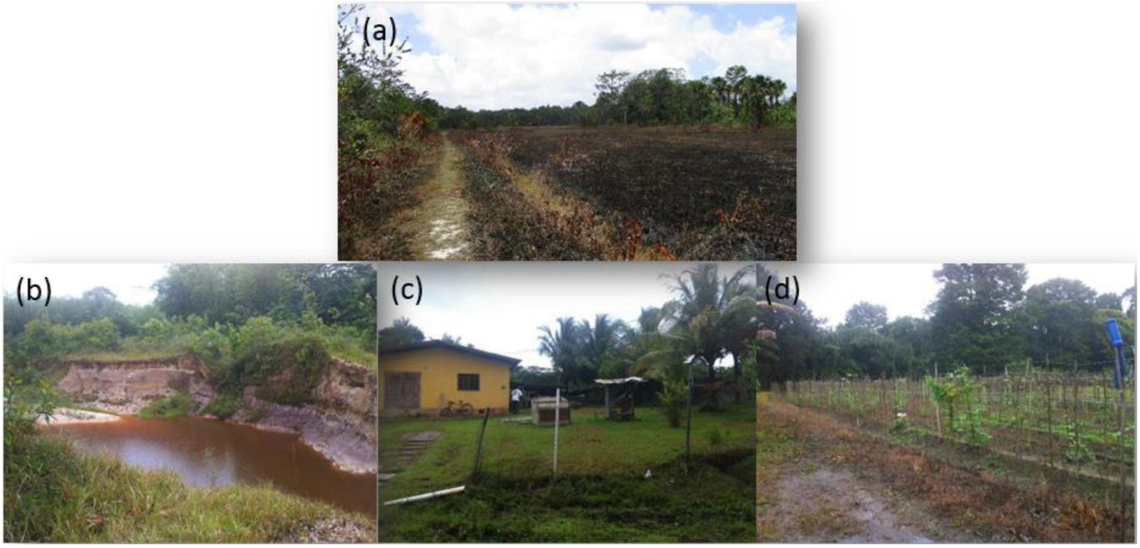


Fig. 4 Anthropogenic impacts within the Aripo savanna, Trinidad. **a** Burning. **b** Abandoned quarry. **c** Residential. **d** Agriculture

in sustainable ecosystem management in the context of SIDS, (3) develop a framework for the provision of ecosystem services from soil natural capital in the Aripo savanna, (4) develop a rating framework based on the contribution of land use/land cover to soil ecosystem health, and (5) suggest solutions for decision makers in sustainable ecosystem management.

2 Sustainable land management and soil natural capital

The concept of sustainable land management includes environmental impact, economic viability, biodiversity social justice, and limits to resource availability (Dumanski et al. 1991; Harmsen and Kelly 1992). Understanding the role of soil processes in relation to the functioning of land systems poses challenges to researchers. There are three main categories of soil natural capital (1) mass, which can be further subdivided into solids, liquids, and gases; (2) energy, e.g., thermal, chemical, and electrical; and (3) organization/entropy, which can be divided into physicochemical, biotic, and spatiotemporal structure (Table 1) (Robinson et al. 2009).

The solids within the soil mass consist of both organic and inorganic matter. These make up the inherent and dynamic capital of the soil. The measurable characteristics of the solid phase are considered as quality aspects and include surface area, surface charge, and cation exchange capacity. These physicochemical characteristics function to filter and purify water, determine soil fertility, and trap contaminants. The liquid portion of the soil mass is primarily the dynamic soil water, which plays an important role in soil formation, nitrogen, and carbon cycle and microbial activity (Skoop et al. 1990). Measurable qualitative characteristics of the liquid phase include pH, redox potential, salinity, and nutrient concentrations. The gas phase of the soil mass consists of air-filled porosity or the volume of gas in the soil. Soil gases control aerobic and atmospheric processes and affect climate change (Zak et al. 2000). Some of these gases include oxygen used for plant respiration, and CO_2, NO_X, CH_4, and H_2S in wetland soils.

Soil thermal energy is vital for the biogeochemical function of soil. It is important for rapid reactions and quicker material turnover, thereby controlling the release of nutrients which affects plant growth. Thermal energy can affect carbon sequestration and life functions of microbes (Brock 2012). Soil chemical energy applies to the free energy content of a soil chemical substance which applies to soil particles. Chemical energy is important for ion movement, accumulation, and availability of elements for the uptake by plants (Tan 2010). Soil electrical energy correlates to soil properties such as soil texture, cation exchange capacity, and organic matter. It is important as it can affect crop productivity, drainage conditions, water holding capacity, and salt concentrations (Atwell et al. 2013).

