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Soils of Southern Western Ghats (India) – a potential archive of late Holocene Climate records

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Abstract- The climate system of the Earth undergoes dramatic changes over the past few millennia and information about these changes can best be obtained from the study of a spectrum of climate dependent natural processes that are measurable using geological archives. Such measurements of climate parameters using proxies in geological archives are now being used widely to refine climate predictive models deduced from limited instrumental measurements. Although several archives are used to measure climate parameters using proxy evidences, the potentials of soils are rarely being used in paleo-climate studies. Here, we examine records of climate changes in a few soil profiles in the forestlands of the Southern Western Ghats, SW India. The altitudinal height of the studied locations ranges from 150 m to 2000 m above msl. Clay, sandy clay and sandy clay loam are the dominant soil types of the area. Among the different forest categories of the study area, tropical montane forests sequester higher organic carbon and nitrogen in the soils. Radiocarbon dates of the organic rich samples of the soil profiles vary from 3150 ± 90 yrs BP to Modern age. The study reveals that the soil of the study area is developed in high rain fall events punctuated by a dry event at 1500-1000 yrs BP.

Index Terms- Late Holocene soils, Paleoclimate, Western Ghats, Southwest India.

I. Introduction

Soil is an end product of crustal weathering and is often considered as an archive of paleo-ecological and paleo-climatical proxies (Sukumar et al. 1995; Schirrmeister et al. 2002). The process of soil formation (Pedogenesis) takes time and the different soil strata within a soil profile and are not laid down at different periods as are sediments, but form out of pre-deposited sediments or rocks (U.S. Army Corps of Engineers 2011). The formation of soil is conditioned by a suite of factors like ambient climate, characteristics of parent rock materials, type of landscape, nature of flora and fauna etc. The top most part of the soil profile containing the decomposed organic materials and mineral horizon, that is rich in organics play an important role in supporting natural vegetation (Jin et al. 2014; Roberts 2011). The soil and vegetation have a complex interrelation because they develop together over a long period of time. The vegetation influences the chemical properties of soil to a great extent (Gairola et al. 2012; Chen et al. 1997).

Western Ghats, an orographic feature extending from Kanyakumari in the south to Tapti in the north, cover six states in the Western India. This linear mountain system with very limited passages to cross the high raised system, have a total length of 1600 km, along the west coast. This unique mountain chain plays an important role in maintaining the geo-hydrological and climatological setting (especially monsoon) of the Peninsular India. This mountain chain act as the drainage divide for numerous west flowing and east flowing rivers - the life lines of the Peninsular India. The Western Ghat mountains host a spectrum of forest categories including tropical wet evergreen, moist deciduous forests interspersed with grasslands (Varghese and Menon 1999; Rugmini and Balagopalan 2006). Grasslands blanket the hilltops or its slopes with comparatively thin soil blanket. Many valleys occupied with tropical montane forest (shola) contain peat deposits or organic matter rich layers which offer a good register of Holocene climate and ecology (Sukumar et al. 1993). Studies revealed that this national/global asset is fast degrading due to natural and anthropogenic causes, including the climate change (IPCC 2007). Although many studies are available on the biological aspects of these unique mountain systems (Ramabhat and Kaveriappa 2009; Swarupanandan et al. 1998; Chandrashekara 2004), lack of adequate studies on the abiotic components, especially soils, and its evolutionary phases is a major lacuna challenging effective conservation and wise management measures of the concerned authorities. Therefore, an attempt has been made here to study a few aspects of soil characteristics and its geochronological and climatological bearing in the soil development of the Southern Western Ghats, an example.

Study area

The study area lies in the north eastern part of the Idukki district (10°0'0" & 10°20'54" N Latitudes and 76°46'13" & 77°13'56" E Longitudes), Kerala, which is the part of Southern Western Ghats (Fig. 1). The area is drained by the west flowing Periyar and east flowing Pambar rivers of Kerala state. The altitude range is in the category of 150-2000 m above mean sea level (msl). The climate of the region is controlled by south-west and north-east monsoon. The south-west monsoon contributes 60% of the annual rainfall and north-east monsoon contributes about 25% and the remaining contributions are from summer showers. Geologically the area falls within the Archean crystallines comprising charnockite, charnockite gneisses, hornblende-biotite gneiss, quartz-mica gneiss and pink granite. The study area is attracted with megalithic cultures. Many dolmens (Muniyaras) are seen on the hill tops of Marayoor, Chinnakanal and Kanthalloor regions (Nikhildas, 2014).

