Vol. 52, No. 1, pp 34-39, 2024
Indian Journal of Soil Conservation
https://www.iaswc.com/ijsc.html

Changes in soil physical properties in the post flood scenario in selected land use systems in Central Kerala, India

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ARTICLE INFO

DOI : 10.59797/ijsc.v52.i1.147
Handling Editor : Dr I. Rashmi

Article history:
Received : August, 2023
Revised : March, 2024
Accepted : March, 2024

Key words:
Land use systems
Short duration flooding
Soil bulk density
Soil porosity
Soil texture

ABSTRACT

Kerala had a flood on Aug, 2018 with a different duration or temporal variation from three to seven days due to heavy and unexpected rain during the month. The current study focussed on the impact of flood on soil physical properties [soil texture, soil porosity and bulk density (BD)] of five different land use (LU) systems (forest, rubber plantation, nutmeg plantation, coconut plantation and open land) in Thrissur district of Kerala, India. Coconut plantation showed a significant decrease in soil BD (0.14g cc^{-1}) and porosity (8.03%) due to flood. Soil texture has changed in forest (sandy clay loam to clay loam), coconut (loamy sand to sandy clay loam) and open (loamy sand to silty clay loam) LU system after flood. The results support the resilience of tree-based LU system (forest, rubber plantation and nutmeg plantation) or the quick recovering capacity against the long-term effect of flood. Integrating tree species into coconut plantation and tree less systems would help to restore the LU system from the adverse impact of short duration floods.

1. INTRODUCTION

Extreme precipitation events, landslides, and floods are the most common natural disasters that affect human society and economy (Hirabayashi *et al.,* 2008; Crozier, 2010; Coumou and Rahmstorf, 2012; Roxy *et al.,* 2017). India is experiencing frequent flood events (Mohapatra and Singh, 2003; Sahoo *et al.,* 2019) due to extreme and unpredictable precipitation (Fowler *et al.,* 2010). The warming climate gradually increased the recurrence of great floods and extreme precipitation events, which is consistent with the observations as well as climate model projections (Ali *et al.,* 2014). The European Union defines a flood as "a temporary covering of ground that is not normally covered by water" and indicates that the flood is made up of temporary and semi-permanent areas (EEA, 2016). The temporary portion can last from minutes to months. Spatial extensions can range from a few square meters to ten thousand square kilometres.

The depletion of rainfall acceptable capacity (RAC) and the emergence of water-resistant soil crust in deep furrows as a result of higher water table and higher rainfall cause soil flooding in a region (Yong *et al.,* 2011). The extent of dynamics in soil properties in soil flooding condition may depend on several factors *viz.,* soil type, soil texture, duration of water logging and soil organic matter (SOM) (Cosentino *et al.,* 2006; Li and Shao, 2006; Bandyopadhyay *et al.,* 2010). Decline in permeability of soil, depletion in aggregate stability and swelling of colloids would affect the soil physical properties caused by the soil water logging (Ponnamperuma, 1984; Reddy and Delaune, 2008). Moreover, soil waterlogging reduced oxygen availability, eventually reducing the decomposition activity led by microorganisms that promote the development of soil aggregates (Vishnu *et al.,* 2019).

Wetting and drying of soil have a significant effect on soil aggregate stability both macroscopically (Shiel *et al.,* 1988) and microscopically (Watts *et al.,* 2001). Differential swelling in soil particles, air entrapment and compaction of soil, heat of wetting and expansion of extension of electrical double layer are some of the changes happening due to wetting. On drying, soil may not fully reorient to the previous condition (Kay, 1990; Wagner *et al.,* 2007), which is more profound in soils having greater clay contents and SOM, drying cycle increases the adhesion between both SOM and clay particles due to the consumption of water

(Wagner *et al.,* 2007). Consequently, the mechanical strength of the soil increases with increased amount of SOM and clay content (Zhang *et al.,* 2005).

