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Land Degradation Neutrality and Land Use Options

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Abstract

Discussions around climate change seldom refer to soil, even though one of the major soil forming factors is climate. Because land mass is fixed in quantity, there is an ever-increasing competition to control land resources in terms of their services for the living organisms. Land area is dwindling due to many reasons. The main reason is its degradation, both natural and anthropogenic. It seems, therefore, logical to save our motherland and focus on land degradation neutrality (LDN) whereby the amount and quality of land resources, necessary to support the ecosystem functions and services and enhance food security, remain stable or increase within specified temporal and spatial scales and ecosystems. Three case studies are mentioned here to show how to address the LDN, one in high rainfall areas and the two others in the semi arid tropics (SAT). These observations can act as model land use options to further LDN in similar areas in other parts of the world including India. Land degradation neutrality (LDN) may also reduce carbon footprints and thus nullify the ill-effects of global warming.

Key words: Land degradation neutrality, land use, ecosystem, global warming

Introduction

The United Nations Convention to Combat Desertification (UNCCD) is spearheading the issues of land/soil degradation to arrest these precious natural resources becoming unfertile at the global level (Cowie et al., 2018; IPBES, 2018). Such steps will render land resources to be protected and restored for promoting sustainable use of terrestrial ecosystems including forests. The main objective is to help reversing land/soil degradation and to combat climate change.

Since major soil (and landscape) forming factor is climate (Jenny, 1941), the issues of climate change always involve soils/lands so far as its effects on terrestrial ecosystem are concerned. Since landmass is finite, there is an ever-increasing competition to control land resources in terms of their services for the living organisms, bringing tremendous pressure on the carrying capacity of land.

There are many reasons for land area being dwindled of which degradation of both natural and anthropogenic is important. It seems, therefore, logical to save our motherland and focus on land degradation neutrality (LDN), where LDN will help to provide necessary ecosystem functions and services of the land resources and enhance food security. It will also assist to keep the land resources stable and may also improve its quality within specified temporal and spatial scales and ecosystems. Since land and/or soil degradation has the potential to cause social problems leading to poverty and malnutrition, the implementation of LDN requires involvement of multi-stakeholders with adequate support of the national and regional governments (**Figure 1**); Bhattacharyya, (2020a).

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Land degradation neutrality is directly related to land use. Therefore, to achieve LDN there should be a mutual convergence of present and suggested land use out of the probable options to develop an acceptable land use policy. The present effort delves in this direction citing various case studies in India.

Achieving Land Degradation Neutrality

Land degradation neutrality (LDN) could be achieved by balancing degradation for which major requirement is the information on soil and land. Soil resource inventory for the entire country (Bhattacharyya et al, 2009; Bhattacharyya 2020a, b), details of soil information system (Bhattacharyya et al. 2014a,b, 2016,2019a,b), and other information are available (Bhattacharyya et al 2019c; Bhattacharyya 2020a, b). These datasets provide various case studies in different ecosystems of the country which act as models.

Target audiences for LDN include individuals/organizations which may influence for improving or transforming land management practices and land use planning at different scales. For Indian situations this may well include i) each and every citizen, ii) the farmers (do's and don'ts), iii) government organizations (implementation: land use for agriculture a state subject, conflict of interest!), iv)

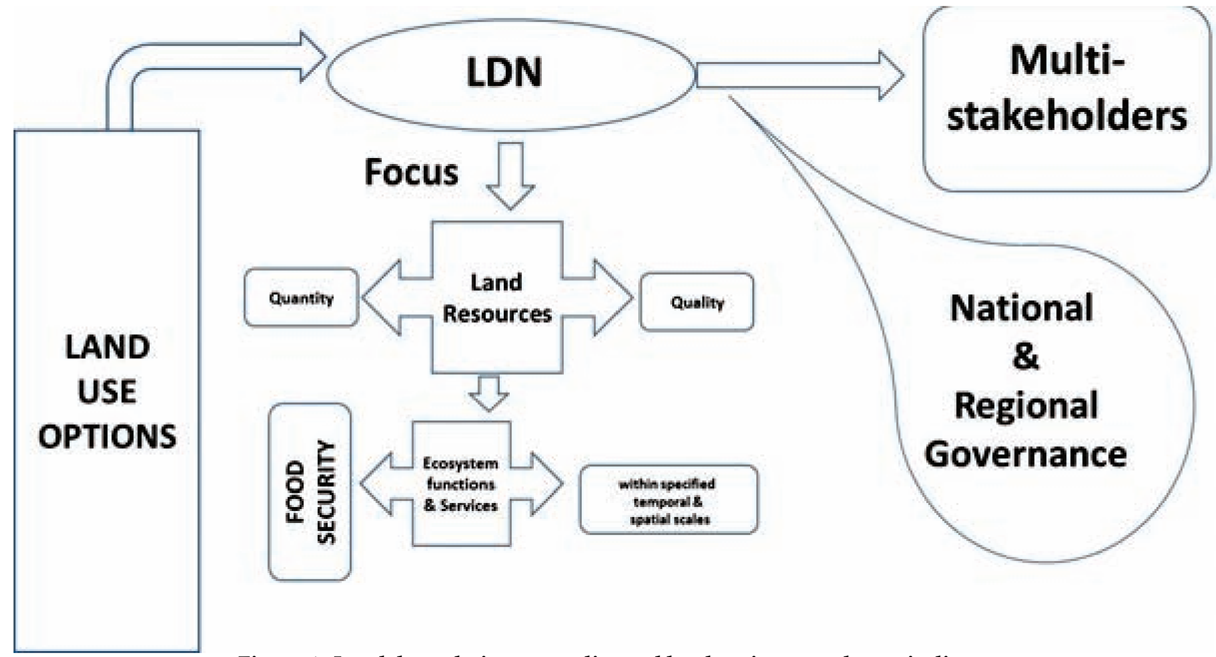

Figure 1. Land degradation neutrality and land options : a schematic diagram

non-governmental organizations (NGOs), v) universities (academia with special reference to agricultural universities (Bhattacharyya et al, 2018a, b), and vi) research institutes (councils etc.).

Indian perspective for LDN might consider the recommended doses of management of the national agricultural research system which maintain

- The rice-wheat cropping system with special reference to the Indo-Gangetic Plains (Bhattacharyya et al., 2004, 2014b, 2019c).
- The process of natural soil/land degradation in the drier tracts of India with special reference to
  - o present land use (Bhattacharyya, 2015), and
  - o selection of crops in the event of using poor quality irrigation water (Padekar et al., 2014, 2016).

