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Subsurface Drainage and Storage Properties in the Western Ghats - A Study in the Basin of Netravati

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Abstract

One of the reasons for the highly subdued response of the catchments, even to rainfalls of very high daily intensity, in the wet tropical areas of the Western Ghats in Karnataka is their soil mantle, which is very thick, well drained and very stable. An attempt is made in this work to understand the factors leading to such features, through a field study of the hydrological properties of the soils in the region. Cores extracted at road cuttings, from three different depths, at ten sampling sites scattered over the upland areas of the Kumaradhara basin, selected with due regard for the type of land covers commonly associated with hydrology, have been subjected to laboratory experiments to determine the soil texture, the porosity and the hydraulic conductivities. Ring infiltration tests have also been conducted on the field to cross verify the laboratory results. Storage capacity of the soils is estimated and compared with the rainfall magnitude in two small catchments in the area. The results indicate that the surface soils are sandy, while even at great depths, soils are Silty sands or Sandy silts, with high porosities and low drainage rates. The results are interpreted to mean that preferential pathways of macro-pores and soil piping would be an important feature in these areas. It is emphasised that more elaborate studies need to be taken up in order to understand the subsurface runoff processes in this hydrologically unique tropical region.

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Keywords: Catchment response; Soil hydrological properties; Western Ghats; Laboratory tests and field verification; Soil type and aquifer storages.

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1. Introduction

Numerous studies carried out using data of streamflow in the Western Ghat regions of Karnataka (e.g. Putty and Prasad, 2000a; Putty, 2009; Aniruddha, 2013) have established that runoff in this mountainous region is dominated by delayed flow contributed by the subsurface storages. Hence, a knowledge about the storage and drainage properties of the hydrologically active mantle of the earth is very important in the study of runoff processes in the region. Further, a reconnaissance travel through the hilly tracts of the region bestowed with very heavy rainfall shows that the region is characterised by an exceptionally thick layer of soil, which is also highly stable – vertical road cuttings taller than 20 m are found to be intact for decades, despite daily rainfalls exceeding 25 cm are a common phenomenon. Observation of water level in the wells across the region during the Monsoon season indicate that fluctuations in the water table are also very significant, being of the order of 10 to 12 m, in the upland areas. Hence, a study of the soil characteristics in the region of the Western Ghats would be informative and interesting too. Even though there have been a few studies on soils in the region (KSDA, 1985; Bourgeon, 1989; NBSS&LUP, 1996; Sivaprasad et al.,1998; Harindranath et al., 1999), the only one that seems to have concentrated on the aspects that shape the hydrological response of the catchments has been by Bonell et al., 2010. The present work aims to augment this study by procuring data from southern parts of the Western Ghat region of Karnataka. This paper reports a study on the hydrological properties of the soil, carried out in the upland areas of the basin of Netravathi, one of the largest west flowing rivers in South India. The intention of the work has been to understand the soil type, the porosity and the permeability of the soil at various depths and under various land cover types, the factors influencing the soil properties and to explore the possible influence of these characteristics on runoff production in the region.

2. The Study Area

The Western Ghats form an unbroken relief dominating the west coast of the Indian peninsula, for almost 600 km, extending between north latitudes of 8^0 and 21^0 (Figure 1). These mountain ranges also pass through the state of Karnataka covering the entire district of Kodagu and parts of six others. Also called the Sahyadri ranges, they posses some unique hydrological features, unfamiliar to the tropics, resulting mainly due to the characteristics of rainfall and geology (Putty and Madhusoodhanan, 2013).

Morphologically, this region can be divided into three zones – (i) the escarpment of the Ghats, which consists of numerous high altitude peaks, characterized by rounded crests, (ii) the foot of the escarpments on the west, towards the coast, where the Ghats descend very fast, characterized by very deep and steep valleys, and (iii) the back slope of the Ghats extending about 50 km into the South Indian Plateau, forming the hilly hinterland characterised by numerous peaks of intermediate level. The Western Ghat ranges form a barrier to the monsoon winds originating in the Indian ocean and moving north east. Hence rainfall in the region is very heavy during the South West Monsoon, which lasts between June and October. Annual rainfall exceeds 6000 mm all along the escarpments, with the wettest areas in the region recording about 8000 mm. Rainfall magnitude decreases steadily towards east, to a minimum of 1200 mm in areas bordering the Ghats.