The soil physicochemical structure impacts many properties and aspects of soil behavior. These include: (1) aggregate stability and the degree of aggregation, which defines the functionality of the soil; (2) level of anisotropy, which controls downward and lateral flows of soil solution and gases; (3) mechanical resistance, which controls root penetration; (4) microhabitats for soil organisms, which supports biodiversity and biological organization; and (5) composition and nature of minerals and soil organic matter which is important for biotic and abiotic processes (Robinson et al. 2009).

Biotic structure consists of food webs and biodiversity, including the gene pool. Biological populations benefit humankind as they influence the rate and extent of soil processes and control many biogeochemical processes (Van Epps 2006;

Young et al. 1998). The spatiotemporal structure refers to soil heterogeneity and self-organized gradients and patterns. These are regulated by topography, parent material, climate, and vegetation (Imeson and Prinsen 2004). Gradients and patterns which can be scale-dependent and fragmented (Robinson et al. 2009) are important for the function of ecological, hydrological, and geomorphologic processes.

Soil quality is key to the productivity, economic, social, and environmental components of LULC systems (Smyth and Dumanski 1995). Recently, there has been an emphasis on maintaining soil stocks as a means of ensuring quality (Miller and Wali 1995). In the Caribbean region, poor soil quality has been associated with indiscriminant LULC, thus creating only short-term economic viability. Monocultures on hilly areas, overgrazing during times of poor vegetation cover, clearing of land with little attention paid to seasonality, shifting cultivation, charcoal burning, fragmentation of land, poor land distribution, quarrying, squatting, land tenure problems, and slash and burn practices have all contributed to the issues of erosion, loss of topsoil, formation of gullies and soil slumps, and loss of soil structure and function.

3 Aripo savanna LULC in relation to soil trends

3.1 Forest

Forest ecosystems in the Aripo savanna, much like other tropical forest ecosystems, are being cleared at an alarming rate for wood harvesting, domestic activities, and agriculture. Globally, agricultural expansion into forested areas can account for at least 50% of deforestation in the last 50 years (Aide et al. 2013). For tropical regions, the rate of deforestation is estimated at 17 million hectares per year. Globally, vegetation removal has led to changes in soil organic matter, as well as the edaphic properties of the soil (Diez et al. 1991a; de Moraes et al. 1996). Some of these changes include reduction in biodiversity (Pandit et al. 2007), increases in soil pH and exchangeable cations, with decreases in exchangeable acidity (Martins et al. 1991; Liu et al. 2002), increases in CO_2 release to the atmosphere (Houghton et al. 1983; Houghton 1990, Le Quere et al. 2009), and decreases in soil carbon content after initial decline (Cerri and Andreux 1990; Chone et al. 1991). However, in the humid tropics such as in the Aripo savanna, high rainfall amounts (2400 to 2600 mm yearly average) cause decreases in pH and acidification of soils due to persistent leaching of cations after vegetation removal. Changes in soil nutrients, including carbon and nitrogen contents, has also been reported after forest clearing (Diez et al. 1991b; Martins et al. 1991; Cerri et al. 1991 and Veldkamp 1994; Le Quere et al. 2009). Deforestation of tropical forest soils results in the disturbance of natural soil-plant cycles and makes these forests more vulnerable to climate change (Johnson and Wedin 1997; Bonan 2008). Loss of topsoil is a major consequence of tropical forest deforestation, as temperatures are increased and fresh organic matter is no longer provided (Ross 1993). Increased temperatures causes increased rates of organic matter oxidation, depleting carbon stocks in soils. Because the topsoil is a major store of carbon and nitrogen which influences atmospheric levels, there is potential for impacts on climate change. Forest clearing has an important influence on decomposition rates and exposed tropical soils generally have less mineral nitrogen, lower cation exchange capacity, less exchangeable potassium, and lower pH. Compaction of topsoil, erosion, and impeded drainage occurs when soil is left exposed.

3.2 Grassland

Increased variability and reduction of rainfall have been shown to reduce primary production in grasslands globally (Harper et al. 2005). Prolonged water deficits increases plant and microbial stress thereby reducing CO_2 efflux in soil (Bremer et al. 1998). Many water-deficient grasslands are characterized by patchy vegetation patterns (Lejeune et al. 2002). Evidence of this can be found in the grasslands of the Aripo savanna where only plants that are adapted to drought conditions thrive. Another phenomenon which further complicates the grassland soil ecosystem is the suppression of soil respiration after large rainfall events (Harper et al. 2005). Reduced CO_2 efflux can occur as a result of decreased diffusion in fine textured soil with high water-filled pore space (Bouma and Bryla 2000). The claypan soils found in the Aripo savanna restrict infiltration in some areas and reduce soil water availability to plants. This results in the occurrence of patchy vegetation patterns, most apparent at the plant-interspace scale (Schlesinger et al. 1990). In the areas where both water infiltration and carbon accumulation is enhanced, plants aggregate creating patches of lush vegetation. While most grasslands globally are heavily managed for the purpose of grazing and agriculture, the tropical grasslands of the Aripo savanna are largely left undisturbed partly due to the lower productivity of the claypan soils. Claypan soils generally have a restrictive high clay layer approximately 20–40 cm deep within the soil profile. They are characterized by slow water flow, sensitivity to runoff and erosion, high variability in crop productivity, water quality impairment through herbicide and sediment surface water contamination (Lerch et al. 2005), and poor root development (Jung et al. 2006).