Kerala experienced a flood in 2018, which was considered as the worst in history since 1924 (Vishnu *et al.,* 2019). In Aug 2018, colossal flood resulted severely in human lives (more than 440 were killed and above one million were evacuated to relief camps) and property (worth $3 billion), predominantly in Alappuzha, Thrissur, Ernakulam and Kollam districts of Kerala (Duncombe, 2018; Vishnu *et al.,* 2019). The excessive rainfall that happened on Aug 15th, 16th and 17th caused the vast flooding in Kerala (Mishra *et al.,* 2018). Overall, Kerala has received extravagant precipitation in Idukki (60% higher than normal) and in Ernakulam, Thrissur, Malappuram, Alappuzha, Kollam and Kottayam districts (between 20% and 56% higher than normal) in the monsoon season of 2018 (IMD, 2018a,b,c). The flooding caused the Kerala soil to experience 3-5 days of inundation, exposure, scour, and elution, accompanied by a series of changes in soil oxygen, water content, temperature, soil microorganism content and metabolism in the flood affected region. These factors may have eventually resulted in a dramatic change in the physical properties of the soil.

Numerous researchers across the world (Irfan *et al.,* 2010; Yong *et al.,* 2011; Ammara and Shumaila, 2012; Valipour, 2014; Raut *et al.,* 2014), inspired to quantify the decline in soil productivity due to water logging to ease the selection of absolute soil conservation practice for different LU systems (Rivera, 1999). The impact of flood is also dependent on specific LU types, where forests have higher resilience than plantation soil (Maranguit *et al.,* 2017). Although, most of the recent studies have focused on the vulnerability of LU systems to flooding due to change in the land use pattern (Hussein *et al.,* 2020; Sugianto *et al.,* 2022), studies related to the long-term impact of floods on the soil physical properties in different LU systems have not yet been studied well in Kerala. Also, Kerala experienced a near flooded situation in 2019 (Ali and George, 2021), with excess rainfall in many locations, affecting people's lives, infrastructure, and agriculture (Vijaykumar *et al.,* 2021). In this context, the present study was conducted to understand the impact of the flood occurred in 2018 on the physical properties of soil in severely flood affected five different LU systems (forest, rubber, nutmeg, coconut and open) of the Kurmali river basin in Thrissur district, Kerala, India.

2. MATERIALS AND METHODS

Study Area

The current study was conducted to assess the effect of flood on the physical properties of soil in selected flood affected and adjacent non flood affected tree-based LU systems in 'Kurmali River' basin of Varandarappilly grama panchayat, Thrissur, Kerala, between 10° 20′ and 10° 30′N, and 76°30′ and 76°15′E. Kerala, having diversity in LU systems, was affected by a flood that had a duration of three to five days in *Varandarappilly Panchayath*. Most of the land area of Thrissur is divided into three primary uses: 50.89% is residential or agricultural mix, 25.46% is forest category, and 11.65% is agricultural land (District spatial plan of Thrissur, 2011). The study site presented in Fig. 1 consisted of five different LU systems under both flood affected and non-flooded conditions. The predominant a soil types are alluvial and laterite within the region.

Under the current study, ten different land systems were tested: 1) Forest flood affected; 2) Forest non flooded; 3) Rubber flood affected; 4) Rubber non flooded; 5) Nutmeg flood affected; 6) Nutmeg non flooded; 7) Coconut flood affected; 8) Coconut non flooded; 9) Open flood affected; 10) Open non flooded.

For the forest LU system or vegetation, a semi-deciduous forest type Chimmony Wildlife Sanctuary was considered for the study. The nutmeg plantations are the home gardens with an abundance of nutmeg trees; which was selected due to the local farmers approached the university frequently and raising an issue about decline in soil productivity after floods. Rubber plantations were under the control of Harrison Malayalam; the open LU system without trees and was situated near river banks. *Karuvannur* river emerges from the Pulmai hills of Chimmony Wildlife Sanctuary in the western ghats and ends in the Arabian Sea by flowing westerly from Thrissur district, in which the Kurmali river is one of its main tributaries.

Climate and Weather

The study area has a tropical, humid climate with a harsh hot season and abundant seasonal rainfall during the monsoon season. The hot season starts in March and ends in May, followed by the south-west monsoon (June-Sept). The retreating monsoon season starts in Oct and ends in Nov. The end of Dec is marked by the cessation of rain, and the remaining time is generally warm. On an average, there are

