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Soil Clay Minerals and Ecosystem Services

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Abstract*—Information system and its utility in ecosystem services is a step ahead of understanding and managing natural resources including soils/soil minerals. Ecosystem services provide a value on diversity in soils, plants, and animals and the way these natural resources perform various functions. It includes a range of services which are essential to our health and well-being of the society, in general, and environment, in particular. Therefore, georeferenced information system with soil/soil mineral shall help students and planners to protect the mother earth.*

I deeply appreciate the honour the Clay Mineral Society of India has done me for delivering the 6th Professor S.K. Mukherjee CMSI Foundation Lecture. Professor Mukherjee's research forte was Soil Science and Physical Chemistry, but he was at ease from Physics to Philosophy and Social Sciences. During the passage of my research efforts, Prof. Mukherjee's contribution influenced me through deliberations made by my teachers and senior colleagues. As a student of soil science, with my little experience in clay mineralogy, as a part of pedology, I have decided to share some of our research findings, as a tribute to this great scientist.

The subject of clay mineralogy has become more incisive with the increased availability of modern technologies like remote sensing and geographical information system, pedometrics, pedo-transfer and taxotransfer rules, and soil & clay mineral database storage and retrieval. Since all the gamutes of agriculture depend directly on soils, and soil is controlled by the clay, as the reactive substrate, it is appropriate to revisit soil and clay mineralogy and their influence on ecosystem services. It is for this reason, I have decided to flag some examples of soil clay minerals and ecosystem services.

Important Ecosystem Services

Clay minerals as an important aspect of pedology is the study of soil/clay minerals in their natural environment. Four important ecosystem services soil minerals in different size fractions provide are i) provisioning services, ii) regulating services, iii) cultural services, and iv) supporting services. The first one include food, raw materials and water retention, while the regulating services are a) climate, b) water regulation, c) carbon sequestration and d) erosion and flood control. The supporting services include i) weathering/ soil formation, and ii) nutrient recycling. And lastly the cultural services include cultural heritage (Figure 1) (Bhattacharyya 2021a).

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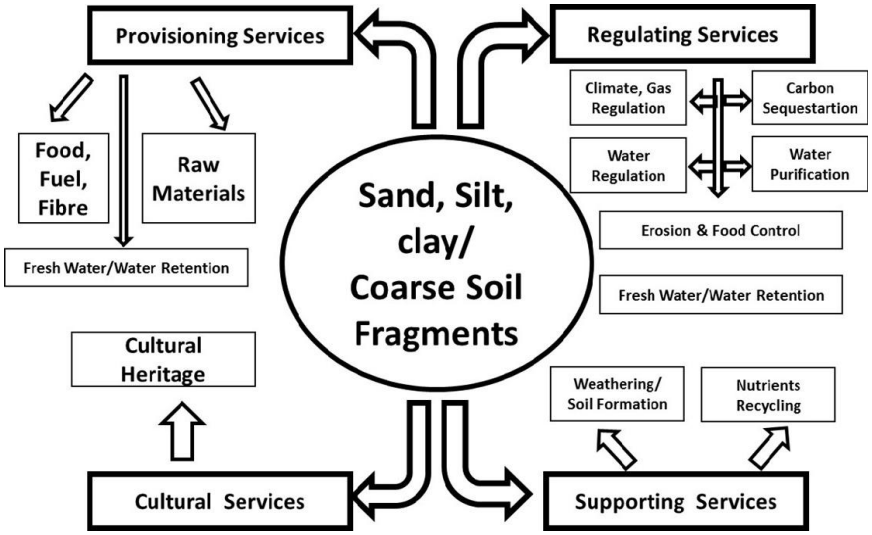