Geologically, the study area consists exclusively of Precambrian formations with Gneiss and intrusive Granites forming the important rock types. The combination of such old rocks and heavy but low intensity rainfall has resulted in a well developed soil mantle characterising most of the slopes of the Western Ghats. Predictably, the region is an abode of rich vegetation, varying in type from grasslands to dense semi- evergreen to evergreen forests. Large areas of forest in the hinterland have been converted into Cardamom and Coffee plantations. Paddy, grown in the wide valleys, is the most popular food crop.

The present work being a preliminary study, investigations have been restricted to a small part of the upland areas of the basin of river Kumardhara, a tributary of Netravathi. Basically, two parts of the basin (Fig.2), the catchment of HongadaHalla and the region of Somavarapete, draining to the rivers Harangi and Kumaradhara, have been investigated, since studies on runoff generation in these regions are underway at the National Institute of Engg., Mysore. These regions experience heavy rainfall, typical of the Western Ghats – the normal annual rainfall varying between 3500 mm and 7000 mm over the area from where soils samples are collected.

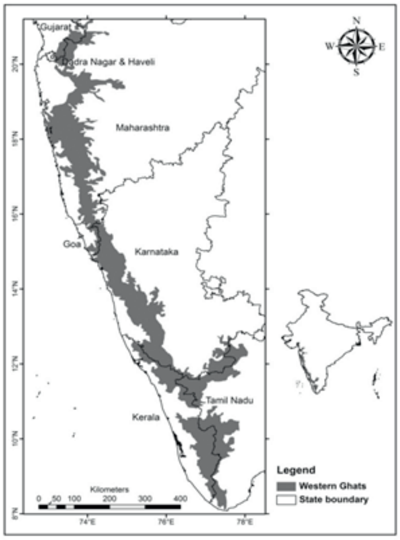

Fig. 1. Location and the extent of the Western Ghats

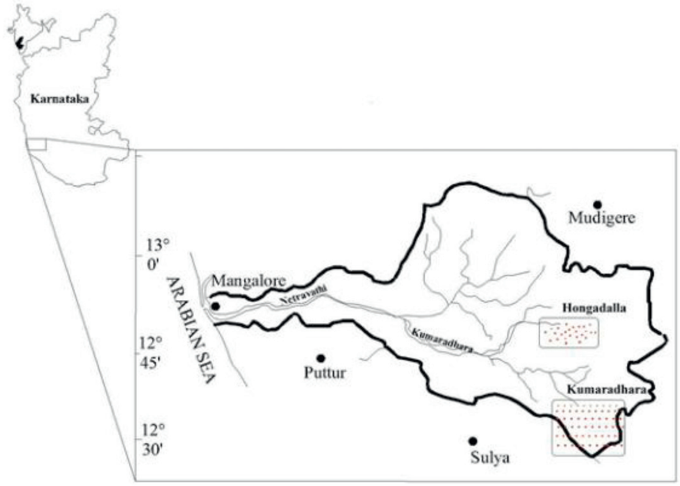

Fig.2. Location of the study area

3. The Methodology

The properties of the soil mantle that influence the pattern of catchment response to rainfall and control the flow in the stream are the infiltration rates, the storage capacity of the aquifer and the hydraulic conductivities. The infiltration rates are a surface property, which, together with rainfall intensity, influence the partitioning of rainfall into overland flow and flow in to the ground. Infiltration rates are influence by the land cover, in addition to the soil physical properties. The storage capacity is a function of the size of the aquifer and its porosity, and forms a very important control of the streamflow pattern in regions of excessive rainfall and infiltration. Hydraulic conductivity controls the rate of inflow to the aquifer store and the pattern of release of stored water as ‘subsurface flow’, more often than not, misquoted as ‘base flow’. The latter two properties are influenced almost exclusively by the soil texture and structure and hence form the centre of focus in the present work. It is well known that these properties vary widely over the mantle of the soil, both spatially and along the depth, variation over the depth at a location being indicative of the magnitude of development of the soil. It is believed that he soil properties and the land cover are interdependent also. Hence, any investigation aiming to understand the soil hydrological characteristics should be accomplished with a sufficiently large sample drawn from different sites, under different covers. In the present work, studies were carried out on samples from a total of ten sites, five each from the two parts of Kumaradhara basin, known to be characterised by two slightly different types of soils (Bourgeon, 1989). In each case, soil samples were drawn from the soil mantle under land covers including grass land, dense forest, with cardamom in some cases, and scrub forest. At each of the sites, soils were sampled at three different depths from selected deep and vertical road cuttings, an easy means to understand about the soil profile. Samples were drawn from