3.3 Agriculture

Global food demand is rapidly increasing; it has been forecasted that a 100–110% increase in global crop demand will take place between 2005 and 2050 (Tilman et al. 2011). Agricultural intensification has contributed to environmental impacts such as decreased biodiversity (Dirzo and Raven 2003), habitat fragmentation, increased greenhouse gas emissions (Burney et al. 2010), and pollution of aquatic and terrestrial ecosystems (Vitousek et al. 1997). Globally, the conversion of native ecosystems to cropland has led to soil disturbance that disrupts soil structure, enhances decomposition, accelerates soil erosion, and redistributes organic carbon deeper in the soil profile through the mixing action of tillage implements (Ogle et al., 2005). In the tropics and sub-tropics, these effects are particularly severe as a result of high demographic pressure, shortage of prime agricultural land, harsh environments, and resource-poor farmers (Lal 1993). In the Aripo savanna, more land is being cleared every year for the expansion of agriculture into the savanna ecosystem, diminishing the soil's stability, resilience, quality, and ability to perform ecosystem services.

In order to meet global food demand, sustainable crop production is needed to achieve greater yields with lower impacts on the environment. Alternative pathways of agricultural development to meet the needs of future generations have been the focus of increased food production. Increased inputs, improved agronomic practices, improved crop varieties, agricultural technologies, and enhancements to soil fertility have been put forward as different methods that can be used to increase crop yield sustainability (Tilman et al. 2002).

3.4 Quarries

Quarrying of construction materials has serious implications on soil compaction, soil loss, soil profiles, and topography of an area (Moreno-Penaranda et al. 2004). Soil degradation occurs as a result of the unsustainable exploitation of soil materials. Soil stock degradation on a global scale is usually the result of soil loss or damage due to previous quarrying activities. Consequences of quarrying activities are generally loss of soil organic matter and its associated nutrients, absence of topsoil, periodic sheet erosion, drought, surface mobility, compaction, wide temperature fluctuations, absence of soil-forming fine materials, and the shortage of essential nutrients (Wong et al. 1999a, b). Some tropical regions experiences both humid wet and dry seasons. The seasonality differences influence the physicochemical and microbial characteristics of the soil, which in turn can affect the nature of the wastewater discharged into soils. Poor quarrying activities can therefore have adverse soil consequences, leading to the deposition of large volumes of waste in the soil. As a result of open pit mining, there is vegetation destruction as well as the formation of dumping grounds with harmful minerals and chemicals that contaminate the soil (Ezeaku 2012).

Restoration of quarry sites usually involves improvements to physical and chemical soil properties and vegetation cover. However, excavated quarry sites in the Aripo savanna are left exposed and have become catchment basins for rainfall as the exposed claypan soil hardens. Regrowth of vegetation becomes difficult because of reduced infiltration and seasonal waterlogging.

3.5 Residential areas

The UN has forecasted that by the year 2050, 66% of the world's population will be living in urban areas. Understanding of the highly variable and poorly characterized impacts that growing residential areas have on the soil ecosystem is only in its beginning phase (Pouyat et al. 2010). Residential soils, if largely left undisturbed, act as sinks for atmospheric nitrogen (Racti et al. 2008), offsets carbon emissions (Townsend-Small and Czimczik 2010), and provide storm water treatment (Zhu et al. 2004; Dietz and Clausen 2006). Disturbed residential soils are often thought to be low in fertility, highly compacted heterogeneous combined soil (Craul and Klein 1980; Short et al. 1986). Generally, soil can be contaminated as a result of disposal of municipal and industrial wastes, domestic heating, industrial emissions, heavy traffic, and past LULC (Thorton 1991; Wong et al. 2006). Heavy metals contamination in residential areas is of particular concern because of their long residence time in the soil and their toxicity to humans (Kabata-Pendias and Pendias 2001). Other sources of soil contamination found in residential areas include atmospheric deposition, paint particles, bonfires, contaminated material used for site leveling, runoff from metal surfaces, use of ash and mineral waste for constructing paths, burial of metal-containing wastes, and leisure activities (Alloway 2004). In the tropics, household gardens are prevalent as a means of supplementing income; people thus can be at greater risk from consuming fruits and vegetables grown in contaminated soil. Residential areas in the Aripo savanna were found to generally have mixed land use/land cover determined by needs of residents, these includes subsistence agriculture, use as a dumping ground, and native vegetation. The influence that these have on soils include: ground water contamination, soil pollution, soil compaction, loss of habitats, and erosion and soil loss.