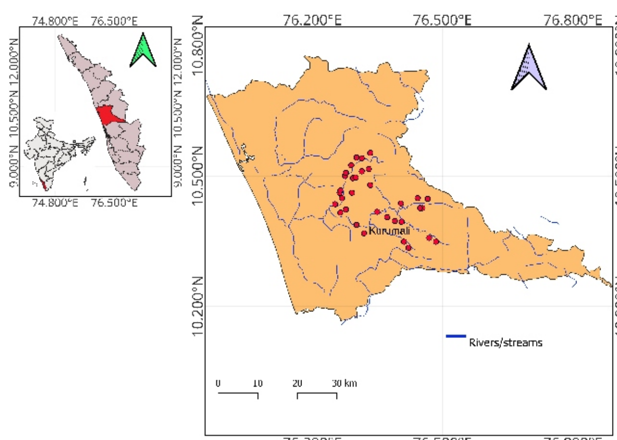

Fig. 1. Map of study area

124 rainy days annually with an average rainfall of 3000 mm. In March and April, the coastal region has a mean daily temperature of 31° C (83°F), while the interior has a temperature of 36°C (97°F). Relative humidity throughout the year is very high within the region, and the average RH during the year is about 70%. During the study period (2019–2020), the low land of the *Karuvannur* basin had a mean annual rainfall of 2858 mm, the midland had 3011 mm, and the highland had 2851 mm. In the south-west monsoon period, about 60% of the annual rainfall was recorded, while 30% was recorded for north-east monsoon period. A 10% annual rainfall was also recorded during the summer period.

Soil Sampling and Analysis

Soil samples were collected in March 2019 (*i.e*., six months after the flood) from the representative flood-affected and adjacent non flood affected areas of the respective five different LU systems. Five representative samples from each flood affected and non-flood affected area were collected from all five LU systems, *viz.,* rubber plantations, coconut plantations, nutmeg plantations, natural forests, and open land as controls. A total of 50 samples were collected from different LU systems. Large crumbs or aggregates of soil encountered during the sampling were broken and were kept in a clean paper bag for air drying. After air drying, the soil sample was grounded using mortar and pestle sieved through a 2 mm sieve, and kept in cloth bags for the further analysis.

Soil Physical Properties

Soil porosity was estimated by the particle density method given by Black *et al.* (1965), and BD was calculated by taking out the core samples in metal rings having a diameter of 0.05 m and a height of 0.04 m (Gupta and Dakshinamoorthy, 1980). Soil texture was estimated by the feel method proposed by Thien (1979).

Statistical Analysis

All soil physical parameters are expressed as the average of five replicate samples from 0-20 cm depth. Statistical evaluation of the results was performed using Microsoft Excel. A student's t-test was accomplished to test the significance differences ($p \leq 0.05$) on soil physical properties before and after flood of each LU systems.

3. RESULTS AND DISCUSSION

Soil Texture

Forest, coconut and open LU systems showed a difference in soil texture class after flood, while rubber and nutmeg plantations didn't show any change after flood (Table 1). Under forest LU system, the soil texture class change from sandy clay loam to clay loam structure. Coconut plantation had a change from loamy sand to sandy cloam texture while open condition had a change from loamy sand to silty clay loam texture.

Table: 1
Soil texture of five different land use systems under flood affected and non-flooded conditions

S.No.	Land use systems	Soil texture (0-20 cm)
1.	Forest flood affected	cl
2.	Forest non flooded	scl
3.	Rubber flood affected	scl
4.	Rubber non flooded	scl
5.	Nutmeg flood affected	scl
6.	Nutmeg non flooded	scl
7.	Coconut flood affected	scl
8.	Coconut non flooded	ls
9.	Open flood affected	sicl
10.	Open non flooded	ls

cl = clay loam, scl = sandy clay loam, sicl = silty clay loam, ls = loamy sand

In open conditions, the textural change may be due to the deposition of flushed soil particles (silt and clay) from the upstream and middle streams of the Kurmali river since it is situated near the Kurmali river bank in the downstream part. Noe *et al.* (2013) also reported the flushing of silt and clay particles from the upstream during flooding and their deposition in the downstream. Another study by Campbell *et al.* (2002) revealed that flooding caused the destruction of soil texture because it carried away tiny soil particles like clay and deposited them when the velocity of the flooding water ceased. In all the other LU systems, we can see a deposit of clay particles after a flood. Since all the tree dominating systems (forest, rubber and nutmeg) are capable of holding the soil particles up to a certain limit through their compacted rooting systems, their textural change might be due to the addition of soil particles during flooding.