Such efforts can also deliver multiple benefits from soil organic carbon (Bhattacharyya, 2015, Banwart et al., 2014, van Noordwijk et al, 2015). Different types of soil degradation have been reported and discussed (**Figure 2**). A few will be discussed here with special reference to chemical degradation and soil erosion.

Soil/land degradation requires land resource inventory. For achieving land resource inventory, a few case studies have been detailed here. Such studies may act as model (**Figure 3**) to replicate to achieve more LDN to reach the required target set. Knowledge of geology and soil minerals also helps in achieving LDN which reaffirms the role of natural resource managers in LDN.

CASE STUDY I : Humid to Per-humid Bioclimatic System

In the Konkan, Maharashtra spatially associated red (Alfisols) and black (Vertisols and their intergrades) (Soil Survey Staff, 2014) soils are frequent (Bhattacharyya et al, 2020). These red soils are often referred to as laterites (Shahasrabudhe and Deshmukh, 1981). 'Red' and 'laterite' terms as well as 'lateritic' have led to controversial opinions. Contrary to the common understanding that these soils are difficult to support crops (Aleva, 1994), these associated soils in Konkan, Maharashtra are cultivated with profitability to various agricultural, horticultural and plantation crops (Bhattacharyya et al., 1993, 1999, 2019c, 2020). Among many horticultural crops Alphonso variety of mango is the most popular in this part of the Western Ghats, Maharashtra.

Konkan, Maharashtra is different in contrast to other parts of the state in terms of geology, climate, soils, environment and land use options. It represents a coast line of 720 km covering an area of ~30 lakh hectares. This terrain represents humid to per humid bioclimatic system (Bhattacharyya et al, 2008) with a mean annual rainfall of 2500-4000 mm. Northern part of Konkan is similar to other part of basaltic landscape (Bhattacharyya et al, 2018). This is due to the geographically low elevation of these districts resulting in more width (distance between the Arabian Sea and the Western Ghats) (**Figure 4**). This permits better residence time to basaltic alluvium to settle the sediments enabling the formation and persistence of deep black soils. In contrast, southern

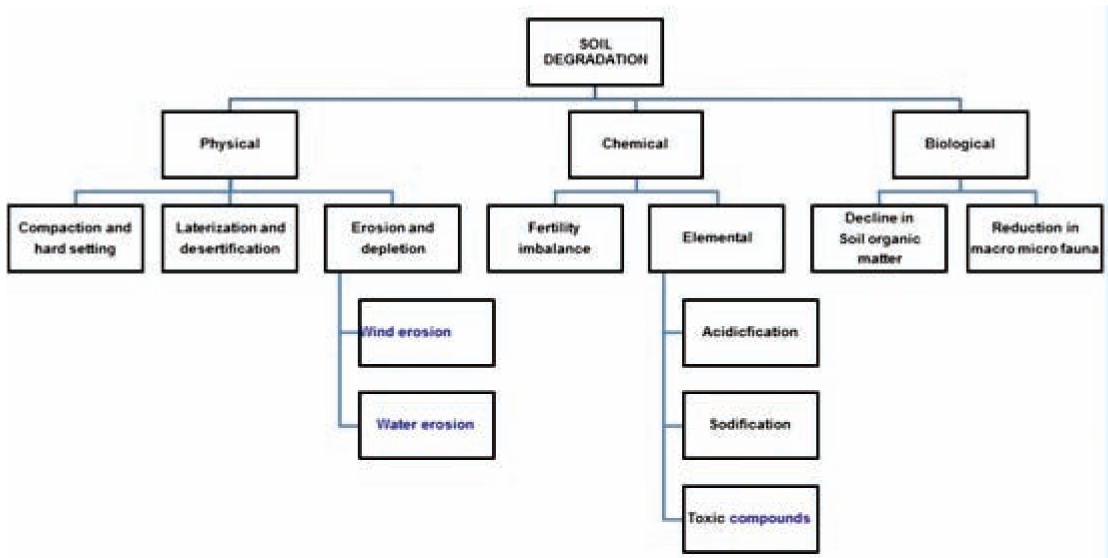

Figure 2. Types of soil degradation and their subtypes

part of Konkan gradually narrows down and represents an undulating, steeply sloping landscape forming red soils with hard cover locally known as *jambha katal* (hard rock; laterite) (Bhattacharyya et al., 2019c).

Mango is an important rainfed perennial fruit crop of Konkan, Maharashtra. Various developmental programmes helped to increase the area of this fruit in Konkan. However, availability of productive land always remained a major limitation for expansion of mango area in this part of Maharashtra. The land available near Sahyadri hills and away from the shore around 20 km are not suitable for mango plantation due to late flowering and subsequent late harvesting. Many cultivable waste lands are not usable due to social factors (Bhattacharyya et al., 2019c).

Against this background, the unused hard laterites were utilized by many entrepreneurs for Alphonso plantation. These areas due to their proximity of sea coast with the direct exposure to the sea favour very early flowering and development of excellent quality fruits to fetch premium price in the nearby metropolitan cities and towns. Besides, the quality of Alphonso mango grown on hard rock is also found to be good when all measurements of various quality parameters are taken into consideration.

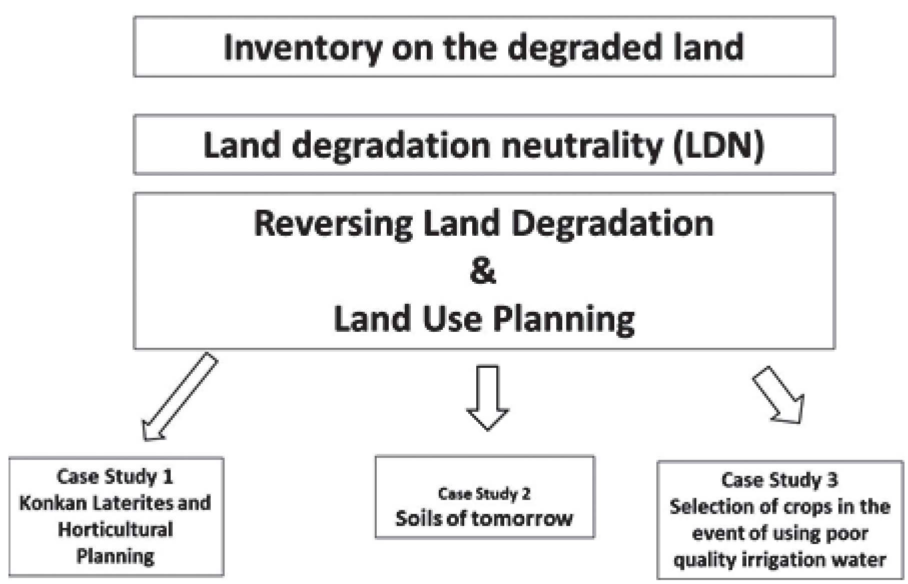

Figure 3. Different model case studies of India to achieve land degradation neutrality (LDN)

