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Impact of Land Use on the Soil Quality of Kuttanad Region, Kerala

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ABSTRACT: Changes in land use and improper soil management have led to severe land degradation around the globe through the modification of soil physicochemical and biological processes. This study aimed to assess the soil properties of different land use system types. Soil samples (0-15 cm depth) were collected from three land uses Paddy field, Settlement with Mixed Trees (SMT), and urban area, and analysed for physical parameters like Bulk density, Particle density, Porosity, Water Holding Capacity, Electrical Conductivity (EC) and chemical parameters like soil pH, Soil Organic Carbon (SOC), Cation Exchange Capacity (CEC), Phosphorous, Potassium, and Magnesium. Soil pH was 6.32 in urban, 5.25 in SMT and 3.80 in Paddy indicating that the surface soil was acidic. The SOC is low in SMT (5.25), Urban (3.06), and paddy (6.006) indicating declining soil fertility in SMT and Urban areas. The high level of phosphorous in SMT (37.38 Kg/ha) and Urban (25.984 Kg/ha) also shows the discharge of effluents in these land uses. The findings demonstrated that significant effect of land use change on soil nutrient status and organic matter. Findings also that land use change deteriorated native soil and physicochemical and biological properties.

Keywords: Soil Nutrient, Physicochemical, Biological, Land Degradation, Land Use.

INTRODUCTION

Land-use change is one of the prime causes of several environmental problems like global warming and climate change, surface, and groundwater quality issues, and land and soil degradation. The present study concentrates on the issue of soil degradation. Kuttanad is a wetland situated below mean sea levels in the state of Kerala. It is a vast flood plain jointly created by the depositional work of four rivers namely Pampa, Manimala, Achankovil, and Meenachil. Since it is a flood plain, it is highly fertile. Traditionally this region is a rice-growing tract and, thus, it is called ‘the Rice Bowl of Kerala’. Besides paddy, the region has vast expanses of the waterbody that includes rivers, estuaries, kayals, and backwaters. With an increase in population and the expansion of their settlements, the areas of paddy and waterbody began to shrink and it reached a critical level. Presently, the settlement with mixed trees (SMT) and built-up lands/construction lands are expanding in this region. This type of land-use change, that is, from paddy fields/waterbody to SMT/built-up land may have serious environmental effects. It may have impacts on soil and surface water quality (Kumar, 2005; An *et al*., 2006; Chen *et al*., 2006; Ayoubi *et al*., 2011). Thus, it is essential to analyse the process and pattern of land-use change and its impact on the soil of the Kuttanad region. It is in this respect that the present study was accomplished.

MATERIALS AND METHODS

Study Area

Kuttanad region extends between north latitudes 9° 14’ 58” and 9° 47’ 14” and east longitudes 76° 20’ 26” and 76° 36’ 39” and comprises the area of 42 panchayats spread over Alappuzha, 27 panchayats in Kottayam and 7 panchayats in Pathanamthitta districts (Fig. 1). The total geographical area of the region is 1136 sq. Km. comprising wetlands, dry garden lands, and backwaters. Kuttanad is bordered by Kaduthuruthy – Vaikom road in the north, Kaduthuruthy – Kottayam – MavSelikkara railway line in the east, Mavelikkara – Haripad – Thottappally road in the south and Thottappally – Alappuzha – Thanneermukkom road in the west. The rivers Manimala, Meenachil, Pampa, and Achenkovil, along with their distributaries crisscross Kuttanad wetlands. The organic matter transported from high ranges makes Kuttanad a unique ecosystem in the world. Kuttanad wetland comprises marine, estuarine and fluvial systems.

Soil samples were collected from various landuses namely paddy, SMT (settlement with mixed trees), and urban environment. These collected soil samples (5 samples from paddy, 8 samples from SMT, and 5 samples from the Urban environment) were tested in Central Soil Analytical Lab, Thiruvananthapuram for 11 soil physico-chemical parameters including soil bulk density, particle density, porosity, Water Holding Capacity (WHC), Electrical Conductivity (EC), pH, Soil Organic Carbon (SOC), Cation Exchange Capacity (CEC), Phosphorous (P), Potassium (K) and Magnesium (Mg). Like WPI, a statistical technique named Soil Quality Index was incorporated to analyse the soil quality in various land uses. Soil Quality Index can be given by (Dawoe *et al*. 2014; Adugna and Abegaz, 2016).

$$CH_{smt}, CH_{ur} = \frac{LUsmt \text{ or } LUur - LUpa}{LUpa} \times 100$$

where CH_{smt} and CH_{ur} are the percentages of changes in soil property of SMT and urban areas respectively to paddy fields. LU_{pa}, LU_{smt}, and LU_{ur} are the average values of different soil parameters in paddy, SMT, and urban areas, respectively.