4 Soil natural capital framework for the Aripo savanna

A modified framework from Dominati et al. (2010) for the provision of ecosystem services from soil natural capital in the Aripo savanna is presented in Fig. 5. The framework was modified to reflect the existing soil conditions in the ecosystem, the ecosystem services essential to support the needs of land use/land cover, as well as the impacts of LULC on the soil and possible management strategies specific to degradation processes. The framework was used to characterize soil stocks and their direction of flows within the savanna soil ecosystem in relation to land use/land cover. Using an

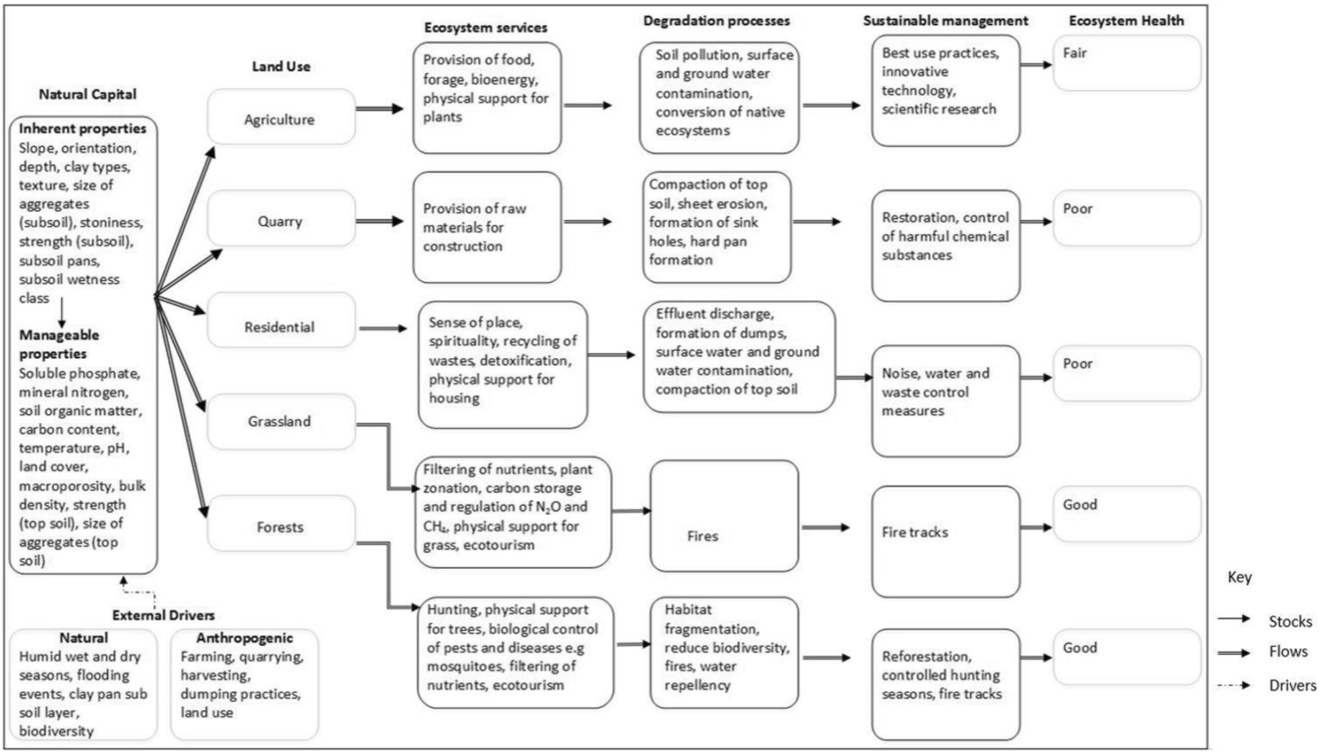


Fig. 5 Framework for the provision of ecosystem services from soil natural capital in the Aripo savanna (modified from Dominati et al. 2010)

ecosystem health model (Fig. 5), the impacts of LULC on the soil ecosystem health was rated with the subsequent ecosystem health assessment added to the framework.