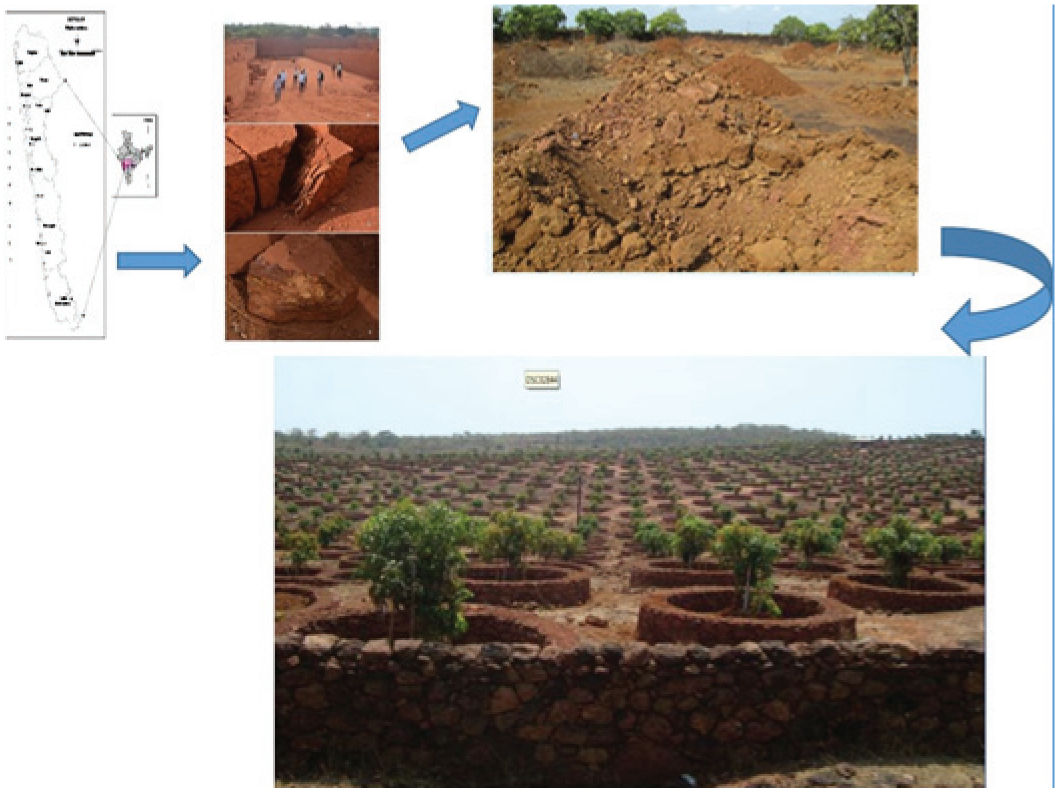

Figure 4. Hard rock plantation in Konkan, Maharashtra

During post-1990 period, Horticultural Revolution enhanced most of the areas for expansion of fruit trees in Konkan. The areas left were only the hard rock surfaces which were expanded by the local farms and the agricultural university experts following the standard procedures (Bhattacharyya et al., 2019c). Their wise observations of early flowering and production of good quality mangoes in the cracks of hard rock opened new vistas of using degraded and unused lands to attain the land degradation neutrality (LDN).

Mechanisation techniques involving drilling, blasting and excavation of pits in basalt rocks played an important role to upscale similar areas under mango cultivation in Konkan (~ 3 lakh ha area) and elsewhere. Studies show that mangoes grown on hard rock to bring land degradation neutrality in this part of India bear quality mango as products (**Table 1**).

The technique for hard rock plantation has been discussed elsewhere (Bhattacharyya et al., 2019c). Primary laterite has been reported to form mainly in Deccan Plateau, especially on the higher elevation of the Western Ghats with variable thickness of 50-90 ft. Most of these secondary laterites between Mumbai and Ratnagiri-Sindhudurg stretch further to Goa, separating the hills from the sea.

These secondary laterites appear as a plateau (200-300 ft. above mean sea level, amsl) between Ratnagiri and Goa extending from the coast to the inland towards the Western Ghats. This laterite is conglomeratic and occurs on higher elevation (Pascoe, 1964). In southern part of Konkan this laterite is found at 35 ft. with an underlined rock of gneissic and metamorphic origin. Most of the laterites in India are reported near the Western Ghats and in the southern part of Maharashtra. Laterite is highly porous and when freshly queried it is soft and can be easily cut into pieces. When exposed it hardens due to desiccation of the argillaceous components and converts into so called hard laterite.

CASE STUDY II : Semi-arid Bioclimatic System

Black soils (Vertisols and their intergrades) occupy 76.4 Mha in India (Bhattacharyya et al, 2013). These soils and the associated red soils occupy nearly 159 Mha in the semi-arid areas (Bhattacharyya et al., 2008a) covering arid, semi arid and parts of sub-humid bioclimatic systems (Bhattacharyya et al, 2008a). It is established that due to aridity in the atmosphere, soil pedo-environment dries up to begin the formation of pedogenic carbonates (PC) which triggers subsoil sodicity resulting in chemical degradation of soil

Table 1. Characteristics of Alphonso mango grown in Konkan, Maharashtra (Salvi et al., 2016)

S. No.	Parameters	Values (qualitative/quantitative)
1.	Fruit shape	Oblong
2.	Fruit length (cm)	8.5-11.2
3	Fruit weight (g)	200-300
4	Fruit skin thickness	Thin
5	Colour of mature ripe fruit skin	Yellow colour
6	TSS (°B)	17.2 – 19.5
7	Acidity (%)	0.20 -0.35
8	Pulp (%)	70-87
9	Pulp colour of ripe fruit	Yellow orange
10	Pulp consistency	Thick
11	Fibre content	Absent
12	Taste	Sweet pleasant
13	Flavour	Strong pleasing flavour
14	Peel weight (g $100g^{-1}$)	9-11
15	Pulp aroma	Mild
16	Fruit maturity	Medium (February-May)
17	Stone weight (g $100g^{-1}$)	28.0 – 37.5 (10-12%)
18	Beak	Absent (Blunt)
19	Fruit skin	Can be easily peeled out without pulp
20	Ripening (days)	6-10 days after plucking fruits from tree
21	Keeping quality (days) of ripe fruit	6-10
22	Post harvest-life (days)	18-28
23	Storage condition	At room temperature cool dry place
24	Pulp to stone ratio	5:1
25	Pulp to peel ratio	8:1

