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Rishabh Pawar

M.Sc. Scholar, Department of Soil Science and Water Management, COHF Neri, Hamirpur, Dr. YSP UHF Nauni, Solan, Himachal Pradesh, India

Rakesh Sharma

Scientist, Department of Soil Science and Water Management, COHF Neri, Hamirpur, Dr. YSP UHF Nauni, Solan, Himachal Pradesh, India

Anil Kumar

Scientist, Department of Soil Science and Water Management, COHF Neri, Hamirpur, Dr. YSP UHF Nauni, Solan, Himachal Pradesh, India

Swapana Sepehya

Assistant Professor, Department of Soil Science and Water Management, COHF Neri, Hamirpur, Dr. YSP UHF Nauni, Solan, Himachal Pradesh, India

Corresponding Author:**Rishabh Pawar**

M.Sc. Scholar, Department of Soil Science and Water Management, COHF Neri, Hamirpur, Dr. YSP UHF Nauni, Solan, Himachal Pradesh, India

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Impact of land use change on soil erosion, sedimentation and soil microbiome

Rishabh Pawar, Rakesh Sharma, Anil Kumar and Swapana Sepehya

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Abstract

Land holds a central position in human existence and development. Since their appearance on earth, humans have used land and its resources to meet their material, social and cultural needs. Land use change is necessary and essential for development and social progress as it has broad lines of impact, with a potential for influencing economic growth, quality of life, management of environmental resources and national food supply. The unmanageable use of land is the main reason for destruction of our environment. Land management and the related land use changes have an effect on the spatial patterns and magnitude of accelerated soil erosion, which can affect land productivity, food security, soil microbial diversity and sedimentation rate. There is a serious lack of knowledge concern on how land use change affects soil erosion, sedimentation and soil microbiome. Therefore, a proper knowledge of relationship of these aspects would provide crucial information for planning conservation strategies.

Keywords: Land use change, soil erosion, sedimentation, soil microbiome, economic growth

Introduction

Land is a non-renewable finite resource that supports all primary production systems as well as basic social requirements such as infrastructure, transport, industries etc. Given the finite supply of land resource, sustainable use and management of land resources is a necessity for the well-being of people of a country (Rathee, 2014) [1]. Land use change has thus, aroused the increasing attention of scientists worldwide. During the last three centuries in the world nearly 1.2 million km² of forests and woodlands, 5.6 million km² of grasslands and pastures have been converted into other types of land use and the cropland has increased sharply to twelve million km² during the same time span (Ramankutty and Foley, 1999) [2]. Land used for crops and ranching expanded at the cost of forests and natural grasslands (Goldewijk and Ramankutty, 2002) [3]. A country's socioeconomic priorities at any given time shape the drivers of the land-use change. The ever-increasing population has resulted in gradual decrease in per capita availability of land, besides affecting it adversely making it unproductive day by day. The direction and scale of these changes that have come about because of refreshed urbanization focus in country's development strategy. With rising rate of urbanization, more changes in land-use are taking place to supplement evolving demands and expectations. India, as a developing country, is pushing its industrial and service sector to create favourable conditions for production and consumption of goods and services that in turn is altering the land use patterns substantially. It is widely recognized that study of land use change phenomena at local, regional and global levels is crucial for understanding the negative impacts on environment, which include impact on soil erosion, sedimentation, soil microbial diversity etc. Thus, for the sustainable development of an area, regular monitoring of land use changes is essential. Hence, the proper understanding of the influence of the various human induced land use practices with regard to the environmental change is essential as it helps to simulate the changes and develop effective policies for land management.

Land, Land use and land use changes

Land may be defined as a place on which all human activity is being conducted. FAO defines land as a "delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and

swamps), the near-surface sedimentary layers and associated groundwater and geohydrological reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity (terracing, water storage or drainage structures, roads, buildings, etc.)". Use of land resources by the people gives rise to — "land use" which varies with the purposes it serves, whether they be food production, provision of shelter, recreation, extraction, processing of materials and the bio-physical characteristics of land itself. Hence, land use is being shaped under the influence of two broad sets of forces – human needs and environmental features and processes. Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures etc. It also has been defined as the total of arrangements, activities, and inputs that people undertake in a certain land cover type. Land cover is the biophysical state of the earth's surface differences so that they are used properly in studies of land and immediate subsurface (Turner *et al.* 1995) ^[4]. It describes the physical state of the land surface i.e., cropland, mountains or forests (Meyer, 1995) ^[5]. Land use changes refers to the conversion and modification of land based on human and socio-economic priorities at a given time. Directorate of Economics and Statistics, Ministry of Agriculture, Government of India classifies land-use under nine categories, which are as follows:

- 1. Forests:** This includes all land classified either as forest under any legal enactment or administered as forest, whether state-owned or private, whether wooded or maintained as potential forestland. The area crops raised in the forest and grazing lands or areas open for grazing within the forests remain included under the "forest area".
- 2. Area under nonagricultural uses:** Land under settlements (rural and urban), infrastructure (roads, canals etc.), industries, shops etc. are included in this category. An expansion in the secondary and tertiary activities would lead to an increase in this category of land-use.
- 3. Barren and wastelands:** The land that may be classified as a wasteland are barren hilly terrains, desert lands and ravines. This includes all land covered by mountains, deserts, etc. and land that cannot be brought under cultivation except at an exorbitant cost whether such land is in isolated blocks or within cultivated holdings, etc. It normally cannot be brought under cultivation with the available technology.
- 4. Permanent pastures and grazing lands:** This includes all grazing land whether it is permanent pasture/meadows or not. The commons of the village is included under this category. Most of this type land is owned by the village 'Panchayat' or the Government. Only a small proportion of this land is privately owned.
- 5. Area under miscellaneous tree crops and groves:** This includes all cultivable land that is not included in 'net area sown' but is put to some agricultural use. Land under thatching grasses, bamboo bushes and other groves for fuel etc., which are not included under "orchards", are classified under this category.
- 6. Culturable wasteland:** This includes land available for cultivation, whether taken up or not taken up for cultivation once, but not cultivated during last five years or more in succession including the current year for some reasons. It can be brought under cultivation after improving it through reclamation practices.

- 7. Current fallow:** This represents cropped area, which is kept during the current year. This is the land which is left without cultivation for one or less than one agricultural year.
- 8. Fallow other than current fallow:** This is also a cultivable land which is left uncultivated for a period of not less than one year and not more than five years. If the land is left uncultivated for more than five years, it would be categorized as culturable wasteland.
- 9. Net area sown:** The physical extent of land on which crops are sown and harvested is known as net sown area. This represents the total area sown with crops and orchards. Area sown more than once in the same year is counted only once.

An insight to Table 1. shows the land use pattern of the country with reference to the above nine categories during 2017-2018.

Table 1: Land use pattern of India (2017-2018)

Land Use	Area (in'000ha)	Percentage
Total geographical area	328.73	-
Reporting area for land utilization	304.88	100
Forests	68.75	22.55
Not available for cultivation	41.54	13.63
Permanent pastures and other grazing lands	11.04	3.62
Land under misc. tree crops and groves	3.57	1.17
Culturable wasteland	13.94	4.57
Fallow lands other than current fallows	9.89	3.25
Current fallows	13.32	4.37
Net area sown	142.82	46.84

Source: Directorate of Economics and Statistics, Ministry of Agriculture, Government of India ^[6]

Changing land use pattern over the years

Land-use in a region, to a large extent, is influenced by the nature of economic activities carried out in the region. However, economic activities change over time, land, like many other natural resources, is fixed in terms of its area. India has undergone major changes within the economy over the past four or five decades and this has influenced the land-use changes in the country. The changes in land use from 1960-61 to 2014-15 have been given in table 2. An insight of the data reveal that some categories have undergone increase while some have registered decline. Share of area under forest, area under non agricultural uses, net sown area and current fallow lands have shown an increase over 50 years. The rate of increase is highest in case of area under non-agricultural uses. This is due to the changing structure of Indian economy, which is increasingly depending on the contribution from industrial and services sectors and expansion of related infrastructural facilities. Also, an expansion of area under both urban and rural settlements has added to the increase. Thus, the area under non-agricultural uses is increasing at the expense of wastelands and agricultural land. The increase in the share under forest can be accounted for an increase in the demarcated area under forest rather than actual increase in the forest cover in the country. The trend of current fallow fluctuates a great deal over years, depending on the variability of rainfall and cropping cycles. The categories that have registered a decline are barren and wasteland, culturable wasteland, area under pastures and tree crops. As the pressure on land increased, both from the agricultural and non agricultural sectors, the wastelands and

culturable wastelands have witnessed decline over time. The decline in land under pastures and grazing lands can be explained by pressure from agricultural land. Illegal encroachment due to expansion of cultivation on common pasture lands is largely responsible for this decline.