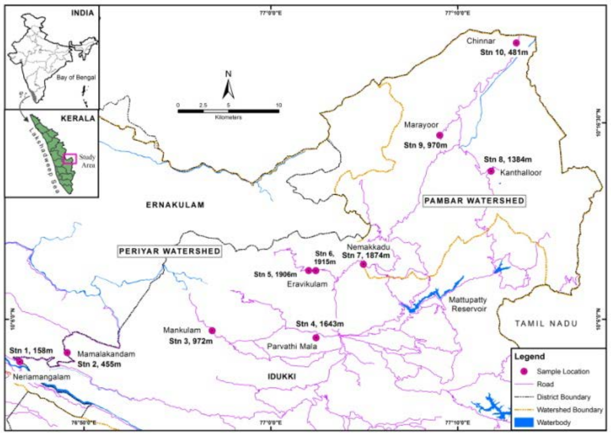

Fig. 1. Study area showing the trench soil sampling locations (Stn 1 – 10). Spot height of the locations are given in meters (m)

II. MATERIALS AND METHODS

A systematic field work was conducted in the forestlands of Idukki district falling within the study area to collect primary and secondary data for the study. Ten stations were identified in the area for collecting soil samples from 1m deep trenches. Soil samples were collected from a transect stretching from Neriamangalam in the west to Chinnar in the east, covering all the major landuse classes/vegetation types of the Western Ghats. Table 1 depicts the salient features of the trench sampling locations along with the respective spot heights. The co-ordinates of the trench sampling locations were fixed with a hand held GPS (Trimble Juno SB). Soil samples are collected from each trenches having a size of 1m x 1m x 1m. Soil subsamples are collected from the walls of the trenches and preserved in neatly labeled polythene bags. Utmost care was taken to avoid contamination during sampling and transportation. A total of 100 subsamples are collected for the analysis. Roots and plant residues are removed from the samples and then air dried at 50 ± 3°C to constant weight. These samples are then passed through 2.00 mm sieve and finely powdered for geochemical analysis. The original dried samples were used for textural studies following Lewis (1984).

Table 1: Details of the sampling sites.

Stations	Location	Altitude (m)	Forest type *
Stn 1	Neriamangalam	158	Evergreen
Stn 2	Mamalakandam	455	Moist deciduous
Stn 3	Mankulam	972	Evergreen
Stn 4	Parvathy mala	1643	Low elevation Shola
Stn 5	Eravikulam National Park	1906	Grassland
Stn 6	Eravikulam National Park	1915	Tropical montane forest (Shola)
Stn 7	Nemacaud	1874	Hill top evergreen
Stn 8	Kandallur	1384	Dry deciduous
Stn 9	Marayoor	970	Sandal wood forest
Stn 10	Chinnar	481	Dry deciduous
*(Champion and Seth, 1968)			

Colour of the soil samples were identified using Munsell Soil Colour Chart (1994). Soil organic carbon (SOC) is determined by the wet digestion method (Walkley and Black 1934). The pH of soil was measured with the help of portable pH meter. Nitrogen (N) is estimated by Kjeldahl digestion method (Maiti 2003). Radiocarbon dating was carried out at the Birbal Sahni Institute of Palaeobotony, Lucknow using conventional methods. The soil types were identified from the sand, silt and clay by USDA soil classification diagram (USDA 1987).

III. RESULTS AND DISCUSSION

Soil Colour

The soil colour of the trench samples shows significant variations with respect to location, geology as well as depth of sampling points (Fig. 2). The soil samples of the study area exhibit a spectrum of colours- strong brown (7.5 YR 4/6, 5/8 and 5/6), brown (7.5 YR 4/4), dark yellowish brown (10 YR 3/4, 4/6 and 3/6), yellowish red (5 YR 5/8), black (7.5 YR 2.5/1), very dark brown (7.5 YR 2.5/2), red (2.5 YR 4/6 and 4/8), dark reddish brown (5 YR 3/3, 3/2, 3/4 and 2.5/2), dark brown (7.5 YR 3/2 and 3/3) and brownish yellow (10 YR 6/8). The soil samples of Stns 1, 3, 5, 7 and 10 are reddish brown to strong brown indicating higher degree of oxidation and/or hydration of iron oxide minerals in the soil profile. Soils of the shola forest (Stn 6) exhibit dark brown and black with a colour index of 7 YR 2.5/1 and 2.5/2. This could be attributed to the organic matter content in the soils. Certain levels of soil of Stns 2, 4 and 8 also revealed yellowish brown to dark brown colouration. In general, the colouration of the soils of the study area is attributed due to either redoximorphic (redox) process of the ferro-magnesium bearing minerals in the host material or due to the organic input into the system or both (Guimaraes 2013).