(Bhattacharyya et al., 2016b). These soils have characteristic poor physical properties such as high bulk density (~1.8 kg m^{-3}) and poor drainage (sHC<1 cm hr^{-1}). In many cases such situation renders land as barren. The crops/trees grown on these landscapes will receive low available water, poor aeration, poor root proliferation and low yield (Bhattacharyya et al., 2016a). Interestingly in spite of hostile pedo-environment, these soils in the semi-arid tropics, exhibit resilience (Bhattacharyya et al., 2016b) otherwise, these soils could have been infertile and perhaps irreparable. The national agricultural research system (NARS) has been doing an excellent job for many years (Bhattacharyya et al., 2016a). This was shown with SAT soils to understand the fate of soils and landscape with and without management interventions.

Discussions on soils degradation, its uses and abuses are plenty. Very little has been discussed about the future of soils and landscape in the event of continuing present land use types. With the help of soil and mineral information system and using trend of changes of soil parameters the future look of soils and landscape may be predicted. In other words, using the present day datasets and their temporal changes it may be possible to understand soils/landscapes of tomorrow. Using the distribution of carbonate mineral in soils of the semi-arid tropics two probable scenarios of soil properties and their changes have been developed such as, business as usual (BAU) and with management intervention.

Changes in soil carbonate minerals since 1975 till 2030, are predicted in case present land use options are continued (BAU). Carbonates increase from 2% to 7% in black soils, and for (non-calcareous) red soils, these increase to 2%. However, if interventions are adopted, then the content of carbonate minerals might reduce appreciably (**Figure 5**) (Bhattacharyya et al., 2016a). Usually, carbonate minerals start forming pedogenically in the sub surface. If these are allowed to form at the existing rates, then with the present land use options these minerals will engulf the entire soil profile from the surface beyond the root zone depth. With poor drainage, very high bulk density, these SAT soils may look like hard rock in future. The land dominated by such soils will look barren, without much vegetation left on it, as shown on the left side of **Figure 6** (Bhattacharyya et al., 2016a). Fortunately these soils have tremendous resilience, and, therefore, if management interventions are adopted, then the same soils will be mellowed, and the land surface will have lush green vegetation as shown on the right side of **Figure 6** (Bhattacharyya et al., 2016b).

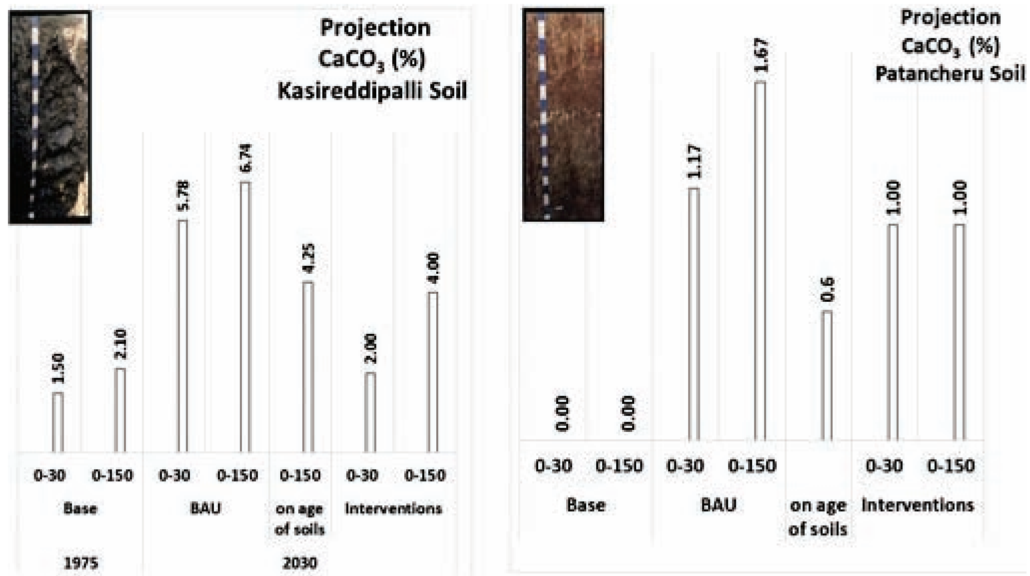

Figure 5. Temporal changes of carbonate minerals in two different soils under BAU (business as usual) and with management interventions

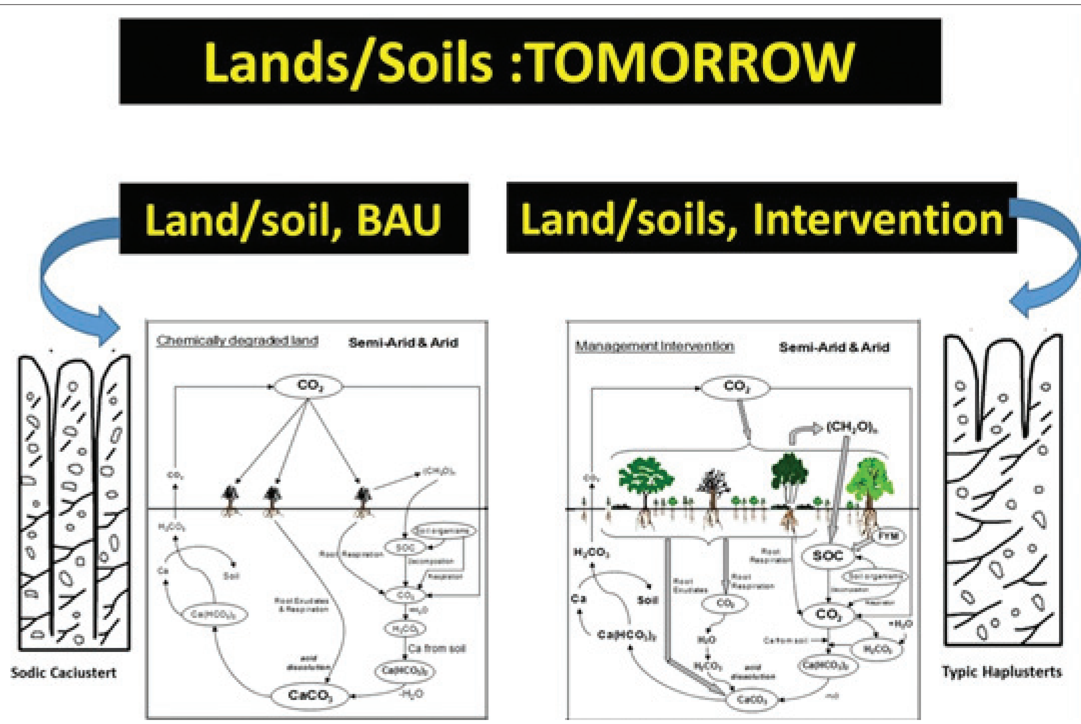

Figure 6. Present and future look of soils and landscape with changes of time and land use changes in business as usual (BAU) and management intervention

