Assessing Soil Moisture and Hydraulic Properties Associated with Tree Density Across Various Land use System in Western Ghats of Karnataka

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***Abstract* - Among various hydrological components, soil moisture and hydraulic properties are the two important factors which significantly influence vegetation density and soil moisture characteristics. Therefore, a clear knowledge of soil moisture pattern and hydraulic properties associated with tree density across various land use system is essential. Hence, a study was conducted in Areangadi region of Honnavara taluk (Uttara kannada, Karnataka) to understand the soil moisture profile and hydraulic properties under various land use/land covers with particular reference to vegetation density. Vegetation density per hector was highest in natural forest and this was reduced up to 50.11 and 50.55 percent in *Acacia auriculiformis (Acacia)* plantation and 88.05 and 88.84 percent in degraded forest during 2009-10 and 2010-11 respectively. Soil moisture variation across various soil depths under different land use system shows that there is an increase in moisture contents both in acacia plantation and degraded forests, whereas in the natural forests, it shows a decline up to a depth of 90 cm and an increase further down (to a depth of 150 cm). It is also noticed that, beyond 190 cm depth, soil moisture in all three land covers remained relatively stable. The study revealed that the variation in soil moisture content depends not only on rainfall pattern and intensity, but also on the tree species and density.**

Among various land use system, average soil moisture was highest (22%) in natural forest followed by acacia plantation (20%) and degraded forest (19%). Saturated hydraulic conductivity (Ks) with depth is decreasing from surface to 1.5 m in all three land covers (Forest, Acacia plantation and degraded forest). However, it is observed that, particularly in forest and plantations there are instances of high rate of hydraulic conductivity at the surface layer, followed by considerable reduction up to 0.45 m depth and become steady thereafter. Further, the present study illustrates that vegetation density has considerable impact on soil hydraulic properties (Ks) and found positively correlated with type of vegetation. Average soil hydraulic property (Ks) was found highest (119 mm/hr) in natural forest followed by acacia plantation (75 mm/hr) and minimum of 18.39 mm/hr was observed in degraded forest.

Keyword: Land use, Soil moisture, infiltration, hydraulic conductivity

INTRODUCTION

Widespread land use conversion is a matter of serious concern in tropical Western Ghats of India which affects the vegetation structure and alters hydrological process including soil moisture, infiltration, evapotranspiration, runoff and erosion (Yadupathi Putty, 2006). Among various hydrological components, soil moisture and hydraulic properties are sensitive parameters which would vary with vegetation density and tree species. There have been a number of recent studies indicating the impact of vegetation structure on hydrological processes (Gash et al., 1980, 1995; Liu, 1997; Bellot and Escarre, 1998; Xiao et al., 1998, 2000; Teske and Thistle 2004; Murakami, 2006; Staelens et al., 2008; Miralles et al., 2010).Thus variation in soil moisture and hydraulic properties can be highly influenced by plant water interaction (Garcia Estringana et al., 2013). However, soil moisture and hydraulic properties exhibits a high degree of spatial and temporal variability. Few studies simply dealt with the influence of land use (Fu et al., 2000), slope gradient (Moore et al., 1988), aspect and curvature (Western et al., 1999), slope and relative elevation (Crave and Gascuel-odux, 1997), precipitation (Famiglietti et al., 1998) and mean soil moisture (Bell et al., 1980; Venkatesh et al., 2011; Purandara et al., 2006; Jagadish et al., 2012). The influence of vegetation and soil properties were reported by Eagleson, 2002, Wang et al., 2008, 2009; Zhang et al., 2011, Chao wang et al., 2013. Therefore, in the present study, an attempt is made to understand the variation of soil moisture and hydraulic properties with tree density across various land use/land covers. Study includes the determination of soil moisture profile and hydraulic properties under various land use/land covers and analysis of vegetation density to understand the influence of soil moisture and infiltration characteristics of soils in head water catchments of Areangadi regions of Honnavar block, coastal Karnataka, India.

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Study Area

The central Western Ghats, locally called as 'Sahayadri Mountains", is a range of mountains in the Peninsular India running approximately parallel to West Coast and become a hub of micro watersheds. These micro watersheds act as primary catchment for the origin of many rivers which flow in both direction (west- and east-flowing). The central Western Ghats of Karnataka generally exhibits a narrow coastal plain followed by small plateaus at different altitudes intervened by steep peaks exposing a long escarpment facing west.