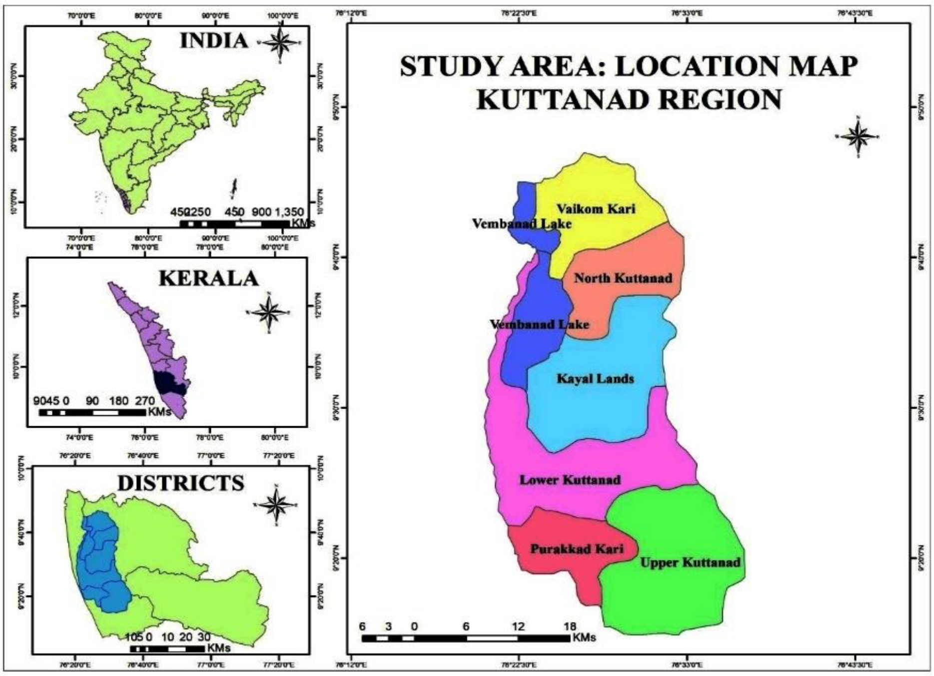

Fig. 1. Study area: Location Map Kuttanad Region.

RESULTS AND DISCUSSION

The term land-use relates to human activity or economic function associated with a specific piece of land. Knowledge of land-use and land cover is important for many planning and management activities and is considered an essential element for modelling and understanding the earth as a system (Lillesand *et al*., 2008). Land-use has generally been considered a local environmental issue, but it is becoming a force of global importance (Foley *et al*. 2005). Worldwide changes to forests, farmlands, waterways and air are being driven by the need to provide food, fibre, water and shelter to the growing population. Global croplands, pastures, plantations, and urban areas have expanded in recent decades accompanied by a large increase in energy, water and fertiliser consumption, along with considerable losses of biodiversity.

Land-use change occurs in various forms, including both changes in area and changes in the intensity of use (Houghton, 1994). To understand the impact of land-use change on terrestrial ecosystems and to predict future alterations in land-use, the factors affecting land-use must be fully studied. The changes in land-use reflect the history and future of humankind. Land-use changes are driven by economic and technological factors, demographic factors, institutional factors, cultural factors, globalization and urbanization. Neither population nor poverty alone constitutes the sole and major underlying causes of land-use change. Rather people’s responses to economic opportunities, as mediated by institutional factors, drive land-use changes (Lambin *et al*., 2001).

Each category of land-use change is associated with many secondary environmental impacts. Deforestation, especially in highlands, increases the frequency and severity of flooding downstream (Meyer and Turner, 1992). The land-use activity also contributes to climate change. Land-use effect on climate includes both implications of land-use change on the atmospheric flux of carbon dioxide and its subsequent impact on climate and the alteration of climate change impacts through land management (Dale, 1997). Land-use change also causes land degradation, increased floods and surface warming.