Bulk Density (BD)

The results of the study revealed that in forest LU systems, BD is higher for forest non flooded (1.09 g cc^{-1}) than forest flood affected (1.07 g cc^{-1}) at the depth of 0-20 cm. Similar, results were also recorded for rubber and nutmeg LU systems (Table 2). However, the coconut and open LU systems showed a higher value under the flood affected conditions.

Even though all LU systems showed a considerable change after flood in BD, only the coconut LU system showed a significant difference (Fig. 2). Coconut LU system only had a significant difference. This is resulted due to change of soil texture of under coconut plantation, as the soil texture changed from loamy sand to sandy clay loam (Table 1). The aggregate stability of sandy clay loam is greater than that of loamy sand, in which sandy clay loam has a higher clay content, which increased the aggregate stability of coconut plantations after flooding. This

Table: 2
Bulk density and soil porosity (at 0-20 cm depth) of five different land use systems under flood affected and non-flooded conditions

S.No.	Land use systems	BD (g cc^{-1})	p-value	Soil porosity (%)	p-value
1.	Forest flood affected	1.09	0.167	48.23	0.088
2.	Forest non flooded	1.07		53.60	
3.	Rubber flood affected	1.02	0.115	53.15	0.570
4.	Rubber non flooded	1.1		52.63	
5.	Nutmeg flood affected	1.07	0.139	50.07	0.055
6.	Nutmeg non flooded	1.13		47.87	
7.	Coconut flood affected	1.19	<0.05*	45.81	<0.05*
8.	Coconut non flooded	1.05		53.84	
9.	Open flood affected	1.24	0.184	41.23	0.072
10.	Open non flooded	1.21		44.32	

**p-value <0.05 – significantly different at 95%*

aggregate stability helps in better compaction of the soil, which results in a higher BD after flooding. These findings are in line with Letey (1958), who reported that the geometry of macropores is limited when the water level rises in soil, which increases the micropore density and ultimately affect the BD of the soil.

The results presented in Fig. 2 indicated that the rubber and nutmeg plantations showed a decrease in soil BD after flood. Even though the results are non-significant, their magnitude of difference is a little bit high. As specified earlier, clay content in the sandy loam texture of these LU systems decreased aggregate stability due to water logging (Li and Shao, 2006; De-Campos *et al.,* 2009), which limited the decomposition of organic matter through the inactivity of microorganisms due to anaerobic conditions (Tang *et al.,* 2011). This is also profound in the current study also, SOC status after flood in rubber, nutmeg, coconut and open has followed the same opposite trend as BD change after flood (Fig. 3).

In the present study, the open condition was taken as the control, but it didn't show a significant difference in BD as expected. There is a negligible increase in BD, which may be due to its texture change from loamy sand to silty clay loam (Table 1). In overall soil BD increased in coconut plantations after the flood. This is may be due to the coconut plantations (monocropping), which follow a wider spacing (7.5 × 7.5 m) in Kerala, have very little root penetration (Kumar and Jose, 2018; Kumar and Kunhamu, 2022) as well as less litter to decompose compared to other tree-based LU systems, which failed to overcome the situation even after six months.

Soil Porosity

At the depth of 0-20 cm, there is a slight increase in soil porosity under rubber and nutmeg plantations after flood, while the other three LU systems (forest, coconut and open) showed a decline trend (Fig. 4). However, only coconut plantation showed a significant decrease in soil porosity