just below the surface, near the middle and at the bottom of the cutting, catering to three different layers of the mantle, often not clearly distinguishable. The important details concerning the sampling sites are furnished in Table 1, and the depths at which the samples are drawn are presented in Table 2. In the lower mantles, cores could be cut only in the lateral direction, nearly perpendicular to the face of the road cutting. Since flow in the soil below the surface takes place mostly in the lateral direction, these samples were considered to be sufficient. However, at the surface, cores were taken both in the lateral and vertical directions. In all the cases, care was taken to see that the samples are representative – they were cut 15 - 20 cm inside the mantle, where the disturbance due to human activities is negligible. Even at the surface, the cores were cut 10 - 15 cm below the surface. In each case, laboratory tests were conducted to determine the particle size distribution, porosity and the saturated hydraulic conductivity. Standard test procedures were adopted and the soils were grouped according to IS-1498, 1970. However, due to constraints of time and availability facilities, the Hydrometer test, used to classify particles below 75 microns, was conducted in only a limited number of cases. In addition to the tests on samples, ring infiltrometer tests were conducted at a few sites, and, results from such tests conducted by earlier workers in the vicinity of a few other sides were used in used in understanding about the soil hydrological properties. As the next step of the work, the an attempt was made to determine the subsurface storage capacity of two catchments in the area, by assuming that the parameter values estimated by the samples for the respective land covers are applicable over the whole of the catchment.

Table 1. Details concerning the sampling points.

Site No.	**Lat. (12°)**	**Long. (75°)**	**Description**
		Sites in HongadaHalla Region	
H1	7’48.02”	43’ 14.3’’	Natural Shrubby region devoid of conversion or disturbance activities.
H2	46’ 48”	43’ 6.3”	Open scrub area subjected to grazing, mixed vegetation with native grass species and shrubs.
H3	46’ 19.9’’	43’ 28.6”	Well-established plain grassland (Maidan type area)
H4	46’ 5.9”	44’ 53.9”	Dense forest area, recently converted to Cardomom plantation.
H5	46’ 23.1”	43’ 27.9’’	Natural grassland, mixed vegetation with shrubs
		Sites in Somvarpete (Kumaradhara) Region	
S1	37’ 37.1”	48’ 58.4’’	Shrubby area, soil of weathered soft rock formation type.
S2	40' 23.9"	45' 10.1	Natural grassland
S3	40’ 15.9’’	42’ 58.0”	Dense forest area, recently converted to Cardomom plantation.
S4	40’ 11.5”	43’ 47.9”	Area with shrubs, mixed vegetation with native grass species and shrubs.
S5	40’ 7.8”	42’ 27.4’’	Natural grassland

Table 2. Depth of sampling.

	Layers	**H1**	**H2**	**H3**	**H4**	**H5**
Hongada Halla	**Total depth (m)**	4.5	6	3.5	4.8	4.3
	Top	0 - 2.8	0 - 3.2	0 – 2.0	0 – 2.3	0 – 2.5
	Middle	2.8 – 4.2	3.2-5.6	2.0 - 3.1	2.3 – 4.45	2.5 - 4
	Bottom	4.2	5.6	3.1	4.45	4
	Layers	**S1**	**S2**	**S3**	**S4**	**S5**
Somvarpete	**Total depth (m)**	3	4.6	5	4.6	4
	Top	0 -1.7	0 – 2.6	0 – 3.0	0 – 2.8	0 – 2.3
	Middle	1.7 -2.7	2.6 – 4.2	3.0 - 4.6	2.8 -4.22	2.3 -3.7
	Bottom	2.7	4.2	4.6	4.22	3.7

4. Results and Discussion

The soil types and the various parameter values representing the soil characteristics pertaining to the sites sampled are listed in Table 3. Some important inferences that could be drawn from the results are discussed below.