Land-use is also one of the most important factors influencing soil quality. Different land-uses have differing impact on the soil’s physical and chemical properties. Land-use change can result in soil quality deterioration and soil degradation. Forest degradation and conversion of forest lands to agriculture or other land-uses may lead to the changes in soil properties and soil fertility losses (Burton *et al*. 1989). Similarly, agricultural land to urban land transformation may also result in severe soil degradation. The widespread land-use changes that have occurred to meet the growing needs of the increasing population resulted in widespread deterioration in soil quality (Islam and Weil 2000).

Land-use Effect on Soil Quality

Soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil degradation is the physical, chemical, and biological decline in soil quality. Soil degradation is caused by its improper use or poor management, usually for agricultural, industrial, or urban purposes. The present study selected five physical and six chemical parameters to evaluate the effect of land-use change on soil quality.

Physical Parameters of Soil Quality

Bulk Density. Bulk density is defined as the mass of a unit volume of dry soil which includes both solids and pores. Land-use change is a major factor affecting bulk density as deforestation, and urbanization could lead to soil compaction and increased bulk density. There were notable differences in bulk density among different land uses in the study area. The mean bulk density of the Kuttanad region as a whole was 1.378 g/cc which increased to 1.490 g/cc in the urban area and 1.439 g/cc in (SMT) settlement with mixed trees (Table 1). The lowest bulk density was recorded in paddy fields (1.168 g/cc). Results point out that bulk density has increased by 27.57% in the urban area and 23.20% in SMT. Loss of organic matter characterised by the conversion of paddy fields into built-ups is the main reason behind the increased bulk density in the urban area (Fig. 2).

Particle Density. Particle density is the density of solid particles that collectively make up a soil sample. It differs from bulk density because the volume used does not include pore spaces. There was a marked variation in particle density among different land uses. The lowest particle density was observed in paddy fields (1.97 g/cc) followed by SMT (2.135 g/cc) and urban areas (2.136 g/cc). The mean particle density of the whole Kuttanad region was 2.09 g/cc. Thus, all the land uses except paddy have recorded higher particle density than the average particle density of the Kuttanad region. The particle density has increased by 8.43% in the urban area compared to the paddy field average. The lowest particle density in the paddy fields is due to its higher clay content (Fig. 3). The lower organic matter characterising the land-use change from paddy to other uses is the cause of higher particle density in the urban and SMT areas.

Porosity. Soil porosity is the gap between solid particles that contains water and air. Pore space determines the amount of water that a given volume of soil can hold. The higher the soil porosity higher the soil quality is. Soil porosity is significantly varied in different land uses in the Kuttanad region. The highest porosity was noticed in the paddy fields (52.43%) and the lowest in the urban environment (43.92%). SMT areas recorded moderate porosity values (Fig.4). Porosity has undergone a decline of 16.23% in the urban area and 13.9% in the SMT compared to the paddy field average. The higher bulk densities in the urban and SMT areas resulted in lower porosity in the same land uses.

Water Holding Capacity (WHC). Water holding capacity is the total amount of water a soil can hold at field capacity. One of the main functions of soil is to store moisture and supply it to plants between rainfalls or irrigations. The soil water holding capacity is highly varied among different land uses in the study area. The highest water holding capacity of 58.530% was noticed in the paddy fields followed by 38.894% in SMT and 38.556% in the urban area. The mean water holding capacity of the Kuttanad region was 44.420%. Results showed that WHC has experienced a decline of 34.13% and 33.55%, respectively in urban and SMT areas compared to paddy fields (Fig. 5). This difference in WHC is due to different bulk densities and porosity. High bulk density reduces soil porosity which in turn reduces soil water holding capacity.

Electrical Conductivity (EC). In soil, electrical conductivity (EC) is a measure of the ability of the soil to conduct an electrical current. Most importantly to fertility, EC is an indication of the availability of nutrients in the soil. Low ECs are often found in sandy soils with low organic matter levels, whereas high EC levels are usually found in soils with high clay content. There were significant fluctuations in EC among different landuses. EC fluctuated between 2.184 ds/m in paddy fields to 0.354 ds/m in SMT. The urban area also had a low EC of 0.41 ds/m. This shows that EC levels have undergone a significant decline of 83.79% and 81.22%, respectively in SMT and urban areas compared to paddy field mean EC (Fig. 6). It is now clear that land-use change from paddy to urban and SMT has resulted in a decline of soil organic matter.