Table 2: Changing land use pattern in India from 1960-61 to 2014-2015

Classification	Land in million hectares			
	1960-1961	1980-1981	2000-2001	2014-2015
Reporting area for land use	298.46	304.16	305.19	307.82
Net sown area	133.20	140.29	141.34	140.13
Forest	54.05	67.46	69.84	71.79
Not available for cultivation	50.75	39.55	41.23	43.88
Barren and uncultivable	35.91	19.96	17.48	17
Pasture and grazing land	13.97	11.99	10.66	10.39
Fallow other than current fallow	11.18	9.72	10.27	11.09
Area under non agriculture uses	14.84	19.60	23.75	26.88
Current fallow	11.64	14.83	14.78	15.09
Cultivable wasteland	19.21	16.74	13.63	12.47

Source: <http://wdi.worldbank.org>, 2015 [7]

Factors influencing land-use changes

Land use changes are influenced by a variety of factors operating on more than one spatial and temporal level and acting not in isolation but in intricate webs of place and time-specific relationships. Land-use change occurs initially at the level of individual land parcels when land managers decide that a change towards another land-use/land-utilization type is desirable. Aggregately, individual land-use decisions produce land-use/cover changes at higher spatial levels. Land managers respond, however, mostly to internal and external influences on the land-management unit, and their decisions are influenced by their personal traits and local environmental conditions as well as by the immediate and broader environmental, socio-economic, institutional, and political settings within which the land unit is embedded (Briassoulis, 2009) [8].

Major drivers of land use changes

As a result of increasing population pressure and economic development in terms of urbanization and industrialization and conversion of various land for agricultural purposes leads to overexploitation of land resources which leads to land degradation. Land degradation is the result of immense population pressure that leads to improper land use without

proper management practices. In recent decades, substantial land use changes have been observed as a result of population growth and economic development. The major driving forces related to land use changes, which have significant effects on the increase in the rate of land use changes are as follows:

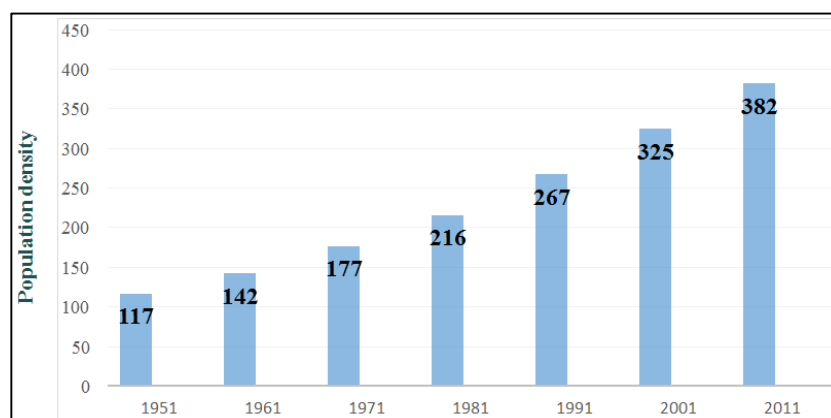
Increasing population: The rapid increase of human population is putting extra ordinary pressure on land. The rapid growth of population leads to the depletion of natural resources, disposal of harmful waste in to environment and changing land use patterns. Overpopulation, consumption, overuse, wastage and misuse of resources have strained the earth's carrying capacity (Garg, 2017) [9]. This is also having serious impacts on the resource base of the region. With the rapid growth in the world's population, many societies have been demanding more from the earth's resources and affecting its land surface at ever-increasing rates. The demands that put pressure on our environment also alter the future of sustainability on earth. As per data of population reference bureau depicted in table 3, the world population has increased tremendously all across the globe in the last decades, which is still increasing and expected to reach nearly 9 billion by mid-2035. More of this growth will take place in the developing countries (United Nations, Department of Economic and Social Affairs, Population Division (2015) [10].