Fig. 1. *Soil/soil minerals provide various ecosystem services*

Soil Diversity and Pedodiversity

India is known as a land of paradoxes because of the diversity of soils and soil minerals (Figures 2, 3). This is due to huge variations in geology (the rocks of various mineral compositions) which is why soil diversity is appreciable in this subcontinent. The variation of climate adds to the variation in soils and their mineral composition. Efforts made to quantify soil diversity in India needs strengthening. Soil diversity is the variation of soils due to various factors which include pedodiversity. Pedodiversity refers to the diversity within the pedo-environment. Pedo-environment varies due to pedogenesis which is again controlled by factors such as parent material, climate, topography and biotic factors. Therefore, pedodiversity is a measure of soil variation and can be considered as a function of soil diversity since the latter shall include edaphology; pedodiversity centres mainly on pedology (Bhattacharyya, 2021b). In India, both soil and pedodiversity and their quantitative approaches are few and far between. Quantified values of pedodiversity can be used to preserve, or even reconstruct the history of soil formation. Just as biologists argue that organisms need to be maintained, soil scientists opined that conservation of soils would maintain organisms as well as other unique soil materials for posterity to maintain biodiversity and ecological balance. This suggests a close relation between pedodiversity and biodiversity as shown by the diversity index estimation (Shannon index) using biological data and soil groups. Pedodiversity, indirectly through basic pedological studies (Bhattacharyya 2021b), helps in understanding soil degradation. The quantified value of pedodiversity may help to comprehend the influence of soil forming factors in a country, districts and blocks.

Soil/Mineral Information System

The first step towards providing ecosystem services is perhaps to have more knowledge about the ecosystem. Fortunately soil and soil clay minerals' information system are available. The available soil information system, as well as clay mineral information system, developed from the geographic soil information system, however, are open for revision, and expansion depending on the scale of use (Bhattacharyya, 2021a, b). The spatial aspects, and dynamics, of soil properties to ecosystem services, are studied, through mapping or scenario modeling of future changes. Where soil/clay mineral information, is missing, pedotransfer functions or mapping, and modelling

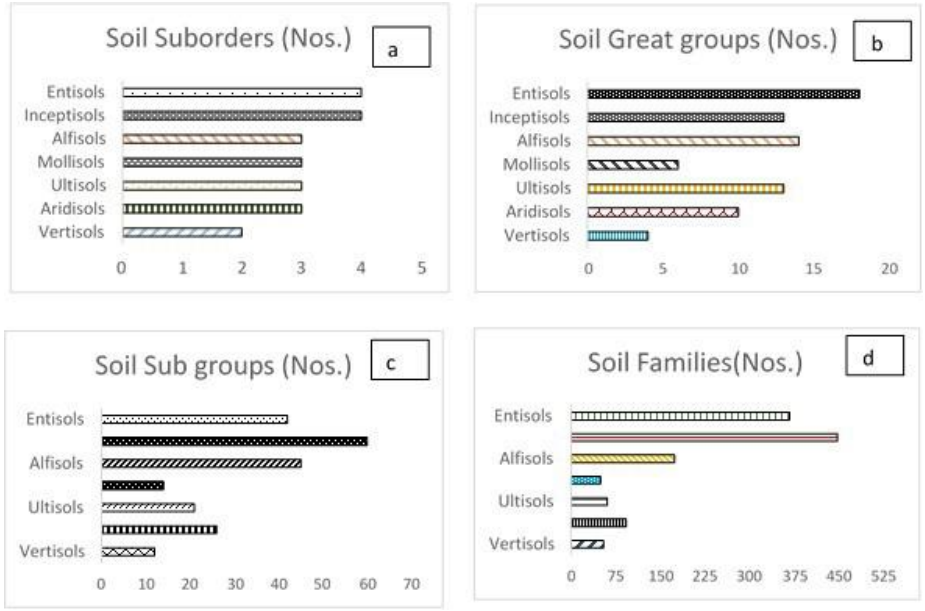

Fig. 2. *Soil Diversity as evidenced by the occurrence of sub-orders (**a**), great groups (**b**), subgroups (**c**) and families (**d**) in various soil orders identified in India (Source: Bhattacharyya, 2021a)*