CASE STUDY III: LDN of Degradation of Soils by Bad Quality Irrigation in SAT

Other than atmospheric aridity poor quality irrigation water also causes the land degradation. In India irrigated area occupies ~58 Mha (35% of the total geographical area, TGA). In Maharashtra the irrigated area is ~ 4 Mha (18% of state area) while in Vidarbha, irrigated area occupies ~ 0.6 Mha (13% of Vidarbha area). On many occasions fate of soils/ lands depends on the quality of irrigation water. The effects of applying poor quality irrigation water are: increase in soil pH, increase in sodium adsorption ratio (SAR), increase in extractable Na and Mg ions, high bulk density (BD), and poor drainage. This results in soil degradation and the soil

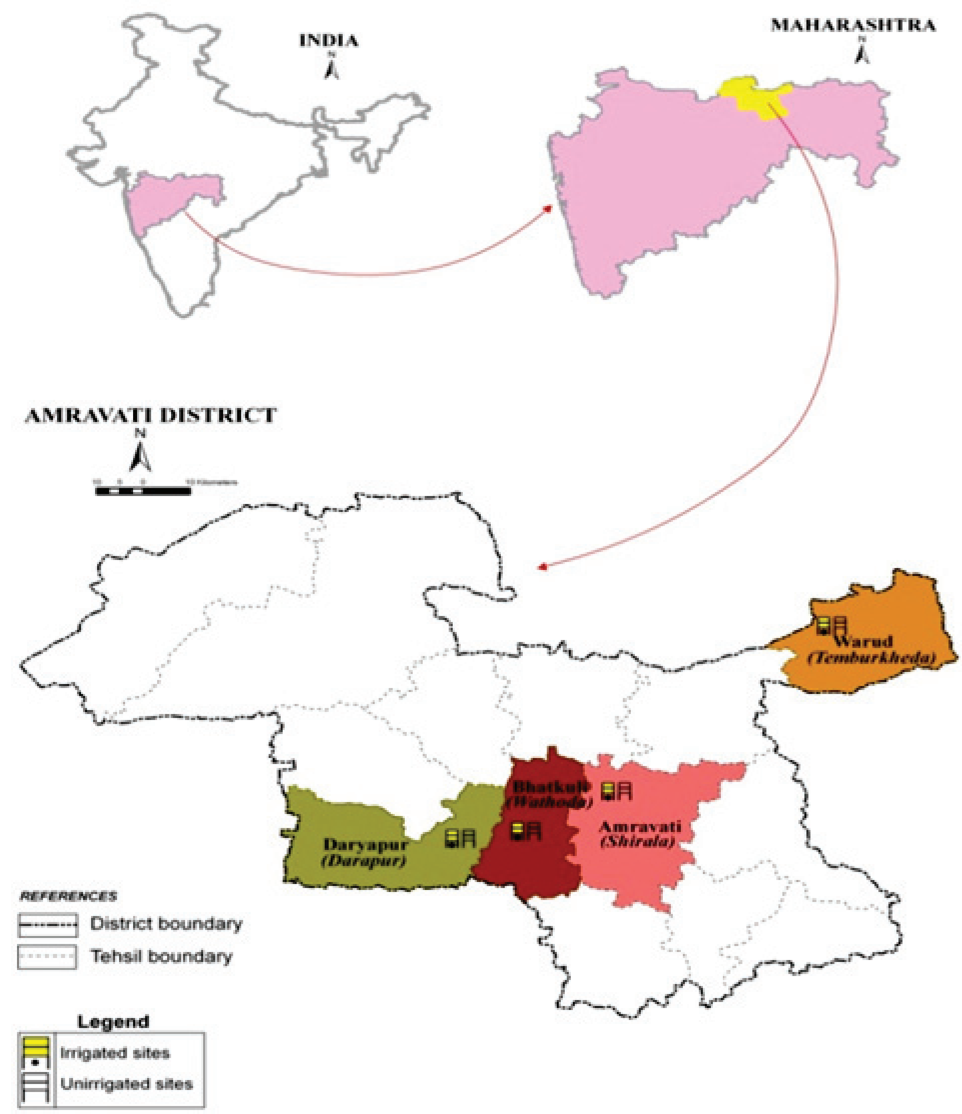

Figure 7. Purna valley (part) in Maharashtra and the areas using poor quality irrigation water

supports poor crop performance.

Chemical soil degradation due to application of irrigation water in the black soils in Maharashtra was studied in the Purna valley (**Figure 7**). Considerable portions of this valley are saline and/or sodic and are prone to waterlogging. Due to poor drainage, salts accumulate in these soils. This is further aggravated by the application of indiscriminate use of poor quality irrigation water. Exceptionally high salinity was of marine origin as a result of incursion of a stretch of sea water into the Purna sub-basin. Groundwater is highly brackish (Padekar et al., 2016).