Table 3: World Population Change in last few decades

Major Areas	Population (Millions)					
	1950	1975	2005	2011	Mid-2019	Mid-2035
World	2519	4074	6465	6987	7,691	8,932
More Developed Regions	813	1047	1211	1242	1,269	1,313
Less Developed Regions	1707	3027	5253	5745	6,423	7,620
Africa	224	416	906	1051	1,305	1,885
Asia	1396	2395	3905	4216	4,587	5,112
Europe	547	676	728	740	746	745
Latin America and the Caribbean	167	322	561	596	645	730
Oceania	13	21	33	37	42	53

Source: World Population Data Sheet, 2019 [11]

In India, increase in population size due to unplanned activities, which leads to urbanization that reduces the agricultural land. As per Indian census during 2011, the population of country is 1,210,193,422 (Provisional Census, 2011) [12]. The Indian population increased with a decadal growth of 17.64%. Moreover, the density of Indian population has increased from 325 persons per square kilometers in 2001 to 382 persons/square kilometers in 2011 (fig.1).

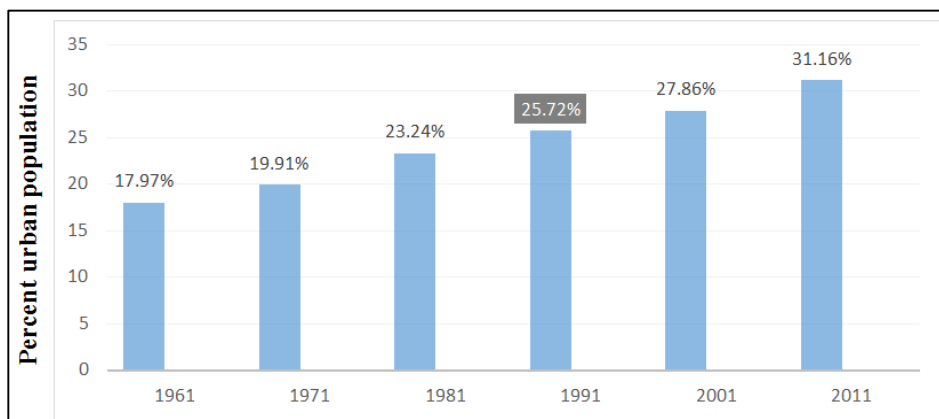


Source: Census of India, 2011

Fig 1: Population density of India over the years

a) Urbanisation: Urbanization is the method of urban areas growth, which result in population growth, increase of built-up area, high density of population and it also psychological stage of urban way of life. The rapid urbanization has led to extensive land use change particularly in developing countries. Uncontrolled momentum of urbanization and land use/ land cover change raises many issues which might have both positive and negative impacts like unauthorized urban sprawl, loss of agricultural land, high land values and other

related problems. Urbanization takes places in two different ways, either in radial direction around a well-established city or along the highways. This kind of dispersed development is called urban sprawl. A wide section of people lives along the margin of urban cities, towns and residential areas. According to population reference bureau, by the year 2030, nearly 60% of the population will live in urban areas and most of them will be in developed countries. Fig 2 shows the increasing rate of urbanization over the past years in our country.

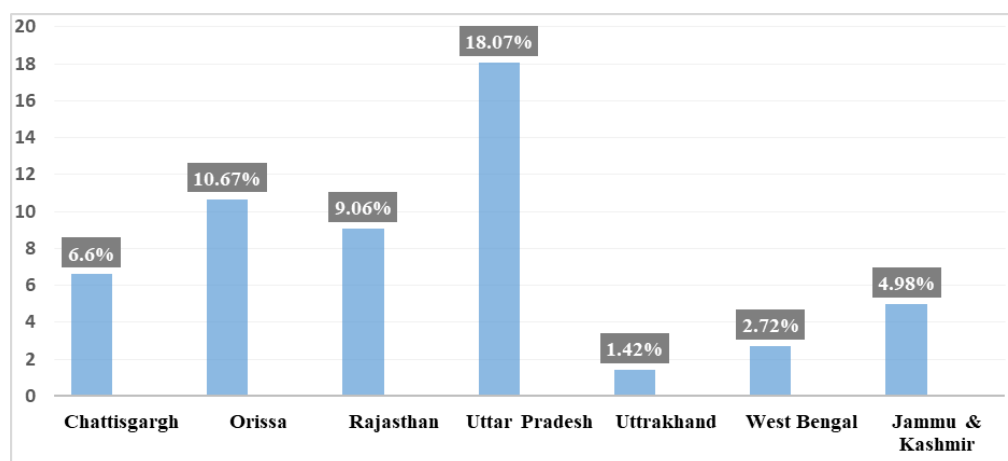


Source: Census of India, various years

Fig 2: Percent urban population of India over the years

b) Industrialization: Industrialization is the period of social and economic change that transform an agrarian society into industrial society. Rapid industrialization have significantly changed the land use pattern, specially the change of agricultural lands. Dramatic increase in population boosted the need for food and fodder production. The transition has been marked by conversion of agricultural land into land earmarked for industrial projects and urban real estate development (Ghatak and Mookherjee, 2013) [13]. The rapid population growth accompanied by expansion of industrial activities have been aggravating resource depletion and alter the land use pattern. Mining of minerals sites displays such