>The framework consists of seven main interconnected components specific to the Aripo savanna soil ecosystem: (1) soil natural capital, (2) land use/land cover, (3) ecosystem services, (4) degradation processes, (5) sustainable management practices, (6) ecosystem health assessment and, (7) external drivers. Soil natural capital can be divided into inherent properties and manageable properties (Dominati et al. 2010). Inherent soil properties are properties that cannot be changed without significant modification or exorbitant costs. They include slope, depth, cation exchange capacity, and clay types. Manageable properties are of more practical importance as they allow for the optimization of soil ecosystem services.

Major LULC covers in the Aripo savanna are highlighted in the framework. These include natural LULC (grassland and forest) and anthropogenic LULC (agriculture, quarry, and residential). Anthropogenic practices modify the soil ecosystem for the provision of services such as food, energy, raw materials, and spirituality. Natural LULC leaves the soil ecosystem unchanged for filtering, storage and regulation, provision of support, pest control, etc.

Anthropogenic LULC are usually characterized by poor practices that negatively impact on the soil natural capital, thereby limiting the ability of the soil to perform its ecosystem services sustainably (Table 2).

Human-influenced LULC, which result in deterioration by conversion of the Aripo ecosystem, also have important implications for soil fertility and climate change. Forest clearing, quarrying, and agriculture practices contribute to loss of native vegetation, decreases in soil carbon and nitrogen on a local scale and soil fertility on a global scale and decreases the soil ability to act as a sink for carbon thereby increasing greenhouse gas emissions (Johnson and Curtis 2001).

Sustainable management practices as a means to determine ecosystem health was also emphasized in the framework. The extent to which best use practices were implemented determined soil ecosystem health. External drivers influence soil processes differently. They can be natural or anthropogenic in nature and can affect the nature or speed of soil processes. By impacting soil processes, they determine the nature of reactions which influences soil natural capital (Dominati et al. 2010). The Aripo framework is practical for tropical small island regions as it identifies the impacts of soil ecosystem services in SIDS by linking LULC to soil natural capital.

4.1 Developing a rating framework for the impact of land use/land cover on soil ecosystem health based on soil quality descriptors

Ecosystem health descriptors are environmental factors that can be measured over a time range and over a spatial region. Descriptors can be determined using measured observations or modeled data. The health of the soil ecosystem is a major

Table 2 Effects of poor practices in Aripo savanna land use/land covers

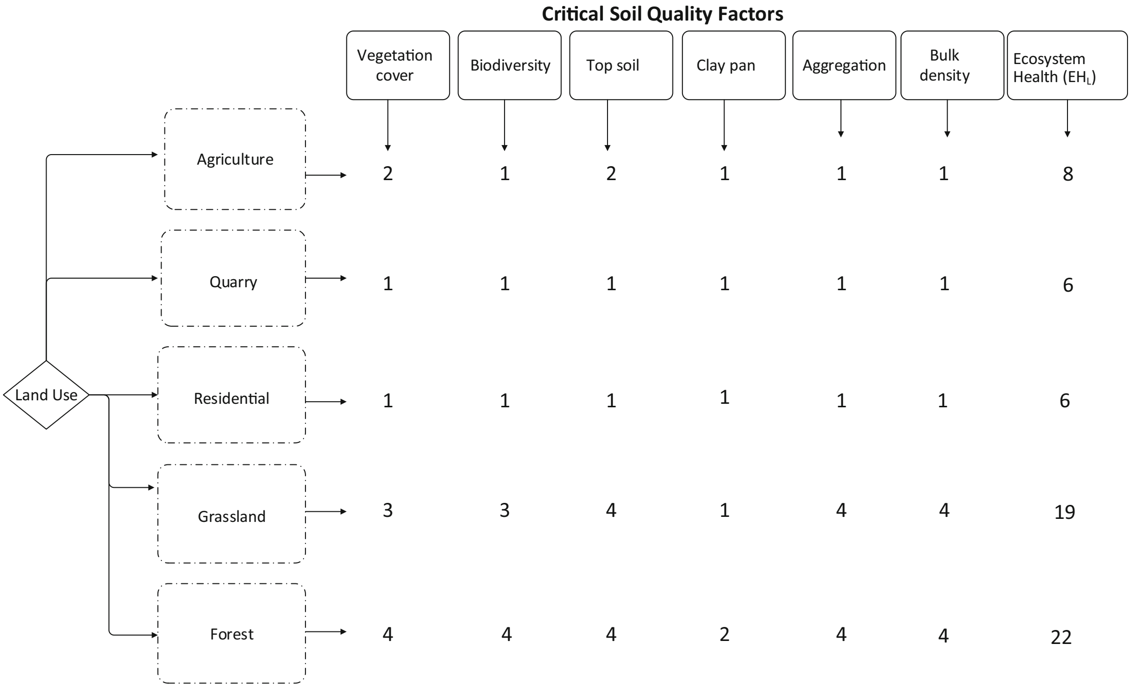
Land use	External drivers	Poor soil practices	Sustainable soil management efforts	Soil ecosystem health assessment
Agriculture	Natural-tropical wet/dry climate, clay sub-soil. Anthropogenic influence of soil properties under agriculture	Leaching and volatilization of waste, excessive use of fertilizers, soil erosion, reduced biodiversity, conversion of ecosystems	Innovative technology, scientific research, increased nutrient and water use efficiency, maintaining and restoring fertility, disease and pest control, sustainable livestock production	Fair
Quarry	Natural-tropical wet and dry climate, frequent flooding events	Removal of top soil, compaction of sub-soil, sheet erosion, sinkholes, hardpan formation, drought, surface mobility, temperature fluctuations, absence of soil-forming fine materials, shortage of essential nutrients	Filling abandoned excavated sites, replanting vegetation, water and waste control measures	Poor
Residential	Natural-tropical wet/dry climate. anthropogenic farming, dumping	Effluent discharge, dumping refuse, water contamination, soil, soil compaction, unplanned housing	Residential restrictions, water and waste control	Poor
Forest	Natural-tropical wet/dry climate. Anthropogenic tree harvesting	Hunting, vegetation removal, reduce biodiversity	Reforestation	Good
Grassland	Natural-tropical wet/dry climate, cracking of claypan soil	Fires	Fire tracks	Good