Climate and Geology

The study area exhibits a tropical climate with mean minimum temperature of 21^0C and mean maximum temperature 33^0C. The average annual rainfall is varies from 3500 to 4000 mm with significant intra-annual variability. About 70-80% of the rainfall is received between June to September due to the south-west monsoon phenomenon, while the remaining rainfall is spread over the rest of the year. Number of rainy days during June to September is about 100-110 days. The period from November to May is almost dry. January and April are the coldest and hottest months respectively in the region and Relative Humidity varies from 70 to 90% from up-ghat to coastal region. The geology of the area consists mainly of Archaen-Proterozoic-Dharwad schist and granitic gneisses, meta-volcanic and some recent sediment (Bourgeon, 1989). Many of the upper geological sequences of this region are lateralized due to their exposure to tropical climatic conditions over a prolonged period. Their thickness ranges from a few cm to as much as 60 m (Geological Survey of India, 2006). The most common type of soil found in here is the lateritic soil. In spite of the lateratisation of soils, vegetation is luxuriant, wherever the soil has not been exposed. Under forest cover, the laterite is soft but on exposure the laterite becomes hard, dark brittle and vesicular in structure. Wherever hard formations are formed, generally they are porous and can be cut into blocks which they extensively used for construction (Sollins and Radulovich, 1988).

Experimental micro watersheds

Three micro watersheds, separated by an average distance of 2 km, were selected for detailed study in the central Western Ghats of Areangadi region in Honavar block, Karnataka. Each micro watershed is covered by homogenous land covers of dense natural forest (23 ha), acacia plantation (7 ha) and degraded forest (7 ha). The selected micro watersheds extend from $74^0$28' 28.98" to 74^0 30' 19.86" E longitude and 14^0 19' 50.09" to 14^0 20' 21.59" N latitude and elevation varies from 60 to 160 m above MSL. Study area map (Fig. 1) was prepared using Arc GIS 10.1 tool by using topographic information collected from the field. The canopy cover in natural forest is moderately thick and considered to have canopy coverage of 60-80%, acacia plantation 30-40% and fully exploited degraded forest have less than 10%.

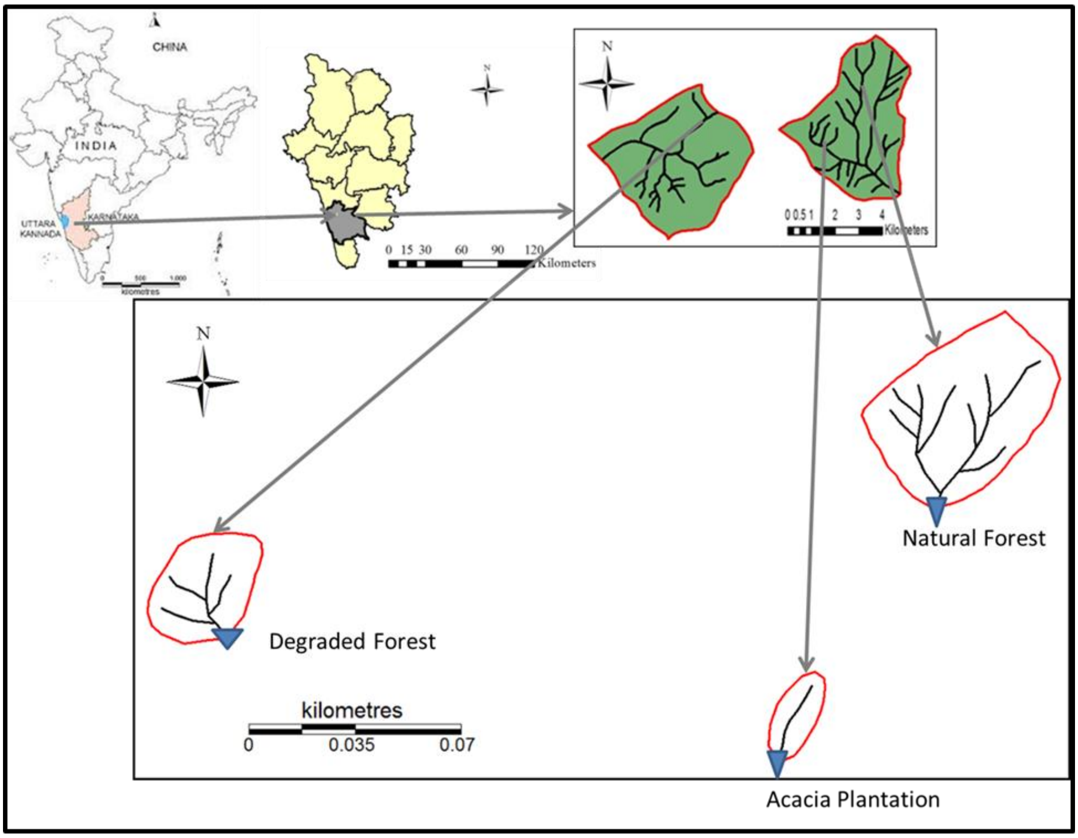

Fig 1: Micro watersheds of different land use systems in Areangadi region of Honavar Block, Karnataka

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MATERIALS AND METHODS

Vegetation Sampling:

The field investigation from October to May was carried out during 2009 - 2011. A Stratified random sampling method was adapted for vegetation analysis and 0.1% percent area was selected for vegetation survey and with the size of 20 x 20 m transact for enumerating tree density (considered only sapling/ poles, trees and stumps with more than 15 cm girth). Further, a nested plot size of 5 x 5m was used for regeneration study. With the help of computer package excel and the following formula, average stand density was calculated and studied the relationship between stand density, soil moisture and hydraulic properties.

$$Density = \frac{Total\ number\ of\ individuals\ of\ a\ species\ in\ all\ quadrates}{Total\ number\ of\ quadrat\ studied}$$

Sampling soil moisture measurement:

The data collected during 2009 to 2011 was considered for soil moisture analysis. Total 10 sampling sites were selected (with in vegetation sampling sites) in three different land use system to measure soil moisture. Soil samples at each site were collected in cloth bags from just below the organic layer (after litter removal). Soil samples were collected at monthly interval from October to May at 14 depth (0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105, 105-120, 120-135, 135-150, 150-165, 165-180-195, 195-210 cm). The soil moisture was measured by gravimetric method. The gravimetric method is the most common and direct way to determine moisture content in the soil sample. It involved collecting soil sample and weighing the sample before and after oven drying for 24 hours at 105^{0}C. Original moisture content can be obtained by equation (Whitney A., 1894 and Kiran Shankar et al., 1979).

$$MC\% = \frac{W_2 - W_3}{W_3 - W_1}$$

Where: W_1: Weight of the tin (g)

W_2: Weight of the moist soil + tin (g)

W_3: Weight of the dried soil + tin (g)

Soil hydraulic conductivity test:

In the present investigation infiltration and saturated hydraulic conductivity was calculated at surface level by using disc-permeameter and Guelf-permeameter in permanently established vegetation analysis plots under different land use system. The disc permeameter basically, comprises of a water reservoir and a bubbling tower. The bubbling tower is connected to the reservoir and is open to the air. The first stage of the infiltration process is controlled by the soil capillaries for a given depth of water on the soil surface. The steady infiltration rate may be attained for a homogenous soil and is determined by the capillaries, gravity, the ponding area and the water head at the soil surface. The disc permeameter can indicate whether the water flow into the soil is controlled mainly by the capillaries or by gravity. The size of the soil pores can be measured by changing the hydraulic head of the water supply. The steady state infiltration rate, from the disk permeameter can be expressed as (Purandara et al., 2006).

$$K_0 = \frac{q}{\pi r_0} - \frac{4bS_0^2}{\pi r_0(\theta_s - \theta_0)}$$

Where 'r' is the radius of disc permeameter ring (cm). θ_s is the saturated moisture content and θ_0 is initial moisture content. During the disc permeameter experiment, data are collected to obtain cumulative infiltration (I) at various time intervals after the start of the test. The slope of early time plot of I vs $t^{½}$, and I may be estimated from the slope of the late time plot of I vs t.

RESULTS AND DISCUSSION

Vegetation Analysis:

Table 1 describes the vegetation survey details of years 2009-10 and 2010-2011. Results shows that the total vegetation density per hector in the natural forest were 5047.12 (2009-10) and 4962.75 (2010-11). However, this was reduced to 50.11 and 50.55 percent in *Acacia auriculiformis (Acacia)* and 88.05 and 88.84 percent in degraded forests. Tree density in natural forest was maximum followed by acacia and degraded forest. The increased stand density in natural forest and acacia was mainly due to presence of seedling / ground cover. In acacia plantation, planting of seedlings at regular spacing leads to the utilization of maximum area. With respect to stumps, watershed having acacia plantation has the highest number followed by degraded and Natural forest. Maximum stand density under natural forest is mainly due to effective conservation practices done by local authority through community participation. While, minimum tree and seedling density with degraded forests are mainly due to biotic interference (pruning of trees for mulching of arecanut and grazing) which ultimately leads to the death of plants. The studies carried out by Rucha Ghate and Harini Nagendra, (2005), and Vardan Singh Rawat (2012), indicate that local enforcement has been most effective in the case where forest management was initiated by the community, with better regeneration, density and basal area. However, inefficient management and uncontrolled grazing and fire, lead to heavy damage to the forest. However, occurrence of higher stump density in acacia showed dependency of local community shifted from native species to Acacia for woody biomass for meeting their needs of household energy and domestic use.