kind of problem in land use. Sometimes, useful land areas become wastelands due to mining and industrial activities. As the top layers of the soil become harder to use site for other purposes, so that the land become barren land. Mining process increase as the demand increases which in turn increases wasted or infertile land. In this type of situation, an interaction of natural processes and human activities cause the land not to properly sustain its ecosystem services. Dumping of mine wastes and tailings and release of effluents over adjacent areas create a land unsuitable for any purpose. An overview of the percent industrial wastelands of the various states of the country due to various industrial activities is shown in fig 3.



Source: Wasteland Atlas of India, 2010 [14]

Fig 3: Industrial wastelands of India

c) Deforestation: The term deforestation means the sum total of activities that contribute to the removal of vegetative cover in the forest by the anthropogenic activities. More than half of the Earth's original forest is gone, cleared for pasture, timber, fuel wood and farming (Emmanuel, 2017) [15]. Deforestation lead to conversion of closed forests into more open ecosystems favorable to grazing involve conversion of forest

land to agriculture land or urban use. It also embraces all other activities that cause temporal removal of forest cover such as slashing and burning technique, shifting cultivation, and clear cutting. Indiscriminate exploitation of forest has generally resulted in a decline in soil nutrient contents. Often, critical limits are exceeded causing irreversible damage to the forest. Without the regenerative function and protecting

influences of trees and their root systems on land, heavy rains on the cleared lands cause erosion to erode the land, thereby causing loss of nutrients to the soil, degrade forest and produce devastating erosion and flooding which destroy highways, dams, bridges, settlements and farmlands (Adetunberu, 2000) ^[16]. Deforestation lead to problems like soil erosion, loss of biodiversity and change in land use pattern. Deforestation has also led to both socio-economic and environmental degradation problems. That is why there is need to manage the forest properly in order for it to perform its function efficiently. Beyond this there is need to indoctrinate the concept of sustainable forest development in order to preserve our forest for the future generation.

Impacts of land use change on soil erosion:

Soil erosion is described as detachment and removal of surface particles from soil as a result of wind or rainfall. Human activity and related land use change are the primary cause of accelerated soil erosion, which has substantial implications for nutrient and carbon cycling, land productivity and in turn, worldwide socio-economic conditions. The FAO led Global Soil Partnership reported that 75 billion tonnes (Pg) of soil are eroded every year from arable lands worldwide, which equates to an estimated financial loss of US \$400 billion per year. Soil type, soil moisture content and underlying geology are pivotal in determining susceptibility (Russell *et al.* 2001) ^[17]. Carling *et al.* (2001) ^[18] stated that "the vulnerability of soils to erosion depends not only on such factors as climate, topography and soil characteristics, but also on the type and intensity of land use". Water is a particularly dominant transport agent. A protective vegetative cover can decrease erosion rates by lowering the water table, reducing surface water velocity and intercepting raindrop impact. Changes in land use or land management can cause increment in soil erosion. Converting forest lands to open lands through the various land uses like industrial, residential, agricultural and transportation land uses resulted in accelerated soil erosion which leads to loss of soil nutrients originally present in the soil. Among different land uses the soil erodibility indices are in the order of barren > cultivated > grassland > forest (Singh and Khera, 2008) ^[19]. The substitution of forests for cropland is responsible for about 52% of this increase in soil loss (Borrelli *et al.*, 2017) ^[20].