determinant of its ability to provide ecosystem services. The health of the soil ecosystem is influenced by the range of LULC the ecosystem is subjected to. Consequently, soil ecosystem health cannot be represented solely by specific LULC but could be explained by critical descriptors that influence soil quality. Therefore, a general rating of LULC for soil ecosystem health in Aripo savanna was based on the critical descriptors that influence soil quality in the savanna (Fig. 6). These descriptors include vegetation cover, biodiversity, topsoil, claypan, aggregation, and bulk density. Descriptors were rated and scores assigned based on trends observed from quantitative physical and structural soil data collected by authors (data not shown), existing literature on species diversity and claypan depth (Richardson 1963), professional judgment, and local knowledge. Observations show that with increased human impact, greater deterioration in the soil health occurs. Therefore greater bulk densities, lower porosities, lower aggregate stability, lower species diversity, and shallower top soils were found in anthropogenic influenced areas than natural areas. However, in natural areas, vegetation zonation was controlled predominantly by depth of claypan with grasses on shallower claypan and forests on deeper claypan areas. A rating between 1 and 4 was assigned based on the magnitude of the influence that a soil quality descriptor has on soil ecosystem health under a particular LULC. Descriptor scores tending towards 1 indicate that the LULC is increasing the negative impact of the soil quality descriptor on ecosystem health while the LULC decreases the negative impact of the soil quality descriptor on ecosystem health as the score tends towards 4. In the rating framework, soil quality descriptors specific to the Aripo savanna were the only source of variation in determining the soil ecosystem health assuming that the variation in climatic elements such as rainfall and temperature was not significant throughout the ecosystem but their impact is influenced by the prevailing LULC. The soil quality descriptors were identified as the important factors influencing the Aripo savanna soil ecosystem and hence the most important factors in the degradation of the soil natural capital in the ecosystem.

The main assumptions in the rating framework include:

1. Soil ecosystem health is determined only by vegetation cover, biodiversity, topsoil, claypan, aggregation, and bulk density.
2. The degree to which soil quality descriptors influence soil ecological health within a specific LULC are rated as they appear in the framework.
3. The influence of climatic elements is only determined by the prevailing LULC.
4. Soil natural capital is undermined more under anthropogenic LULC than under natural LULC.
5. Soil quality descriptors act independently in determining soil health with little or no interaction among them.

Vegetation cover, biodiversity, and topsoil were seen as positive soil quality descriptors for soil ecosystem health, while claypan and bulk density were negative (Fig. 6). Therefore, the rating for vegetation cover, biodiversity, and topsoil tend towards 4 for LULC that ensure the increase of these descriptors and vice versa. The rating tends towards 1 for LULC that increases the negative descriptors of claypan and bulk density on the soil ecosystem health.



Land Use	Vegetation cover	Biodiversity	Top soil	Clay pan	Aggregation	Bulk density	Ecosystem Health (EH_L)
Agriculture	2	1	2	1	1	1	8
Quarry	1	1	1	1	1	1	6
Residential	1	1	1	1	1	1	6
Grassland	3	3	4	1	4	4	19
Forest	4	4	4	2	4	4	22

Magnitude of positive influence on soil ecosystem health: 4-Very strong, 3- Strong, 2- Weak, 1- Very weak.