While gravel is found to characterise the soils only near the surface, sand forms the dominant type of soil fraction at most of the sites. While the 'silt and clay' portion of the soil is predominant often in the soils of Hongadahalla, it is found to be predominant in only two samples from the Somavarapete region. All the five samples on which the Hydrometer test was carried out show that the clay fraction of the soils is less than 10%. The visual indicative tests also go to establish presence of significant amounts of clay only in the top layer under forest covers. Hence, soil classification was done based on the information presented in Table 3. It is seen that while most of the soils in the Somavarapete region are Silty sands, Sandy silts and Silty sands are equally predominant in the Hongadahalla region. The Free swell ratio tests and the Cone penetration tests also show the dominance of Montmorillonite clay mineral in most of the soils. The mineral type is important in shaping the water retaining capacity of the soil. Presence of Montmorillonite goes to mean that water retaining capacity of the soil is high, promoting luxurious growth of evergreen vegetation.

Table 3. Particle size distribution and the type of the soils.

Sites	Layers	Gravel (%)	Sand (%)	Silt & clay (%)	Soil Type
H1 (Grass land)	Top	23	54	23	Gravelly sand
	Middle	0	50	50	Silty sand
	Bottom	3	65	32	Silty sand
H2 (Grass land)	Top	9	64	30	Silty sand
	Middle	12	57	31	Sandy silt
	Bottom	14	46	40	Clayey silt
H3 (Dense forest)	Top	37	43	20	Silty sand
	Middle	5	50	45	Sandy silt
	Bottom	8	42	50	Sandy silt
H4 (Shrubby area)	Top	23	49	28	Silty sand
	Middle	3	34	63	Silty sand
	Bottom	18	30	52	Silty sand
H5 (Grass land with slight shrubs)	Top	21	44	35	Silty sand
	Middle	1	44	55	Silty sand
	Bottom	0	56	44	Silty sand
S1 (Shrubby area)	Top	32	51	17	Gravelly sand
	Middle	39	46	15	Sandy silt
	Bottom	17	60	23	Silty sand
S2 (Shrubby area)	Top	17	47	36	Silty sand
	Middle	1	27	72	Silty sand
	Bottom	1	10	89	Silty sand
S3 (Grass land)	Top	20	51	29	Gravelly sand
	Middle	24	36	40	Silty sand
	Bottom	6	36	58	Sandy silt
S4 (Dense forest area)	Top	7	60	33	Gravelly sand
	Middle	18	61	21	Sandy silt
	Bottom	3	52	45	Sandy silt
S5 (Grass land with slight shrubs)	Top	8	65	27	Silty sand
	Middle	13	53	34	Sandy silt
	Bottom	2	71	27	Silty sand

4.1 Storage Capacities and the Drainage Rates

The dry density, porosity and the permeability at the different sites, determined using the cores sampled, are presented in Table 4. It can be seen from the table that the porosity values even at depths more than 5 m vary between 45% and 55%, except in just a few a cases, indicating that the soils are highly well developed. This is a very special feature of the Western Ghats (Bourgeon, 1989). Hence, they should form a reservoir of very high storage capacities. In order to get at least a rough idea regarding the quantity of water they can hold, the storage capacities are estimated assuming that the porosity values under the various land cover types that have been obtained from the samples hold good generally over the respective covers all over the catchment and that the depth of the soil layers are those obtained from various sites along the highways and presented in Table 4. The land cover types over the catchments of HongadaHalla (89 km^2) and Kamaradhara (45 km^2) are mapped using the Topo-sheets of the Survey of India and the recent Google images. The portion of the catchments in the wide valleys and that under the rocky outcrops are assumed to have zero storage and each of the other portions is assumed to have uniform depth of the soil mantles. The storage capacities estimated using all such information and expressed in terms of depth turn out to be 1600 mm and 2100 mm for the two catchments respectively. In fact, the actual values can be expected to be more since the soil depths are usually much greater than what are reflected at the road cuttings. On the other hand, the normal annual rainfall over the two catchments vary between 4000 mm and 7500 mm, with area averages of about 4500 mm and 5200 mm respectively, spread over about 110 rainy days of the S-W Monsoon. These figures go to mean that if the aquifers are recharged properly the soils can hold the complete amount of rain water and supply slow flow to the stream for long durations. However, flow rates into and inside the soil influence the role of the subsurface reservoir in shaping the runoff processes. Results from the present study provide a small insight in to this aspect.