Salt content of irrigation water (river and well) collected from the irrigated areas ranges from 0.9 to 3.0 dS m^{-1} which falls under C3 and C4 classes, indicating their unsuitability for irrigation and also falls either under medium (S2) or low (S1) category of sodicity (Richards, 1954). There are cases where irrigation water, used to raise agricultural crops, falls in the category of C4S2 and C4S1 class of the United States Salinity Laboratory (USSL) due to high soluble Na-ions and residual sodium carbonate. Assessing quality of irrigation water indicated different threshold values for residual sodium carbonate (RSC)~ 3.5, sodium adsorption ratio (SAR) ~ 10 and electrical conductivity (EC) <0.25 (Eaton,1950; Padekar et al., 2016) (**Figure 8**)

Four different areas show that soils are degraded due to poor quality of irrigation water **(Figures 9, 10, 11 and 12)**. It may be noted that in most of the cases soil drainage is remarkably reduced by 4 to 9 times causing

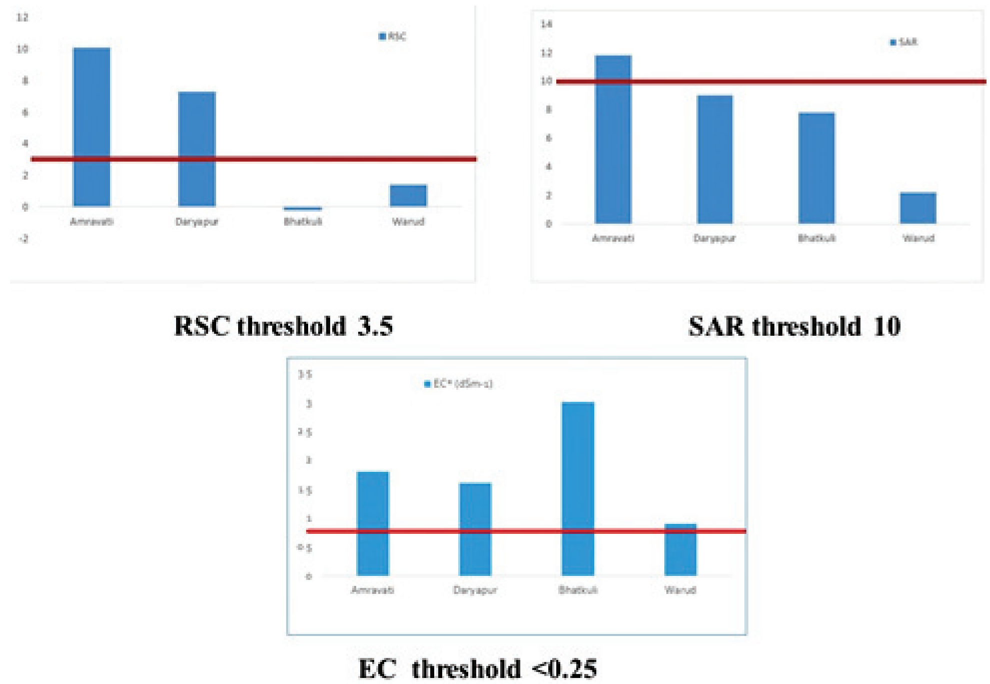

Figure 8. Assessment of irrigation water in four different places in Purna valley, namely Amravati, Daryapur, Bhatkuli and Warud in Maharashtra (Units of EC are dS m^{-1}).

deleterious effect on plant roots and its performance. In Warud, however, situation is slightly better due to two reasons. Firstly, these areas are under perennial trees such as oranges (Nagpur mandarin: *Citrus reticulata* Blanco). These trees due to the proliferated rooting system over years must be dissolving native carbonates maintaining soil health. Besides, native zeolites in these soils also act as soil conditioners to save these soils from further degradation (Padekar et al., 2016; Bhattacharyya et al., 1999, 2014).

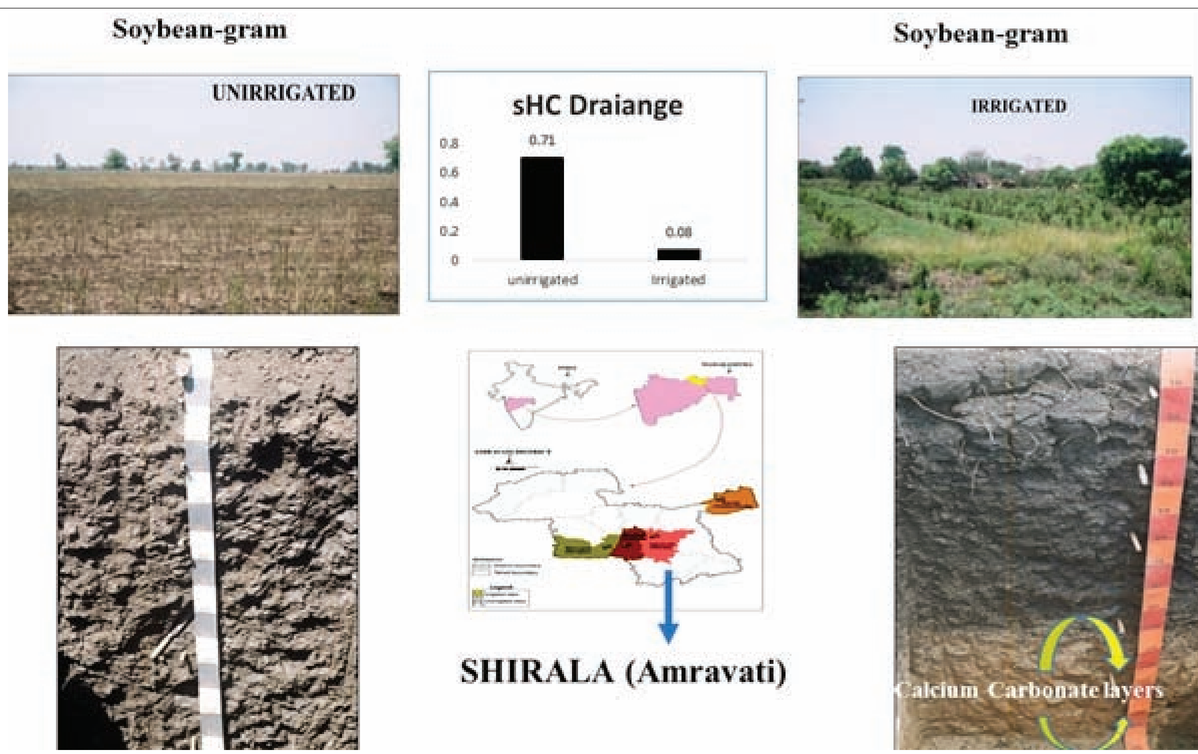

Figure 9. Degradation of soils in Shirala (Amravati) in Maharashtra due to application of C3S2 class of irrigation water