Fig. 6 Rating of land use based on contribution to soil ecosystem health

4.1.1 Vegetation cover

Agricultural land use influences vegetation cover by supplying nitrogen to produce high yielding crop varieties (Matson et al. 1997); however, it can also result in increased diseases in plants, soil pollution, soil nutrient imbalance, and lower pest resistance (Altieri and Nicholls 2003). Irrigation can induce salinity and sodicity affecting the soil microbial activity (Rietz and Haynes 2003), while tillage can influence erosion and water conservation rates of the soil which negatively influences plant productivity. In the quarry land use, reforestation of the vegetation cover is limited by the availability of the soil volume. A change in the type of vegetation cover from annual and perennial herbaceous species to shrubs often takes place after the quarry has been abandoned (Yuan et al. 2006) because of the lack of nutrients due to soil degradation. Complete removal of vegetation cover usually takes place under residential LULC activities, reducing infiltration, and increasing the frequency of flooding events. Turf and lawn grasses typical of residential areas has less carbon and nitrogen fixation when compared with forests (Raciti et al. 2011), resulting in less soil carbon storage. Native vegetation cover that comprises of forest and grasses provide habitats for native species and has the highest percentage of soil carbon stocks (Guo and Gifford 2002). Increased accumulation of organic matter typical of native ecosystems is important for soil aggregation (Elliot 1986). Aggregate structure increases productivity and sustainability.

4.1.2 Biodiversity

Agricultural practices have a profound effect on the reduction of biodiversity where the total number of cultivars is far less than the number of native species (Matson et al. 1997). Agricultural practices promote the development of monocultures, which depletes soil nutrients vital to the diversity of soil microorganisms that aerates the soil. Quarry activities lead to decreased carbon source utilization and functional diversity in revegetated quarries (Zhang and Chu 2011), specifically plant community structure, soil properties, and the disturbance of soil microflora and fauna (Heneghan et al., 2008). Residential LULC activities alter habitats and the ecological processes important for the biotic processes that maintain biodiversity (Hansen et al. 2005). A disturbed soil ecosystem decreases the survival of certain species thereby reducing biodiversity in this land use. Grassland biodiversity supports microflora and nematode diversity. A native grassland ecosystem increases the stability of soil ecosystem patterns and processes (Loreau et al. 2002). Forest biodiversity increases organic matter and soil fertility facilitating nutrient cycles (Chazdon 2008). Forest biodiversity increases habitats, medicine varieties (Ehrlich and Wilson 1991), increases carbon fixation, suppress soil borne diseases and pests. It also increases the varieties of specialized bacteria, e.g., nitrifiers, nitrogen fixers, and fungi (Brussaard 1997) important for various biogeochemical processes.

4.1.3 Topsoil

Sheet erosion is a major effect of agriculture land use that results in the loss of topsoil. As it takes 100 years to replace a centimeter of topsoil (Pimentel et al., 1995), the environmental and economic costs to the soil ecosystem of sheet erosion are immense. Loss of topsoil leads to loss of organic matter, nutrients, and carbon. The topsoil depth can vary with depth of claypan; this can influence soil fertility and plant root establishment. Quarrying effects include the loss of fertile top soil (Barman et al. 2013), land degradation, loss of habitats to flora and fauna, and loss of microbes that aerate the soil and compaction. In residential land use, compaction alters soil physical properties and changes the hydrologic characteristics of the soil by stripping the topsoil layer. Native ecosystems, however, increase the levels of soil microbial activity, primary production, decomposition, and soil organic matter production (Visser et al. 1984).

4.1.4 Claypan

Claypan soils actively under agriculture results in excessive use of fertilizers, as increased runoff results in fertilizer loss (Udawatta et al. 2004). Waterlogging of agricultural fields may also occur because of reduced infiltration into the deeper layers of soil (Steichen 1984). Claypan soils can increase the rate of erosion (Willett et al. 2012) making soil loss problematic on these agricultural fields. Quarrying on claypan soil types firstly exposes the claypan layer to the weather elements. Hardening of the claypan occurs reducing infiltration and increasing flood events (Darwish et al. 2011). While claypan soils can provide a strong foundation for residential land use, the high runoff effect deteriorates the water quality vital for human consumption in these areas (Ward et al. 1994). Further compaction of the already hardened claypan constraints plant growth in urban habitats. Native grassland and forest flooding (Sarmiento et al. 2004) in locales where claypan depth decreases from the soil surface, affects the soil water regime of the ecosystem, reducing vegetation grazing in grasslands while excluding plants not suited to the soil conditions.