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Table 1: Vegetation study under different land use system in Areangadi regions of Honnavar block, Karnataka

Average stand density No/ha	Natural Forest		DF		AaP	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tree	851.67	845.5	380.45	360.3	534.5	498.32
Stumps	60.45	67.25	122.5	148.15	250	310.34
Seedlings	4135	4050	100	45.5	1733.3	1645.22
Total Stand density	5047.12	4962.75	602.95	553.95	2517.8	2453.88

Special variation in Soil moisture with depth

The Figure 2 and 3, shows vertical profile of soil moisture variation under different land use /land covers. Soil moisture profile under Acacia and Degraded forests are increasing and waving type whereas profile of Natural forest is decreasing type up to 90 cm and becomes stable up to 105 cm except in the case of natural forest where it showed significant increase (between 90-105 cm). In general, from 105 to 150 cm soil moisture was progressively increasing and thereafter marginally decreased up to 180 cm. Beyond 180 cm, soil moisture remains constant with minor variations. In the acacia plantation, the major portion of the watershed is covered by 16 year old acacia plantation and the height of the plants varies between 12-18 m. In addition, some regenerated younger plants are also present in the watershed. The roots of the older trees may have a greater depth for extracting the moisture (>150 cm). The younger trees may be extracting water at the surface and sub-surface layer (at 45-100 cm). But from 105 to 150cm, the moisture content is gradually increasing and there after small percent of decrease up to 180cm and become constant from 195 to 210cm depth. This indicates that, the roots have mostly concentrated at different depth 45 to 100 cm and 150- 180 cm depth from ground surface. The same pattern has been observed in the degraded watershed also. Degraded watershed is mainly covered with thick grass, moderately thorn bushy vegetation and few old trees during the post rainy season. Therefore, the moisture is low till a depth of 50-60 cm and thereafter the moisture is increasing up to 150 cm and become constant from 195 to 210 cm depth. In the natural forests which include trees of different age group (young regenerations, poles and old trees) with varied root length contains relatively higher moisture content in the surface layer due to the presence of leaf litter. . However, at the subsurface and deeper depths, the moisture is being extracted by roots of younger regeneration of plants and middle aged trees. Hence, the decrease in moisture content at 30-90 cm and 150 to 185 cm. Therefore, beyond 195 cm moisture remains stable. . Therefore, it is imperative that the groundwater recharge which primarily depends on the movement of moisture and in turn is influenced by factors such as soil type, vegetation density and tree species. It is also important to analyse the subsurface lithology, which is also one of the major facilitator for the moisture content. However, a detailed geological investigations and tree rooting pattern study are required to explain this process in detail. Occurrence of waving type soil moisture pattern across various soil depths could be attributed to following reasons which includes, (i) aspects of experimental plot, (ii) accumulation of leaf litter or grass cover and, (iii) presence of different age group plants and rooting pattern. Several studies explained that land use has major impact on soil moisture with depth especially due to vegetation cover (Famiglietti et al., 1998), density (Hongsong et al., 2010; Lull and Reinhart 1955; Reynolds 1970, Yang Qiu et al., 2001), distribution of root (BojieFu et al., 2003; Hao Zhang et al., 2016), soil physical properties, topography (Venkatesh et al., 2011; Nasta.P et al., 2013) and features such as slope and aspect.

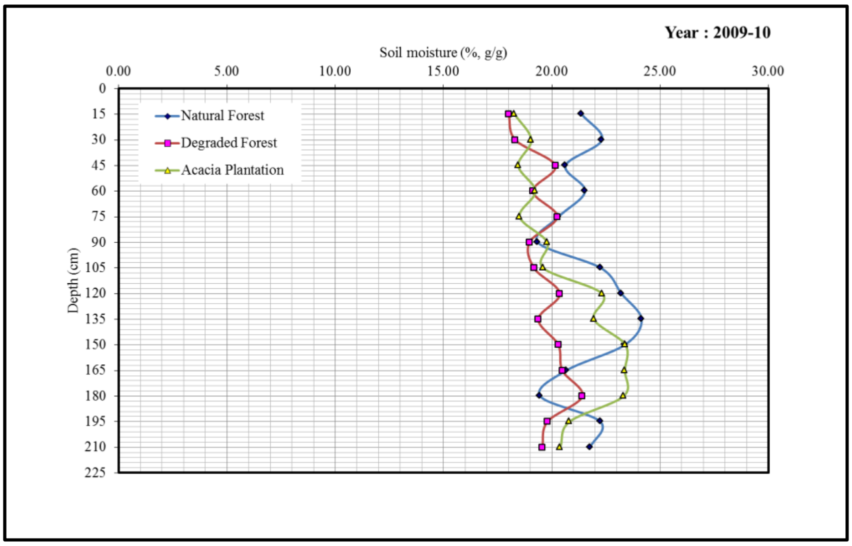

Fig 2: Time averaged soil moisture distribution with depth in different land use system (2009 -10)