Soil Texture

Out of the 100 samples representing the 10 profiles examined (10 each in a profile) for this study, 36% of the samples exhibit sandy clay loam type soil and 26% clay type. The remaining samples fall within a spectrum of textural classes viz: sandy loam (17%), sandy clay (11%), clay loam (6%), loamy sand (2%), silty clay loam (2%) and sand (1%); (Fig. 2). The sand, silt and clay contents in the soil samples of the study area varies from 14.24 to 90.88% (av. 50.7%), 3.42 to 50.23% (av. 17%) and 5.70 to 64.36% (av. 32.3%) respectively.

In general, the soils of the study area are generally sand and clay dominant compared to silt. The only exception to this contention is the case of Parvathi mala (Stn 4), which is mostly silt and clay dominant. In most deciduous forests, soil structure is loose and no sign of any aggregate formation was noticed. Stations 2 (Mamalakandam) and 10 (Chinnar) comprise of more than 70% sand and the values increase from top to bottom layers of the profile. In shola forest, sand percentage decreases with increasing depth of the profile. An overall evaluation of the silt and clay contents reveals the existence of a positive relation with spot heights of the respective sampling locations. The higher the elevation the lesser the content of sand in the soil substratum. With rise in altitude and rainfall, the condition becomes favourable for higher rate of disintegration/weathering of crustal rocks and formation of larger proportion of finer particles (Saeed et al. 2014).

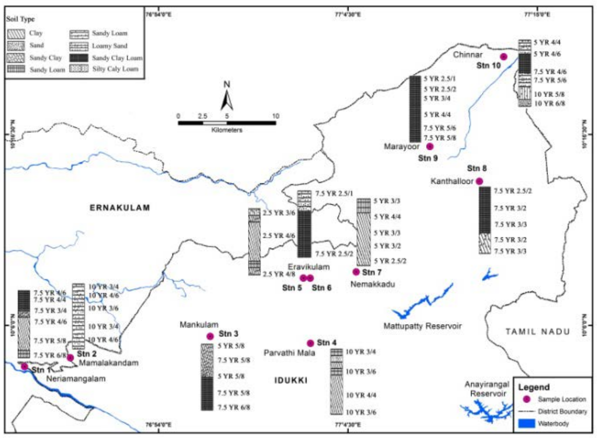

Fig. 2. Soil types (after USDA, 1987) and colour encountered in the trench samples of the study area.

III. Soil Organic Carbon

The SOC content of the trench samples of the study area varies between 0.13% and 13.89% with an average of 1.81%. In surface layer of Stn 6 in the shola forest recorded the maximum SOC value (13.89%), whereas the trench samples of Stn 10 recorded the minimum value (0.22%). Among the samples of the study area, shola forest (Stn 6) recorded the maximum SOC% whereas dry deciduous forest at Stn 10 recorded the lowest.

A decreasing trend in soil organic carbon (SOC) was observed with increasing soil depths (Fig. 3). In the present study, shola forest represents a high SOC value and this result may be due to its unaltered natural setting with profuse growth of trees and shrubs. Dense canopy and thick undercover result in increased amount of carbon return in the form of litter fall. This will contribute to high amount of forest floor organic matter. Apart from this the deeper root biomass of the trees, cool temperature and precipitation (Chapin et al. 2002; Keith et al. 2009) and high species composition of this site was also another contributing factor favouring organic carbon accumulation in soils. On the other hand, factors like decreased litter input, shifts in abundance of woody and herbaceous vegetation, changes in depth distribution of plant roots, altered soil water and temperature regimes which accelerate decomposition and a decrease in NPP (Net Primary Production); (Johnson et al. 1995; Jackson et al. 2000) might have contributed to the loss of SOC in the dry deciduous forested areas.

The higher organic carbon content recorded in the top layer of most of the soil profiles may be attributed to rapid decomposition of forest litter. Clay content is also a key factor in controlling the dynamics of carbon in soil as clay particles are very efficient in trapping organic carbon derived from various sources.