4.1.5 Aggregation

Agriculture due to tillage reduces the number and stability of soil aggregates (Six et al. 2000; Wuddivira and Camps-Roach 2007), it affects soil macroaggregate turnover and microaggregate soil formation. Quarrying activities also affect aggregate stability (Sort and Alcaniz 1996) due to the destabilizing effect of quarrying practices. Residential activities lower macroaggregation and macroaggregate-associated carbon pools, lowering soil saturated hydraulic conductivity (Chen et al. 2014). The compaction of soil aggregates as a result of residential land use activities slow infiltration (Day and Bassuk 1994), while aggregates of native ecosystems are more stable (Cambardella and Elliot 1992) with higher levels of both micro and macro aggregates (Ashagrie et al. 2007), facilitating greater infiltration rates.

4.1.6 Bulk density

In agricultural fields, the bulk density of the soil is reduced shortly after tillage but is increased under no tillage practices (Franzluebbers et al. 1995). Soil moving quarrying equipment can increase bulk density of the soil as a consequence of severe soil compaction (Ramsay 1986). Compaction of clay soils result in loss of structure and are the main forms of soil degradation on these soil types. Residential soil bulk density is considered to be significantly greater in newer urban soils as compared with older urban soils (Scharenbroch et al. 2005).Compaction of soil is also a consequence of residential activities (Raciti et al. 2011), which increases bulk density. Native ecosystems such as forest and grasslands, generally have lower bulk densities due to soil fauna which reduces thickness of organic layers (Schwartz et al. 2003; Frelich et al. 2006), creating bulk densities conducive to an enhanced soil ecosystem.

5 Role of frameworks in community engagement and policy development

Soil ecosystem frameworks developed could enhance the capability of communities to address soil health needs and disparities in ecosystems while ensuring that services provided by soils are appreciated and properly managed. Community engagement in sustainable ecosystem management can stem from the frameworks developed as they provide an understanding of the processes and feedbacks within the soil. This helps in addressing ecosystem health problems in the face of climate change and facilitates the community in making informed and meaningful input in environmental policy development. The soil health of SIDS, mainly dominated by coastal communities, can be influenced by factors such as soil salinization, waterlogging, and soil erosion. These factors lower soil productive capacity, increase food insecurity, increase incidence of soilborne plant diseases, and breeding ground for vectors such as mosquitos (causing infectious tropical diseases, e.g., dengue, malaria, Zika, and yellow fever) at the soil-water interface. Climate change coupled with the effects of land use on the soil ecosystem in SIDS (Lal 1993; Johnson and Wedin 1997; Bonan 2008) emphasizes the need for a clear outline of soil processes and feedbacks for communities, as reflected in the framework. This facilitates a bottom-up approach to policy development. Community involvement in the soil ecosystem health using these frameworks can unfold in numerous ways but not limited to the following: (1)

implementing combined educational approaches and strategies into communities, returning investments to soil health and strengthening the connection to the land and (2) farmers incorporating an agroecological approach where they conduct experiments to monitor soil health.

Policy makers should empower communities to facilitate adaptation processes taking into account local knowledge and creating a facilitating environment and promote environmental education. Funding sources should also be made available to facilitate the contribution of new knowledge into the policy process.

One of the key factors for preserving resilience in SIDS is the use of traditional knowledge; these include institutions and technologies, land and shore tenure regimes, the subsistence economy, and customary decision-making processes. Traditional adaptation strategies such as the development of crops to withstand erratic rainfalls and the construction of groynes, building sand dune fences, and planting trees along the coast as well as relocation can reduce the impact of erosion on coastal communities.

6 Conclusions

Caribbean soil ecosystems provide a significant contribution to human welfare especially in the face of increased food production goals to achieve self-sufficiency; however, these ecosystems are not given adequate weight in the decision-making process. Consequently, indiscriminate land uses have resulted in significant degradation of the soil natural capital. At the continued rate of unsustainable use, most soil ecosystem services will become more stressed and scarce.

The soil framework of the Aripo savanna ecosystem services highlights the likely effects of each LULC upon the soil ecosystem health. Native LULC of grassland and forest generally scored higher than anthropogenic land use/land covers indicating good soil health and sustainable preservation of soil ecosystem goods and services. Unsustainable anthropogenic land use/land covers are commonly practiced in the Aripo savanna, this causes loss of soil ecosystem productive potential. Therefore, to restore the soil ecosystem potentials, reforestation projects should be carried out on abandoned quarries, regulations against the development of squatter settlements should be enforced, and the practice of farming techniques that protect the soil ecosystem and the environment should be introduced and implemented. This review demonstrates the need for research on ecosystem services and natural capital stocks in the Caribbean region in an effort to ascertain their value for the optimization of their use.

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