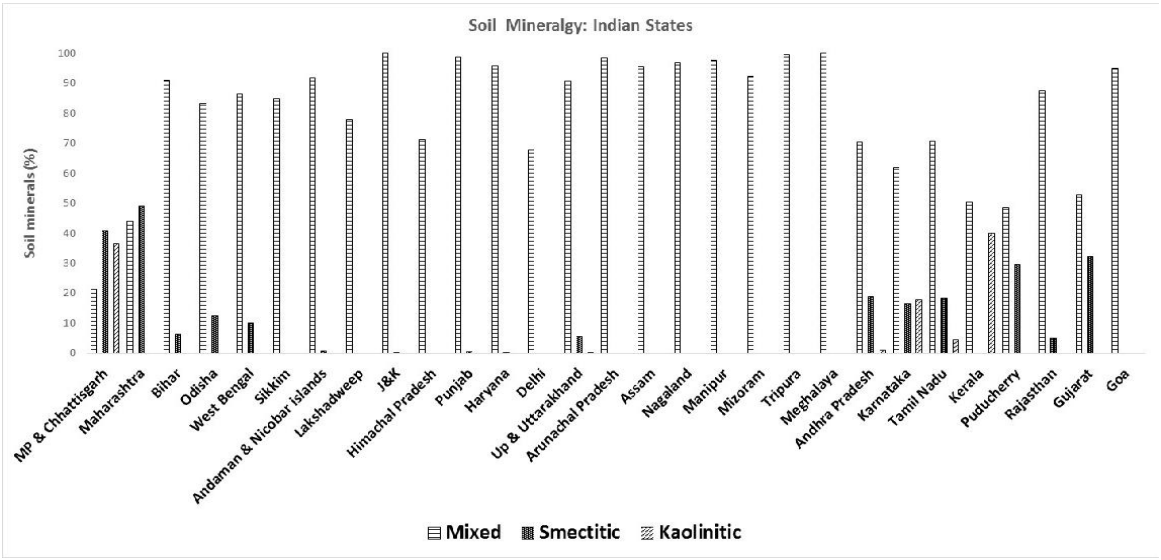

Fig. 3. *Variation of soil minerals in clay fractions in soils of the Indian states (Source: Bhattacharyya, 2021a)(values in % in soil control sections)*

exercises may act as a proxy. Ecosystem services, deal with spatial aspects and mapping of resources. Mineral information system in India, other than soil clay mineral,say, zeolites, palygorskite, carbonates and gypsum in soils need a special mention. Taxonomic database, helped to classify, Indian soils *albeit* state wise, to develop, a tentative mineralogy map. At the field level, many soils were wrongly grouped, as mixed mineralogy class which were revised using research data. Both soil clay minerals and other minerals in different size fractions influence ecosystem services in terms of providing foods and fibres, and controlling soil/land degradation (Bhattacharyya, 2021a, b).

Ecosystem Services and Land Degradation

While making an inventory on the degraded land, land degradation neutrality (LDN) appears an important aspect. The LDN is achieved, if new degradation is balanced, by reversal of degradation, elsewhere, in the same land type, LDN may be achieved by restoration or rehabilitation. The recently held meeting during September 2020 in India in the United Nations Convention to Combat Desertification, discussed land degradation. In the fourteenth meeting of the Conference of the Parties (COP14), India has promised to bring many areas under LDN. Three case studies, namely Konkan laterites and horticultural planning, Vertisols and semi-arid tropics to predict the soils of tomorrow, and the quality of irrigation water *vis-à-vis* chemical degradation of soils were reported as success stories towards LDN since both are related to soil minerals (Bhattacharyya, 2020). Knowledge of geology and soil minerals can, therefore, help in LDN, which, reaffirms the role of mineralogist in ecosystem services, to combat desertification (Bhattacharyya, 2021a, b).

Ecosystem Services and Land Use

The soil clays are also linked with land use options. The most important aspect is that minerals like gypsum and zeolites can maintain soil and biodiversity. The efforts to measure soil and pedo diversity can pave the way to quantify soil mineral diversity which can more precisely help commenting on soil microbial diversity. Soil/ clay minerals, have a role to play in understanding climate change signature, so far as, regulation of climate is concerned. Research data indicate that both di-, and trioctahedral smectites can be useful evidence for climate change. In the Western Ghats, as well as, the red soils, in the southern peninsula, smectite-kaolinite interstratified minerals, are ephemeral, and, therefore, carries signature of climate change. Soils can memorize, past events through soil minerals and, therefore, soil/minerals and cultural heritage are interlinked. Other than minerals, remnants of mineral parts known as bioliths (example, diatoms), could be an interesting areas of study to comment on the age of soils, and the past climate (Bhattacharyya, 2020, 2021a, b).

Ecosystem Services and other disciplines

Soil scientists and soil mineralogists, tentative, to use the term 'ecosystem services' even if their research is devoted to linking soils/ minerals these aspects. Future soil/mineral ecosystem services' research should focus on exploring soil functional diversity of soil biota and the spatial aspects of soil/mineral properties at the lower level of ecosystem services (e.g., water purification, and climate regulation). Soil scientists and mineralogists should engage professionals from other disciplines to promote the contribution of soils to ecosystem services delivery and human well-being. Soil/mineral ecosystem service studies, could be used, in local and national policy development, and in the programmes on natural resource use and management. Little more aggressive, yet, positive attitude, towards what's happening, in the other parts of the globe shall bring the soil and clay mineral scientists, together to show, that they can also contribute to address the global problem.

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