Chemical Parameters of Soil Quality

Soil pH. Soil pH is a measure of soil acidity or alkalinity. It is an important indicator of soil health. Generally, all the land-use units had acidic soils. Extreme acidity of 3.80 was recorded at paddy fields (Table 2). Urban areas had more or less neutral soils where the pH was 6.32. In SMT, the recorded pH was 5.25. The effect of soil pH is great on the solubility of minerals or nutrients. Most minerals and nutrients are more soluble or available in acid soils than in neutral or slightly alkaline soils (Fig. 7).

Soil Organic Carbon (SOC). Soil Organic Carbon is a strong determinant of soil fertility through its positive effects on soil structure and soil chemical and biological properties which in turn stimulate primary production. Organic carbon loss is an indicator of declining soil fertility and increased physical and chemical soil degradation (Gladis *et al.* 2019). SOC has highly fluctuated among different land-use units in the study area. The recorded SOC was higher in the paddy fields (6.01%) whereas it was lower in the SMT (2.904%). Urban average SOC was 3.06%. This shows that the mean SOC levels have experienced a steady decline of 51.68% and 49.08% respectively in SMT and urban areas (Fig. 8). This decline in SOC is due to ‘C’ breakdown through oxidation following land conversion.

Table 1: Kuttanad Region - Mean values of various physical soil quality parameters.

Land-use	Parameter				
	Bulk density (In g/cc)	Particle density (In g/cc)	Porosity (In %)	WHC (In %)	EC (In Ds/m)
Paddy field	1.168	1.97	52.43	58.53	2.184
SMT	1.439	2.135	45.14	39.894	0.354
Urban area	1.490	2.136	43.922	37.556	0.41

Source: Compiled by the Researcher

Table 2: Kuttanad Region - Mean values of different chemical parameters of soil quality.

Land-use	Parameters					
	pH	SOC (In %)	CEC (In Cmol/Kg)	P (In Kg/ha)	K (In Kg/ha)	Mg (In ppm)
Paddy	3.80	6.006	0.46	29.568	345.001	591.288
SMT	5.25	2.904	0.275	37.38	233.382	111.57
Urban	6.32	3.06	0.24	25.984	327.892	153.256

Source: Compiled by the Researcher

Table 3: Kuttanad Region – Soil Quality Indices (%) for 0-15 cm soil layer in Built-up land and SMT.

Sr. No.	Land-use	Quality Index (Q.I.)
1	Built-up	-291.058
2	SMT	-301.884
Cumulative Q.I.		-592.942

Source: Compiled by the Researcher

Table 4: Kuttanad Region: Land-use wise Quality Indices (%) for different soil quality parameters.

Land-use	Parameter										Cumulative Q.I.
	BD	PD	PO	WHC	EC	pH	SOC	CEC	P	K	Mg	
SMT	-23.2 02	-8.376	-13.904	-31.840	-83.791	+38.158	-51.648	-40.217	+26.420	-32.353	-81.131	-301.884
Urban	-27.568	-8.426	-16.231	-35.828	-81.227	+66.316	-49.085	-47.826	-12.141	-4.962	-74.080	-291.058
Cumulative Q.I.	-50.77	-16.80	-30.135	-67.668	-165.018	+104.474	-100.733	-88.043	+14.279	-37.315	-155.211	-592.942

(BD - Bulk density, PD – Particle density, PO - Porosity)   Source: Compiled by the Researcher

Physical Parameters of Soil Quality

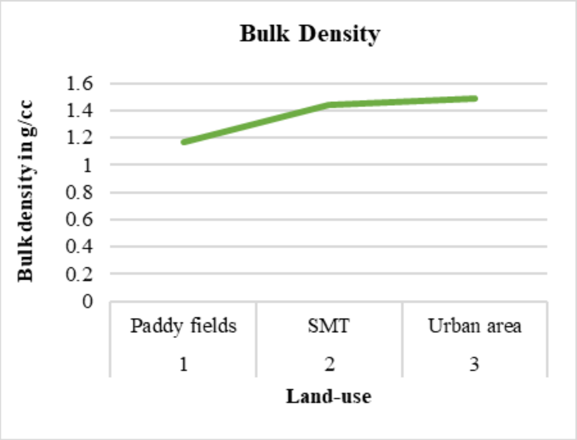

Fig. 2. Bulk Density.