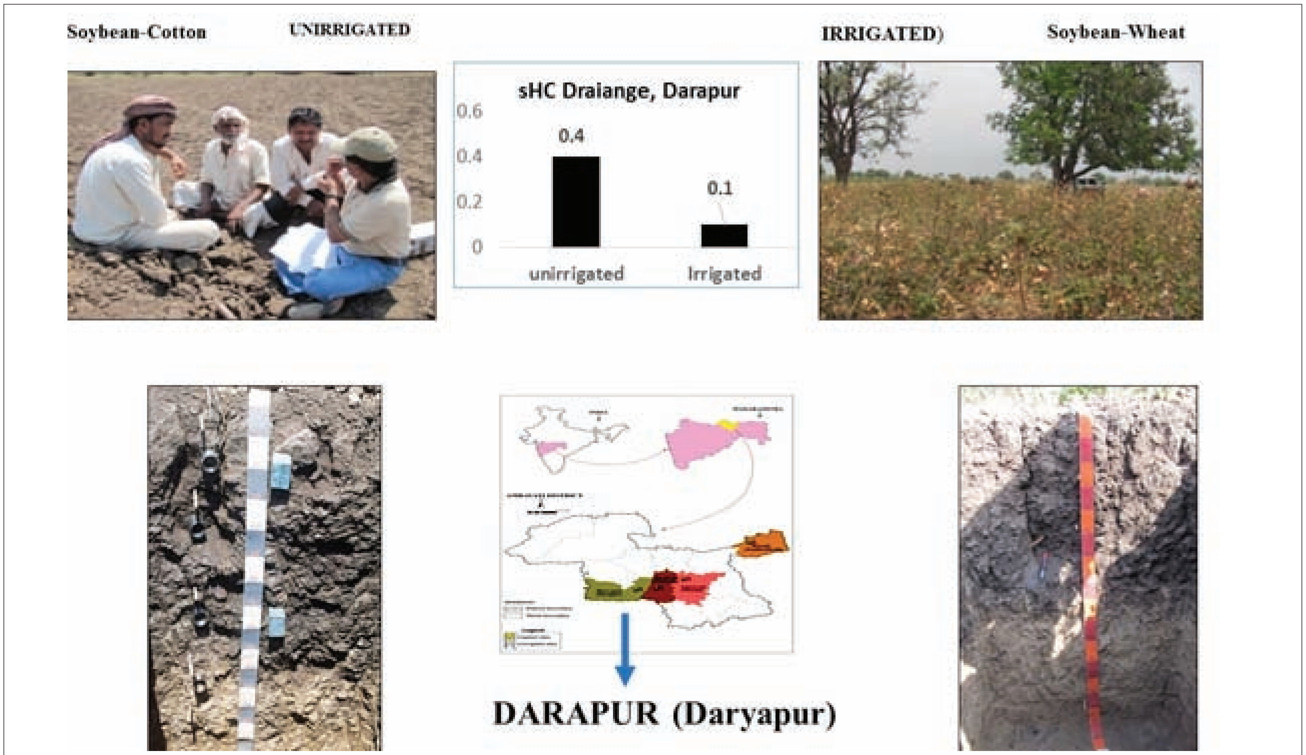

Figure 10. Degradation of soils in Darapur (Daryapur) in Maharashtra due to application of C3S1 class of irrigation water

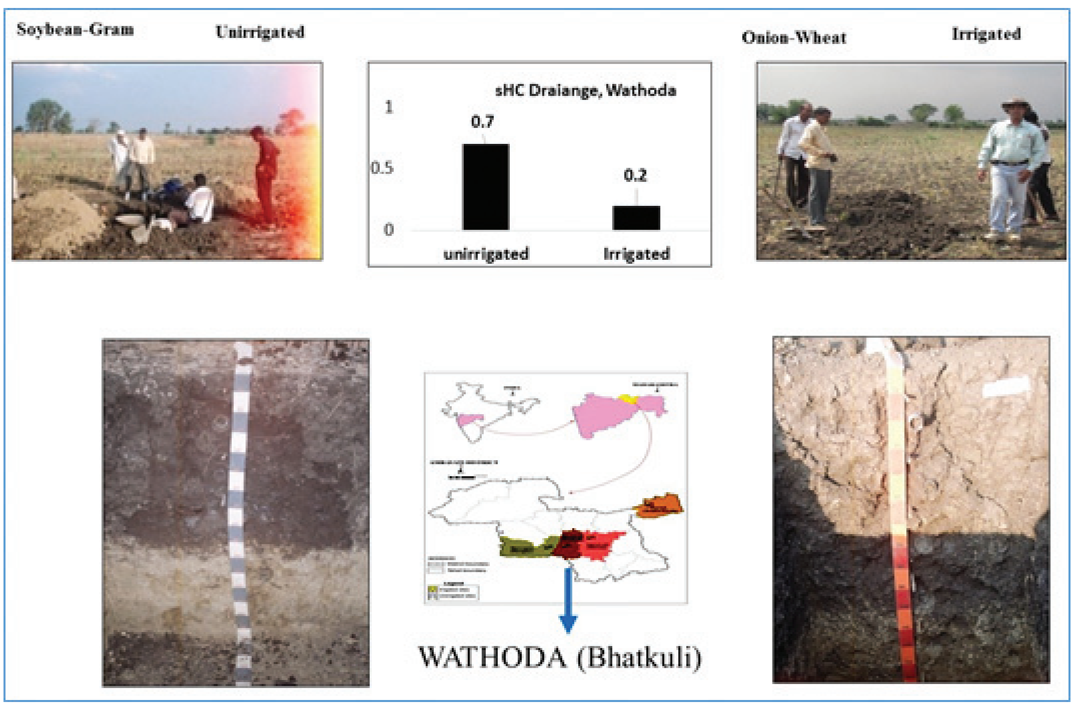

Figure 11. Degradation of soils in Wathoda (Bhatkuli) in Maharashtra due to application of C4S1 class of irrigation water