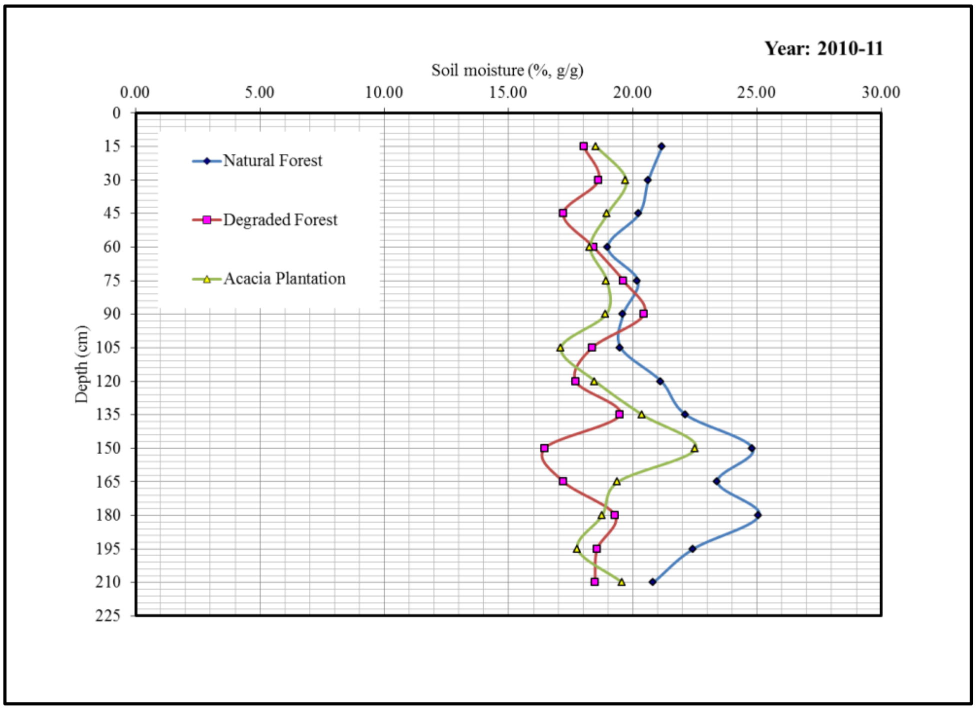

Fig 3: Time averaged soil moisture distribution with depth in different land use system (2010-2011)

Temporal variation of mean soil moisture

Temporal variation of mean soil moisture under different land use system during water scarcity period for two consecutive years (2009 – 10 and 2010 -11, Nov to May) are shown in Fig. 4 and 5. Also shown are the monthly rainfall and its variance over time. The present study revealed that seasonal change in the mean soil moisture is quite significant. As observed in all three land use system, fluctuation of mean soil moisture was found with the rainfall variation and it exhibits two peak and five troughs. It can be seen from the fig 4 and 5 that intermittent rainfall during November and May has given slight increase in mean soil moisture and subsequently this was found to decrease gradually with decrease in rainfall. The trend of soil moisture depletion was continued in spite of small rainfall event occurred during December and April.

In general, it was observed that mean soil moisture content varies with rainfall. However, there is a difference in response to the rainfall due to change in land use system. Between 2009 and 2011, Acacia plantation responded quickly to the rainfall event in the month of December and May indicating an increase in moisture content, whereas in degraded and forested watersheds a decreasing trend was observed. The reason could be the interception of rainfall by the tree canopy in forests and the presence of thick cover grass in degraded watershed. But the mean moisture content has peaked in the early December 2009 in all the watersheds. This phenomenon indicates that, these plants have minimum water-use in the peak winter month and subsequently the moisture content has shown a decreasing trend. Further, the mean moisture content in acacia and degraded forest is low compared to forested watershed. This may be due to the fact that, acacia has enormous roots at different depths for soil moisture intake to survive during dry season. Whereas, in degraded watershed absence of adequate tree canopy and litter biomass leads to top soil exposure to sunlight and loss of surface moisture due to evaporation. Similar findings were also observed in various studies in China, Nigeria, India, Italy and Brazil where soil moisture varies with season, rainfall interception, leaf litter, soil texture, root distribution, slope and aspect (Tomoomikumagai et al., 2009; Walter P 1981, Nasta, P. et al., 2013; Krian Shankar et al., 1979; HaoZheng, et al., 2015; Bojiefu et al., 2003). However, accumulation of soil moisture in the forested watershed may be due to the presence of leaf litter that act as barrier for soil moisture loss and in turn organic matter increases soil moisture holding capacity. The same phenomenon has been observed in the forested watersheds of France (JérômeOgée et al., 2000).