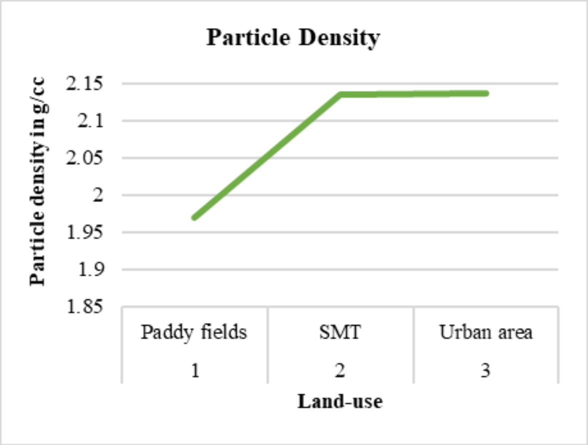

Fig. 3. Particle Density.

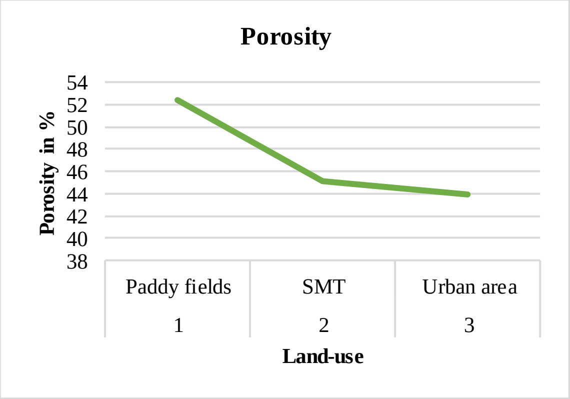

Fig. 4. Porosity.

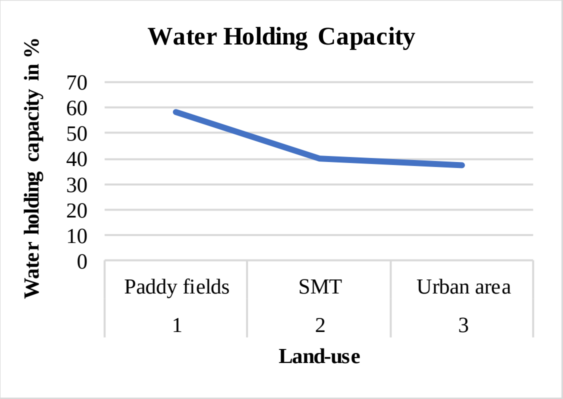

Fig. 5. Water Holding Capacity.

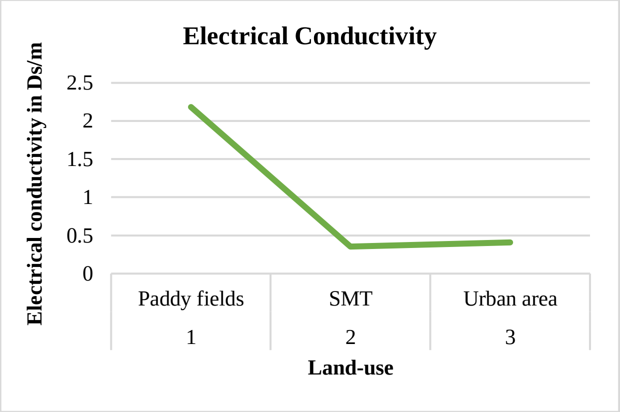

Fig. 6. Electrical Conductivity.

Chemical Parameters of Soil Quality

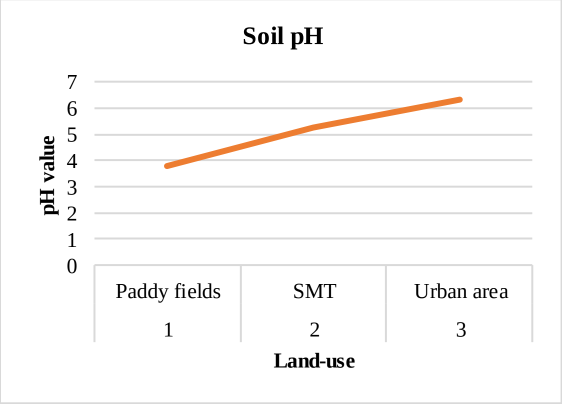

Fig. 7. Soil pH.