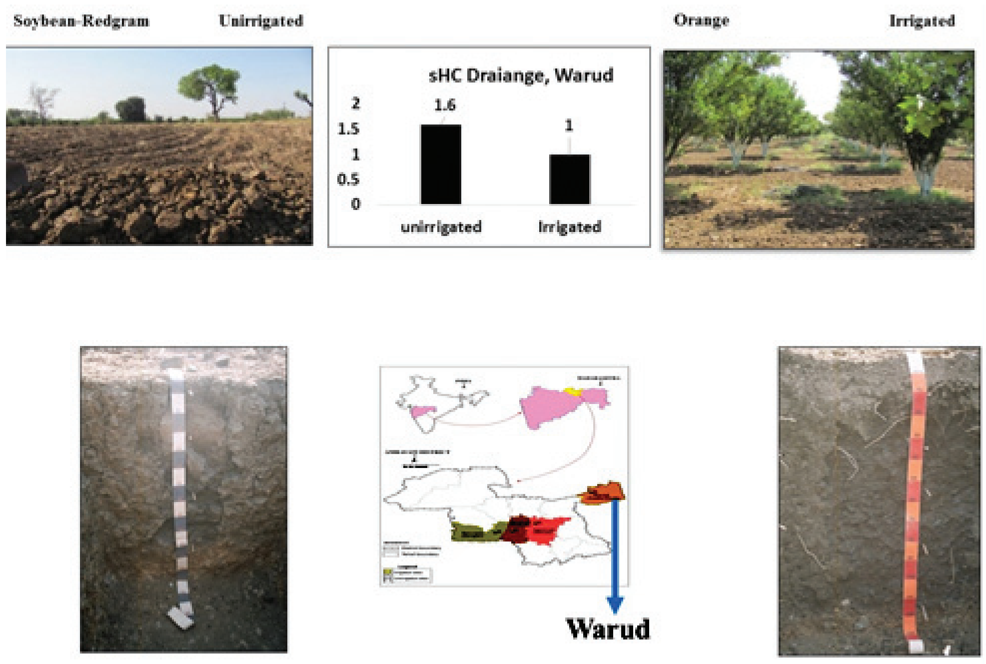

Figure 12. Degradation of soils in Warud, Maharashtra due to application of C3S1 class of irrigation water

Probable Solutions and Land Degradation Neutrality

The land use options to achieve land degradation neutrality are in place as shown above at three different case study areas with varying bioclimatic systems. Horticultural land use options have been a success. It may be mentioned here that the rock-outcrops area in Konkan, Maharashtra is ~3 lakh hectares (Salvi et al., 2009). Similar areas in Maharashtra and India cover 2.12 (including glaciers, sand dunes, mangroves, swamps, salt waste, water bodies, rock lands and outcrops) and 26.46 Mha, respectively (Bhattacharyya et al., 2013,2019). Example of horticultural land use options could be one of the alternatives which the experts of LDN may consider.

Behavioural studies of natural resource like soil and their prediction for future with special reference to climate change have always been a difficult proposition. Such efforts require huge datasets of natural resources including agriculture and allied fields (Bhattacharyya et al., 2016a, 2020a, b)). As shown in the second and third case study of associated red and black soils in SAT (semiarid tropics), resilience was observed when these soils were put to different types of management interventions including chemical and organic inputs (Bhattacharyya et al., 2004). Besides, increased soluble calcium ions in soil solution and in the exchange sites due to continuous dissolution of native calcium carbonate during cropping under improved management practices help in restoring soil quality. Such examples act as models to achieve land degradation neutrality in SAT areas covering nearly 159 Mha in India through upscaling using line departments, government organizations and NGOs. Resilience of soils of SAT suggests that initially degraded soils could be made the vibrant crop production areas to feed the population for another couple of centuries.

There are many other success stories showing excellent examples of land degradation neutrality in India. A few have been shown in this article. The degradation in dry arid areas with desert and coastal sand dunes has been amply demonstrated. Many soil scientists and natural resource managers are hesitant to talk on LDN, even if their research is devoted to land degradation neutrality. Future research should focus to fulfil the target of LDN with an acceptable policy by involving multi-disciplinary experts (**Figure 13**) (Bhattacharyya, 2020a). The contribution of various experts is paramount not only from ecological point of view but also in bringing some areas under agriculture and other allied activities. This will result in not only vertical but also horizontal expansion of areas under agriculture, animal husbandry, fisheries and other non-agricultural sectors. Bringing waste land to harness non-conventional source of energy can be doubly beneficial. Firstly, it will help in using alternate source of energy to reduce carbon footprints, and secondly, shall enable farmers to utilise the generated energy for operating various agricultural implements. Land degradation neutrality (LDN) can thus nullify the ill-effects of global warming or climate change.

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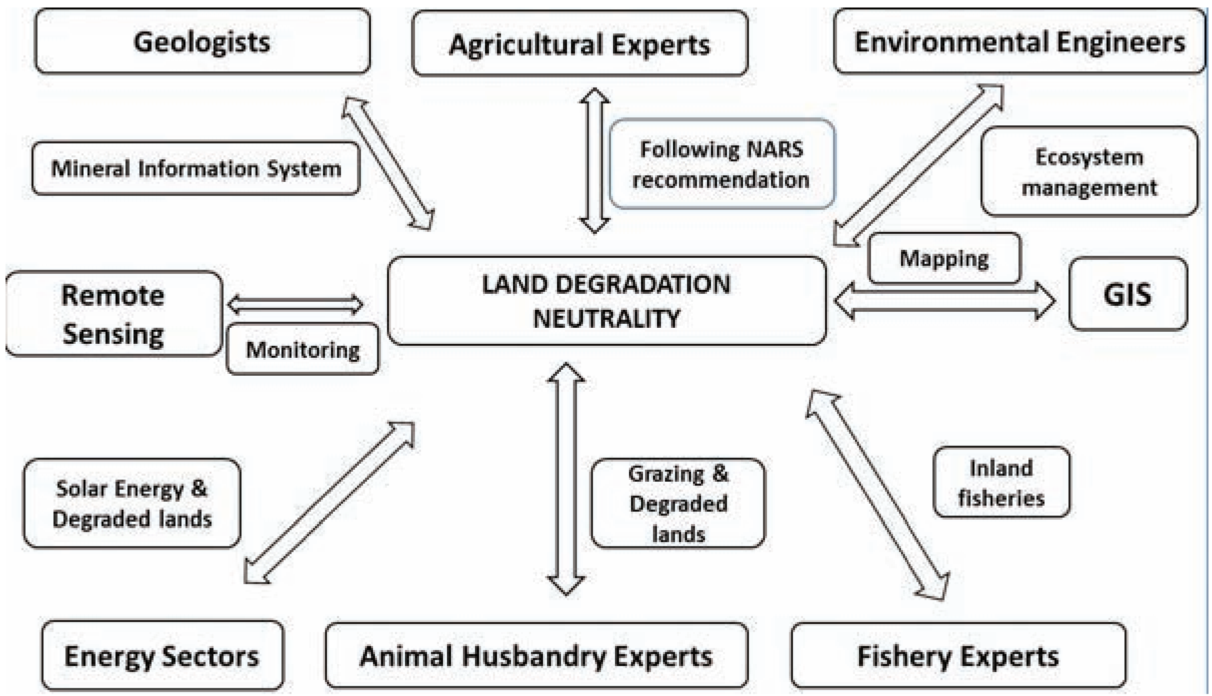

Figure 13. Schematic diagram showing a tentative policy to achieve land degradation neutrality (LDN)

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