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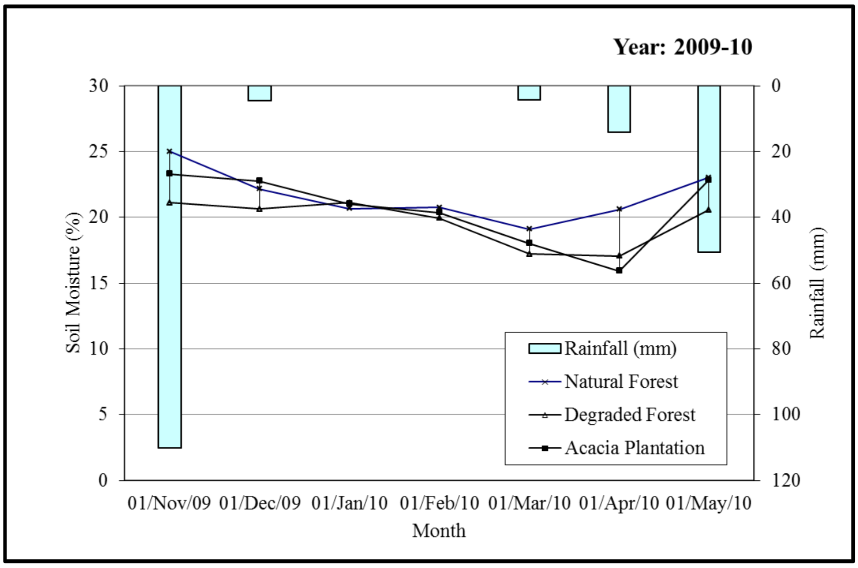

Fig 4 Temporal variation of rainfall and mean soil moisture (up to 210 cm) under different land use system during critical period (Nov-09 to May-10)

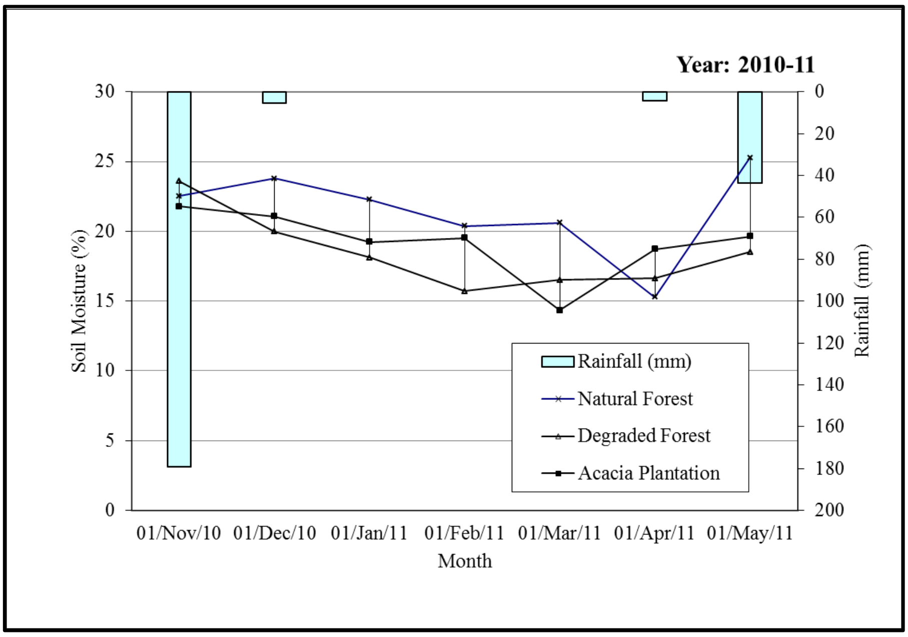

Fig 5 Temporal variation of rainfall and mean soil moisture (up to 210 cm) under different land use system during critical period (Nov-10 to May-11)

Relationship between the stand density and soil moisture

The relationship between tree density and soil moisture was presented in fig 6. The soil moisture was found to vary considerably with tree species and is positively correlated with tree density. Irrespective of land use system, soil moisture increases with increasing stand density. Among various land use system average soil moisture was highest (22%) in natural forest followed by acacia plantation (20%) and minimum of 19% was found in degraded forest. Increase in mean soil moisture under higher stand density may be due to the presence of higher litter on soil surface, which occurs from large number of natural trees and *Acacia auriculiformis* plants which helps in arresting evaporation of soil moisture from soil surface. Additionally, deposition of higher litter improves the soil organic matter which leads to improve soil moisture holding capacity in semiarid tropical region. Diminishing mean soil moisture with decreasing tree density was mainly due to evaporation loss of moisture from soil surface. Our results are consistent with those (Kowal, 1959) who reported high positive correlation between stand density and soil moisture, soil nitrate, organic litter, soil nutrient status and yield of crop. Tyagi et al., (2011) reported that soil moisture in lower Himalayan region of India decreases with canopy density and the studies carried out by Duan et al., (2011) indicated that locations with denser vegetation cover tend to have higher moisture contents.