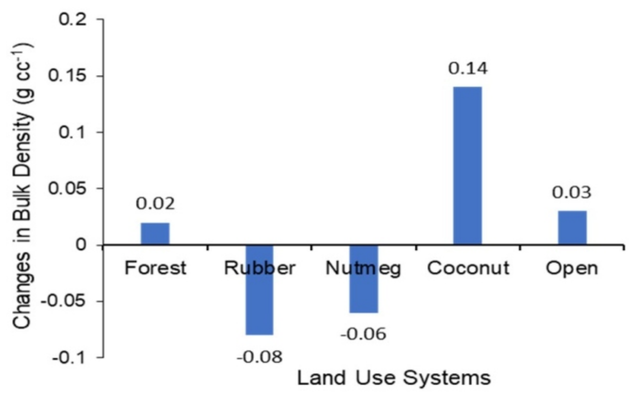

Fig. 2. Changes in bulk density of different land use systems after flood

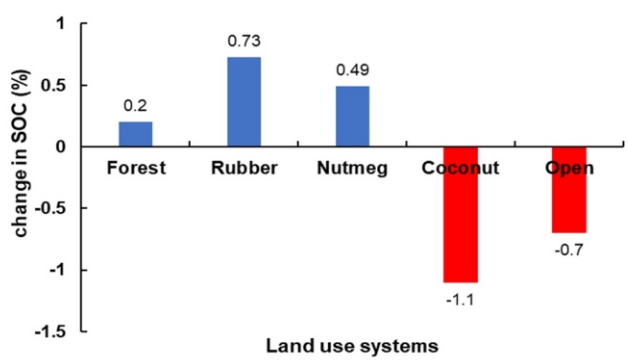

Fig. 3. Change in SOC of different land use system after flood

after flooding (Table 2), due to the lesser accumulation of SOC after flood (Fig. 3) in coconut plantation resulted in a higher magnitude change in the soil porosity than any other LU system.

Soil porosity is negatively correlated with soil BD (Chaudhari *et al.,* 2013). However, forest condition has shown a relatively large decrease in soil porosity after flood (5.38%), which may be due to its textural change from sandy clay loam to clay loam (Table 1). Clay loam has lesser soil porosity compared to sandy clay because of its size, arrangement, and compaction.

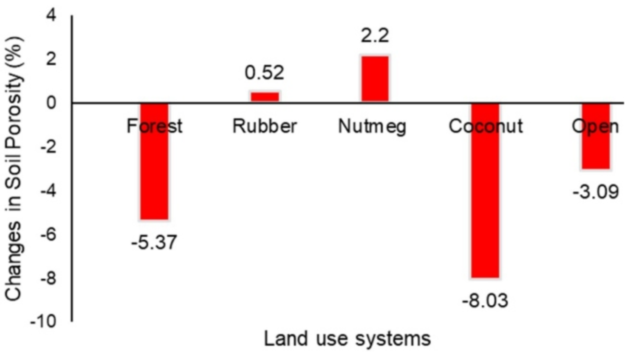

Fig. 4. Changes in soil porosity of different land use systems after flood

Even though the present study considered open LU system as a control to tree-based LU systems, we couldn't find any remarkable or comparable difference between control and other LU systems. The coconut plantations showed a poor performance after flooding than control is may be due the depositional behavioural difference in both LU systems. However other tree-based LU system showed a higher resilience after flood than the control in all physical properties.

Among the studied soil physical properties, soil texture has a good influence on the productivity of the LU system, as this property mediates the SOM addition and soil fertility status. In considerations to plantations crops (rubber, nutmeg and coconut), only coconut showed a textural change after flood, which decreased SOM content of the soil after flood would cause a production loss in coconut in the flooded area. However, home gardens (nutmeg plantations) also reported with an initial productivity loss by the farmers in the flooded area might be due to the nature of nutmeg plant, which is usually an irrigated crop by the farmers that limited the root penetrations of nutmeg into deeper depths. Hence, the current study implicating the importance of tree (shade trees, for instance, *Grewia robusta, Ailanthus triphysa* and *Vateria indica*) integration to the coconut plantations for better productivity and future resilience to flood (Kumar and Kumar, 2020; Arshad *et al.,* 2023).

4. CONCLUSIONS

The five LU systems (forest, rubber, nutmeg, coconut and open) in the Kurmali river basin, Thrissur, Kerala, had a negative effect on the physical properties of the soil due to 2018 flooding. Among the five LU systems, the tree dominating land systems (forest, rubber and nutmeg) were less affected, or they overcame the ill effects very quickly. So, we can clearly state the adaptation of tree components in a LU system to the flooded condition very quickly by improving their soil structure and texture through the addition of organic matter and their resilience to the devasting situation through their deep and compacted root systems, while the other two systems (coconut and open) had a negative effect on soil BD (increased), soil porosity (decreased) and soil texture (changed). Introducing tree components in open land and coconut plantations could help to recover against the changes in physical properties of soil during short-duration floodings.

ACKNOWLEDGEMENTS

We would like to express our gratitude to all those who helped us during the writing of this article. The authors are thankful to the reviewers for their constructive comments to improve the quality of the paper and the farmers of the study area are highly acknowledged.

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