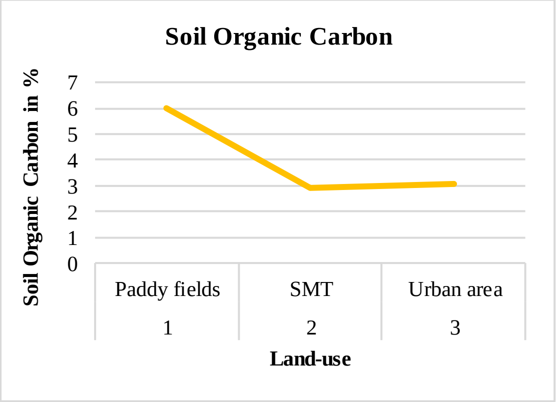

Fig. 8. Soil Organic Carbon.

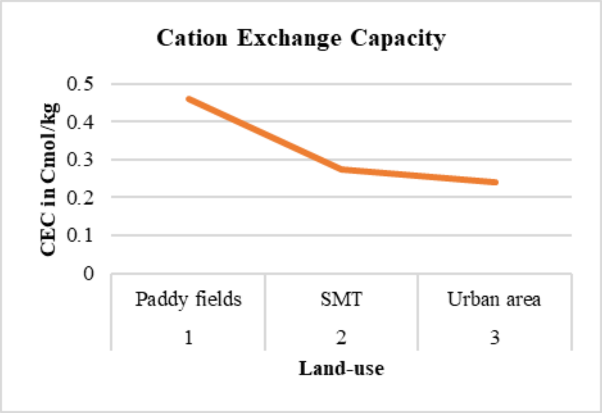

Fig. 9. Cation Exchange Capacity.

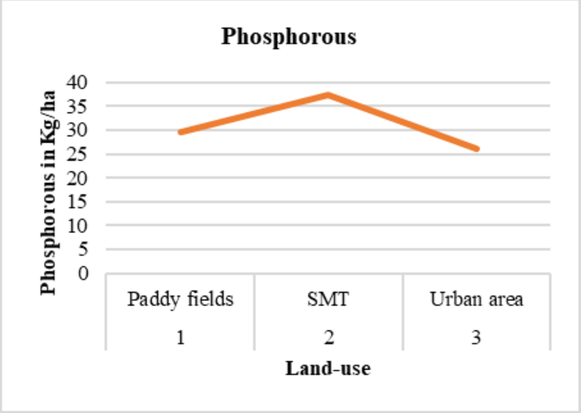

Fig. 10. Phosphorous.

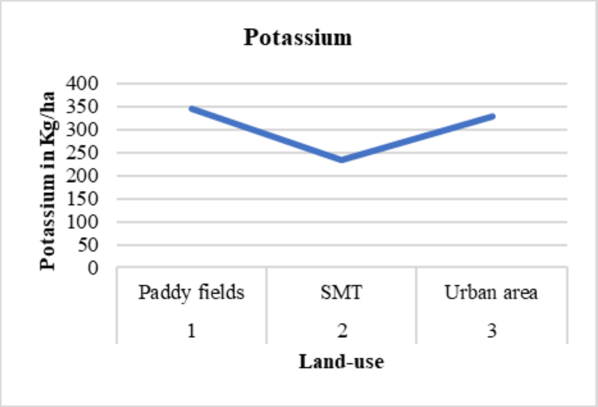

Fig. 11. Potassium.

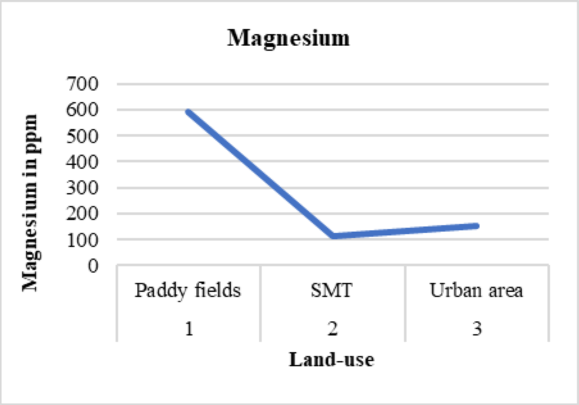

Fig. 12. Magnesium.