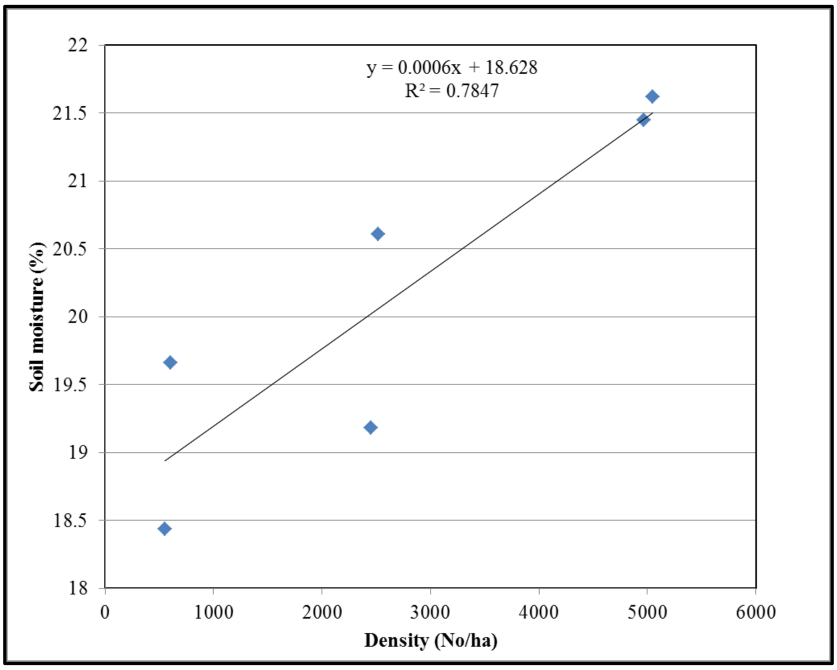

Fig 6 Relationship between tree density and mean soil moisture under different land use system

Spatial variation in Soil Saturated hydraulic property

Saturated hydraulic conductivity (Ks) curves with soil depths for different land use system is presented in Fig. 7. In general, saturated hydraulic conductivity (Ks) with depth decreases from surface up to 1.5 m in all the three land use system. However, it is observed that, particularly in forest and plantations there are instances of high rate of hydraulic conductivity at the surface layer, followed by considerable reduction up to 0.45 m depth and become steady thereafter. The maximum (120 mm/hr) saturated hydraulic conductivity was observed in the Natural forest followed by acacia plantation (74 mm/hr). Hydraulic conductivity in degraded forest show only 18 mm/hr at the surface. In natural forest, it was noticed that Ks value decreases with depth (119mm/hr at surface to 16 mm/hr below 0.5 m depth) up to 0.5 m and thereafter become steady (constant). In acacia plantation, it varies between 19 mm/hr and 74 mm/hr. The higher rate of hydraulic conductivity in the natural forest and Acacia Plantation may be due to the presence of high vegetation density and organic matter up to a depth of 0.30 m, which allow water molecules to flow vertically. The decrease in hydraulic conductivity from surface to 0.45 m depth and remaining steady (constant) thereafter may be due to the increased clay content at deeper soil layer. Decrease in hydraulic conductivity in degraded forest may be due to soil compactness, which reduces total pore space resulting in poor infiltration. Our findings are on par with several studies conducted by Bonell et al., (2010) observed in a complex landscape of Western Ghats of India. In two of the three, dominant soils, Ks changed across woody vegetation classes, with the highest in secondary forest, to degraded forest, to plantations. Further, same study illustrated that areas that had previously been degraded for decades to centuries and then converted to tree plantations had K_S values that were closer to the background Ks (the K_S of local forests) at the surface but not at deeper points in the soil profile. Purandara et al., (2006) found that particularly in forest and teak plantation there are instances of high rate of infiltration at the surface followed by considerable decrease with depth of soil.

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Like vegetation density, soil type and texture also play a very important role in infiltration and hydraulic conductivity. While Bonell et al., (2010) stated that an increasing relationship between Ks and vegetation was specific to soil type. Other study found that coarse soils in general show a higher Ks than fine-textured soils (Saxton et al., 1986; West et al., 2008; Senarath et al., 2010), Bonell et al., (2010) saw Ks decreasing with less woody vegetation in Alfisols and Ultisols but not in vertisols.

In another study, Nath Tara and Bhattacharyya Krishna (2014) concluded that soil texture and soil organic matter content had influenced the hydraulic conductivity of the tea growing soil and a significance positive relationship was observed between hydraulic conductivity with organic matter content and sand, while, a negative relationship was found with clay content.