A glance through the values of the Coefficient of Permeability (K) presented in Table 4 (Col. 5) shows that they are very low, being of the order of a few mm/hour in most cases. It is seen that even on the forest floors, the K values are about 4 to 6 mm/hour, which go to contradict the findings of the earlier workers (Putty et al., 1997, Srinivasa et al., 2010), according to which the K values, obtained using the Double ring infiltrometer, are very high in the region, particularly on the forest floors. Hence, in order to cross verify the results obtained from laboratory experiments on the cores, Ring infiltrometer tests were conducted at four sites in the Hongadahalla catchment, from where samples have been drawn. The results are presented in Table 5, where the values of the equilibrium rates of infiltration, considered equal to K and the values of K for the top soil obtained from the cores are furnished. Results from the study carried out by Srinivasa et al. (2010) in the Kumaradhara catchment, in the vicinity of the sites from where cores are drawn for the present study, are also presented in this table. It is evident that the equilibrium infiltration rates are much higher than the K values at each of the sites. These results may be interpreted to mean either that small core samples drawn are not representative of the drainage properties of the soil on the field or that drainage rates below the surface, even at depths of 20 - 30 cm, from where the cores have been drawn for the present study, are much less than those at the surface.

5. Conclusions

Implications of the findings from the present study on the hydrology of the region are important. That small core samples are not representative implies that preferential pathways like macro-pores (Luo et al., 2010) and soil piping (Jones, 1979, Putty and Prasad, 2000b) would be characterising these areas. Seepage velocities below the surface being much less than those at the surface indicate possibilities of wide spread surface saturation due to rise of perched water tables, producing excessive surface runoff during rains. Both these possibilities need to be investigated in detail through more elaborate and extensive studies. Studies on huge samples are being resorted to in recent years (Subhasisha et al., 2010) to understand preferential pathways and such investigations may be necessary even in the Western Ghats. Studies on surface runoff from field plots during rains also should be taken up. Ground water recharge studies on catchment scales could also be suggested. In summary, this paper may be considered to have highlighted the need for more elaborate investigations to understand the subsurface flow in this hydrologically unique tropical region.

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Table 4. Dry density, porosity and the Coefficient of permeability determined using the cores (V: Verticle; H: Horizontal)

Site	Layers	Dry Density (kN/m^3)	Porosity (%)	K (cm/ hour)
H1 (Grass land)	Top	14.13	43	V: 0.86 H: 0.28
	Middle	15.01	54	0.09
	Bottom	12.75	56	0.05
H2 (Grass land)	Top	12.26	53	V: 0.43 H: 0.30
	Middle	12.75	50	0.25
	Bottom	14.52	40	0.11
H3 (Dense forest)	Top	12.65	51	V: 0.63 H: 0.55
	Middle	12.36	52	0.45
	Bottom	12.46	51	0.38
H4 (Shrubby area)	Top	12.19	53	V: 0.81 H: 0.77
	Middle	11.87	57	0.27
	Bottom	11.87	53	0.02
H5 (Grass land with slight shrubs)	Top	13.73	47	V: 0.81 H: 0.77
	Middle	13.44	48	0.27
	Bottom	12.65	50	0.02
S1 (Shrubby area)	Top	15.07	42	V: 1.734 H: 0.442
	Middle	11.79	54	0.059
	Bottom	11.93	54	0.006
S2 (Shrubby area)	Top	14.32	45	V: 7.225 H: 0.672
	Middle	15.98	39	0.145
	Bottom	12.44	51	0.010
S3 (Grass land)	Top	13.70	47	V: 3.210 H: 0.903
	Middle	14.55	44	0.039
	Bottom	12.78	50	0.015
S4 (Dense forest area)	Top	14.60	53	V: 0.367 H: 0.240
	Middle	15.40	47	0.169
	Bottom	15.61	46	0.156
S5 (Grass land with slight shrubs)	Top	13.83	46	V: 1.734 H: 1.140
	Middle	12.98	50	0.492
	Bottom	12.48	51	0.270

Table 5. Laboratory results compared with the field infiltration capacities

Site	Final infilt. rate (cm/hr)	Top vertical Permeability Kv (cm/hr)	Top horizontal Permeability Kh (cm/hr)
H1(Shrubby area)	0.911	0.8660	0.2880
H2(Shrubby area)	8.650	0.4335	0.3031
H3(Grass land)	1.770	0.6302	0.555
H4(forest area)	2.800	0.8127	0.7742
S1(Shrubby area)	7.0	1.73	0.44
S3(Grass land)	5.6	3.20	0.90
S4(forest area)	89.1	0.37	0.24

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