Total Nitrogen

The rate of soil nitrogen mineralization, used as indices of nitrogen availability and nitrogen mineralization often differs with vegetation type, altitude and topographic position. This may be attributed to variation in soil organic matter, temperature and water availability (Zhang et al. 2012). Nitrogen values of the soil samples of the study area varies between BDL (Below Detection Limit) and 1.09% with an average of 0.09% for the bulk soil. From this, it is clear that soils of the shola forest invariably register higher values of nitrogen (Fig. 3) owing to the presence of thick vegetation and high organic matter content. The total quantity of biomass reaching the soil through litter fall and rate of mineralization of the same are the factors that finally determine the nitrogen value of the soil. The soils rich in organic matter with a slow and steady mineralization rate, as observed in the case of sholas, could maintain a higher nitrogen budget in soils in spite of the higher levels of plant uptake. The statistical analysis reveals that organic carbon shows strong positive correlation with nitrogen ($R = 0.894$) in locations where organic matter degradation is the major pathway of nitrogen to the soil substratum. From this study it is clear that the nitrogen values are higher in the higher altitude soils indicating the fact that temperature, organic carbon and water content are the factors determining the nitrogen trends in the soil substratum (Zhang et al. 2012; Yuksek 2013).

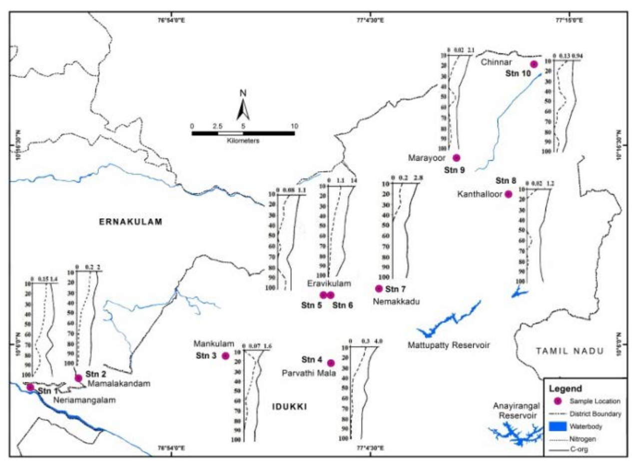

Fig. 3. Variation of nitrogen (N) and organic carbon (C–org) along the soil profiles. Depth of the profile is given in cm and contents of N and C-org in percentages.

Climatic evidences

The radio carbon dates of soil samples obtained for two locations such as Parvathi mala (Stn 4) and shola forests at Eravikulam National Park (Stn 6) having sufficient organic contents for age determination indicate late Holocene age. The Stn 4 at Parvathi mala at a depth of 55 cm bgl yielded ^{14}C date of 3150 ± 90 yrs BP. At the same time a sample 35 cm bgl gave modern age. On the other hand the sample collected from shola forest in Eravikulam National Park (Stn 6) gave slightly younger age of 2060 ± 100 yrs BP for a level 95 cm bgl. Further a sample at 45 cm bgl of the same section yielded an age of 790 ± 80 yrs

BP (Fig. 4). The soil organic carbon and nitrogen shows marked increase in the upper younger layer of the two sections compared to the lower counter parts. Interestingly the C:N ratio exhibits a reverse trend with substantially lower values at the top (Fig. 5a & 5b) and higher values for the bottom layers. This clearly indicates the stratified nature of the soil profile with a period of break in soil development between the upper and lower layers. The period of hiatus coincides with the age range 1500-1000 yrs BP. A similar kind of break obtained for the high altitude lacustrine sediments of Pookot lake, located northwest of the study area in Western Ghats. This according to Veena et al. (2014) is attributed to a dry phase that hit the region somewhere between 1500-1000 yrs BP. Evidences for a dry phase during this period is also observed in the southern part of the study area by Raji et al. (2013) and Vishnu et al. (2013) while studying the lacustrine sediments of Southern Kerala. From these evidences and results of the study, it is revealed that the soil profile of the study area register records of three climate phases in the late Holocene with the lower and upper strata evolved during two distinct events of high rainfalls, whereas the break in the profile is attributed to a dry phase. Detailed study of these climate change records driven by the Asian summer monsoon requires systematic investigations of more organic matter rich soil profiles of the Western Ghats which under progress.