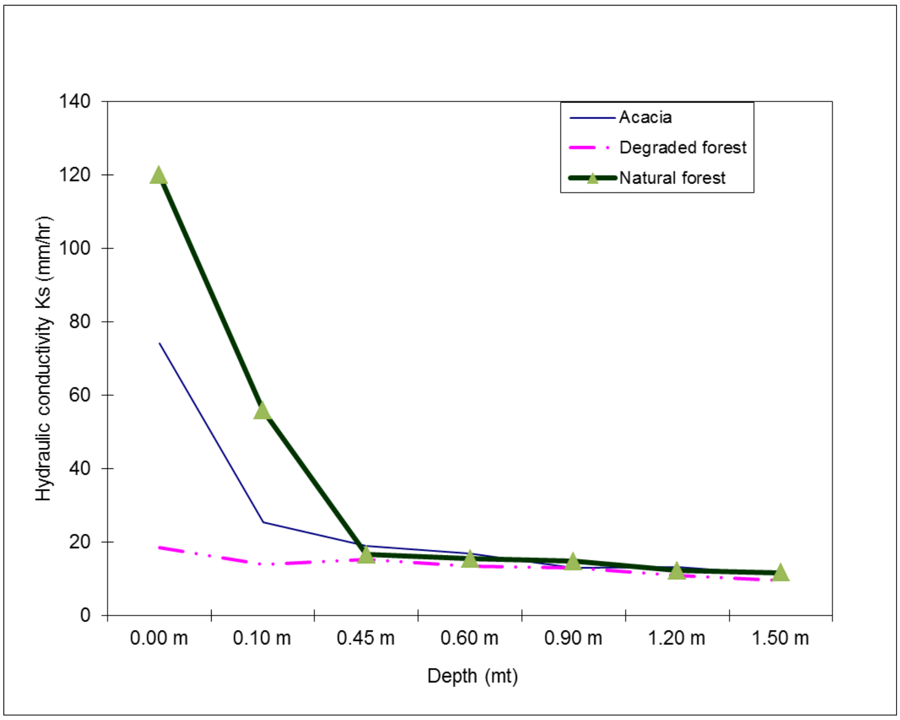

Fig. 7: Saturated hydraulic conductivity of different land use system in coastal zone of Uttarakannada District, Karnataka

Relationship between the stand density and hydraulic conductivity

Fig. 8 illustrates the relationship between vegetation density and saturated hydraulic conductivity of soil under different land use system. Present study illustrated that vegetation density is one of the important parameter which significantly influences soil hydraulic properties (Ks). Further, a positive correlation was found with type of vegetation. Irrespective of land use system, soil hydraulic property increased with increasing stand density. Among various land use system average soil hydraulic property (Ks) was found highest (120 mm/hr) in natural forest followed by acacia plantation (74 mm/hr). Minimum of 18. mm/hr was found in degraded forest. Increase in average soil hydraulic properties under higher stand density may be due to the presence of higher density of roots and soil organic matter and the presence of macro-pores (particularly surface layer) in the subsurface layer which allows vertical movement of water molecules. The study carried out by various scientists (Niemeyer et al., 2013; Thompson et al., 2010; Purandara et al., 2006) have demonstrated the effect of tree density and saturated hydraulic conductivity in various forest type and found there is a direct relationship between vegetation density and hydraulic conductivity $K_{S.}$ The major reason for such a pattern is due to the accumulation of biomass which enhances the infiltration capacity.

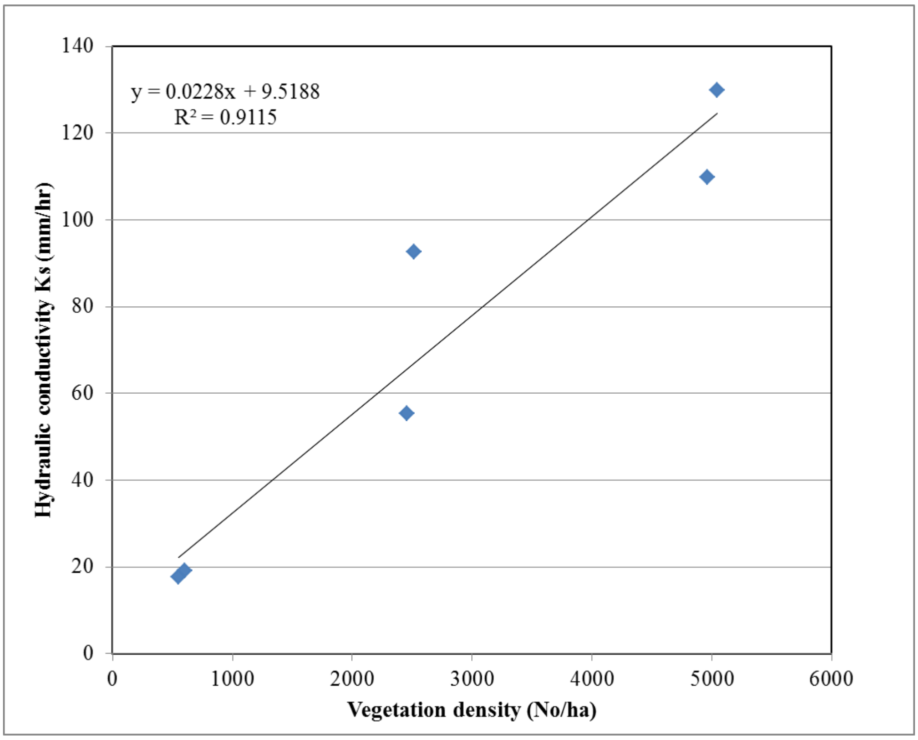

Fig 8 Relationship between stand density Vs hydraulic conductivity (K_s)

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