Impact of land use changes on sedimentation:

Erosional processes have a profound effect on the way in which land uses contribute to sedimentation. Land-ocean transfer of sediment by rivers is a key pathway for material transfer on Earth. Rapidly increasing rates of sediment transport from the land into coastal systems via fluvial networks (streams and rivers) is a global phenomenon, which has been increasing in magnitude since the advent of permanent agricultural practice. The processes of sediment erosion and delivery have pronounced effects on the earth's surface and the well-being of its inhabitants. The transport of eroded sediment into deposition zones leads to sedimentation, which is problematic for aquatic systems. Benthic organisms and fish are suffocated by mud layers being laid down on the sea bed and delicate gills and mouthparts of fauna are damaged by sediment remaining in suspension (Niyogi *et al.* 2007) ^[21]. Land use changes could alter substantially the sediment delivery and water discharge of a catchment, influence the geomorphological processes within the river bed, and sometimes induce non-desirable processes for river management (Kondolf *et al.*, 2002) ^[22]. The rate of

sediment accumulation in water bodies is an increasingly important issue world-wide, and has been attributed to changes in land use, in particular the removal of forest cover to make way for agricultural land. Impermeable urban surfaces will also decrease sediment erosion due to a lack of ground infiltration; however they may result in larger peak discharges (Nelson and Booth, 2002) ^[23]. It has been identified that agricultural and quarrying land uses land use is producing the greatest amount of sediment. In contrast to agricultural and forested and urban catchments are producing the smallest quantity of sediment (Giejsztowt *et al.* 2010) ^[24]. This is possibly due to the effects of livestock induced soil compaction and the loss of vegetation diversity, which reduces soil cohesion and exposes soils to erosion by wind and rain. Contemporary data on the sediment loads of rivers provide clear evidence of significant recent changes in the sediment fluxes of several rivers in response to human impact. The key drivers of increased sediment loads include land clearance for agriculture and other facets of land surface disturbance, including logging activity and mining. Although, programmes for soil conservation and sediment control can result in reduced sediment loads, the trapping of sediment by dams represents the dominant cause of reduced loads. This influence is currently assuming increasing importance at the global scale. Any attempt to link these drivers to changes in the global land-ocean sediment flux must take account of the aggregation and buffering effects that operate in larger basins, which can cause damping and even removal of signals of increasing flux within the upstream basin, and complicate the link between upstream and downstream response to human impact.

Impact of land use change on soil microbiome

Land use is characterized by the arrangements, activities and inputs that people undertake in a certain land cover type to produce change or influencing biological transformations in the rooting zone (Nisar and Lone, 2013) ^[25]. Diverse microbial communities are supported by soil that plays an important role in ecosystem level processes such as, decomposition of organic matter and nutrient cycling. One cubic meter of soil may house many hundreds of species of bacteria, actinomycetes, fungi, and algae. The richness, abundance and activity of the microbial community is vulnerable to influence by soil physical and chemical properties such as pH, moisture, organic matter content, and nutrient availability. Alterations in the physical and chemical nature of the soil may lead to change in soil microbial community, composition, number and changes in microbial function (Bello *et al.*, 2013) ^[26]. Land use systems such as forestry, pasture, cultivated land etc., provide stability and sustainability to the farming system. It affects soil properties, overall soil health and the distribution supply of soil nutrients by directly altering biological transformations in the rooting zone. The conversion of Forest Reserve to other land uses in recent times has caused many complex changes in the forest ecosystem whose impact raises diverse ecological problems (Awotoye *et al.*, 2013) ^[27]. The conversion of forests into agriculture land have negative impacts on soil and diversely affects soil carbon and nitrogen levels (Michel *et al.*, 2010) ^[28]. The highest microbial count was found in forest soils and lowest in agriculture soils, probably because of presence of larger carbon source in the form of organic matter present in the forest soils as compared to other land use systems (Wani *et al.*, 2018) ^[29].

Conclusions

Wastelands are the main land use category responsible for enhanced soil erosion and sedimentation and reduced microbiome. Land uses having more vegetative coverage helps in controlling soil erosion vis-à-vis sedimentation and improves the soil microbiome. Human activities such as deforestation significantly increase runoff generation and sedimentation production, which in turn increases the potential for land degradation. Consequently, careful grazing management must be accompanied as a means to improve rangeland productivity. Therefore, keeping suitable vegetative cover should be considered for soil and water conservation in forests and rangeland. It is thus imperative on the part of policy makers to keep such precious and finite resources in healthy conditions to ensure basic ecological services unhindered, socio-economic and political security unquestioned and resilience to climate change unchallenged. It is in this background, a robust information on land use changes assumes utmost significance for devising strategies to bring back such wastelands into the productive folds once again.

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