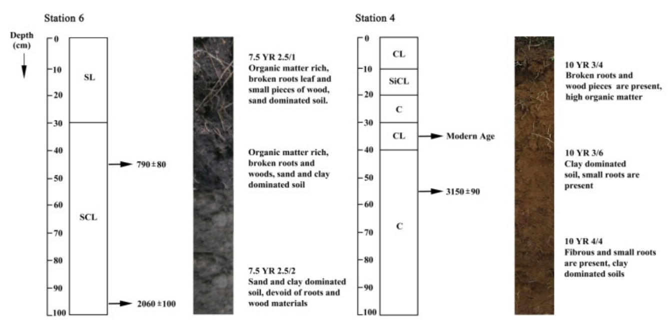

Fig. 4. Lithological and chronological bearings of trench sample in Eravikulam National Park (Station 6) and Parvathi mala (Station 4) (Soil type, colour, soil layer features and age are mentioned in this diagram).

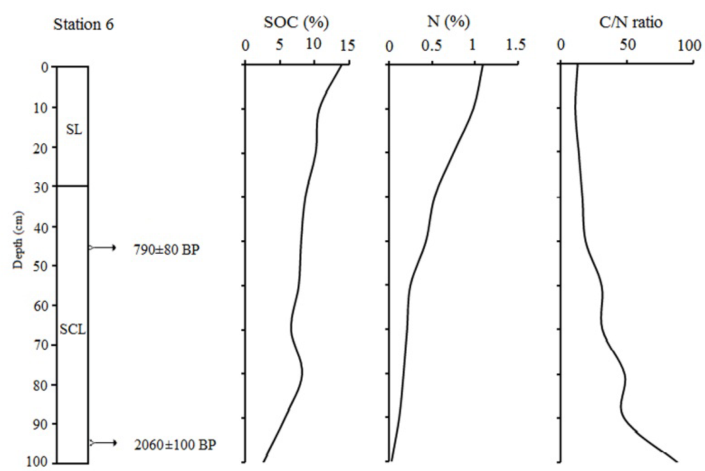

Fig. 5a. Depth wise variation of SOC, nitrogen and C/N ratio in Eravikulam National Park.

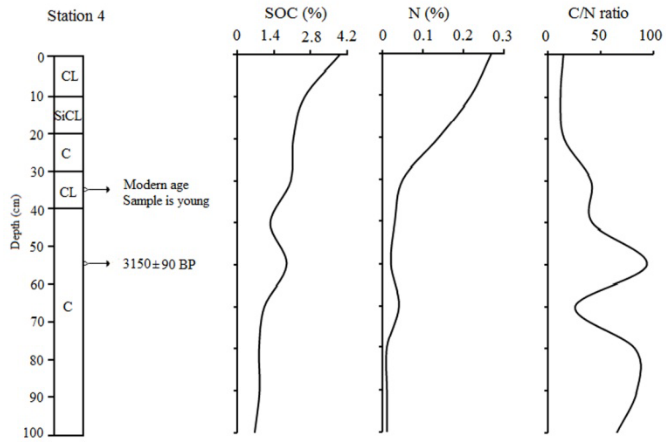

Fig. 5b. Depth wise variation of SOC, nitrogen and C/N ratio in Parvathy mala.

IV. CONCLUSION

Colour of the soils shows marked spatial variation and generally varies from dark brown to yellowish red. Soils are generally sand and clay dominant. Sand shows a negative correlation with elevation, while and silt and clay show a reverse trend. The soil organic carbon also shows wide spatial variation. Among the samples of the study area, Shola forest soil of the Eravikulam National Park accounted for highest content of organic carbon whereas the dry deciduous forest soils registered low values. Compared to other forest types, soils in the Shola forest are rich in organic matter and nitrogen. Improvement of soil fertility by recycling of nutrients from deeper soil layers is also achieved by this fragile ecosystem. The radiocarbon dates of organic rich soil samples indicate that the soils in the study area are generally stratified and the soil apron developed on the flanks of the Ghats are evolved during late Holocene. A break in C:N ratio noticed in the Parvathi mala and Eravikulam Shola soil is attributed to a dry phase within a spell of high rain fall regime. Geochronological examination reveals that the dry phase coincides with the age range of 1500-1000 yrs BP, which is also observed earlier by the earlier researchers.

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