Cation Exchange Capacity (CEC). CEC is the total capacity of soil to hold exchangeable cations. It is an important indicator of soil fertility because it shows the soil's ability to supply three important plant nutrients; calcium, magnesium, and potassium. Soil organic matter and clay content have a direct relation with CEC. The soils of the different land-use units had varying CEC levels. It varied from 0.46 cmol/kg in paddy fields to 0.24 cmol/kg in an urban area. The CEC level has experienced a significant loss of 47.83% in the urban environment and 40.21% in SMT. The highest value of CEC in paddy fields is due to its high clay content (Fig. 9). The lower organic matter and clay content characterising land-use change is the main cause of depleting CEC in SMT and urban areas.

Available Phosphorous (P). Like all other parameters, the available 'P' was also significantly varied in different land-use units. It ranged from 25.984 kg/ha in urban to 37.38 kg/ha in SMT. Paddy fields had a mean 'P' value of 29.568 kg/ha. The comparatively high levels of 'P' in urban areas were due to the discharge of domestic effluents, industries, and outflows from sewage treatment plants (Fig. 10). The higher 'P' stocks in the SMT areas were due to the application of cattle dung and inorganic 'P' fertilizers. Excessive soil phosphorous reduces the plant's ability to take up required micronutrients, particularly iron, and zinc. These high soil phosphorous levels also can threaten streams, rivers, lakes, and oceans.

Available Potassium (K). The available 'K' values were notably lower in SMT (233.382 Kg/ha). The highest 'K' stock was recorded at paddy fields (345.001 Kg/ha) followed by urban areas (327.892 Kg/ha). The higher levels of potassium in the urban areas were due to wastewater discharge and domestic effluents (Fig. 11). Results show that the mean potassium stocks were reported to have declined by 19.7% in the SMT as compared to paddy field average 'K' stocks.

Magnesium (Mg). Results show that land-use changes had a pronounced impact on soil Mg stocks. Soil Mg stocks have highly fluctuated in different land-use units. The highest average Mg was recorded at the paddy fields (591.288 ppm) and the lowest in SMT (111.57 ppm). Urban areas had moderate Mg stocks of 153.256 ppm. Thus, it is evident that the available Mg stocks had experienced a decline of 81.13% and 74.08%, respectively in SMT and urban areas as compared to paddy fields. Mg deficiency leads to a reduction in yield (Fig.12). It also leads to higher susceptibility to plant disease.

Soil Degradation

Soil Quality Index. To understand the effect of land-use change on soil quality a soil quality index was employed. It was calculated for paddy field average values. It suggests that the soil quality has deteriorated significantly in the Kuttanad region. The soil quality index value of the region is -592.942 (Table 3). The conversion of paddy fields into SMT and built-up has caused considerable soil degradation. The degradation of soil is high in SMT than that ina built-up area. This may be due to the availability of different elements in the built-up area derived from urban functions. In the Kuttanad area, paddy fields were first transformed into SMT and then into built-up. The analysis shows that even the first level conversion (paddy into SMT) has caused significant soil quality deterioration. Thus, it can be stated that the land-use change has affected not only the agricultural productivity of the region but also the ecological functioning and environmental conditions of the area (Moges *et al*., 2013).

Among the different soil physicochemical properties, electrical conductivity has experienced the most severe quality deterioration following land-use change (Table 4). It was followed by Mg and SOC. Two parameters, namely pH and P, have undergone positive changes after land conversion. Soil pH has experienced no degradation in both land uses; SMT and built-up. But 'P' has degraded in the built-up environment.

In SMT the highest degradation has occurred in the case of EC followed by Mg and SOC. The lowest quality deterioration in SMT is observed for the parameters of particle density and porosity. But in an urban environment, the lowest degradation was recorded for the parameters K followed by particle density and P. The two most important soil quality parameters, *viz.*, SOC and CEC have undergone significant degradation in both the land-uses. These results clearly show that land-use change has a profound impact on soil quality.

CONCLUSIONS

Land-use change has caused extensive biophysical impacts in terms of soil and water quality deterioration in the Kuttanad region. Land-use change was responsible for significant fluctuations in soil physical parameters like bulk density, particle density, porosity, WHC, and EC. It also affected the chemical soil quality parameters like soil pH, SOC, CEC, soil ‘P’, ‘K’, and ‘Mg’ stocks. All these fluctuations in soil physico-chemical parameters were more significant in the SMT (Settlement with mixed trees) and built-up lands. The soil quality index demonstrates that the paddy land transformation has a serious effect on soil degradation.

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