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**Modelling of Soil Moisture Movement and Ground  
water Recharge in Biligihole Catchment, Uttara  
Kannada District, Karnataka**

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# CHAPTER 1

## INTRODUCTION

### 1.1 GENERAL

The impact of land use changes on hydrological regime has been known for many decades. In many developing countries, extensive areas are undergoing land use change. The largest changes in terms of land area, and arguably also in terms of hydrological impacts, often arise from afforestation and deforestation activities. There is now increasing recognition of the potential for land use and particularly land use change to impact on parts of the water cycle other than just rivers and lakes. The potential impacts on recharge characteristics are of particular concern as the water allocation process assumes a certain level of recharge of suitable quality (on average) each year — if this level of recharge is not achieved this will cause on going aquifer depletion in many parts of the country and cause adverse social and economic consequences. Generally groundwater recharge can be defined as the downward flow of water, originating from precipitation, rivers, canals or lakes, reaching the water table and thereby elevating the water levels. *“Groundwater recharge is the major limiting factor for the sustainable use of groundwater because the maximum amount of groundwater that may be withdrawn from an aquifer without irreversibly depleting it, under current climatic conditions, is approximately equal to long-term (e.g. 30 years) average groundwater recharge. Therefore, long-term average groundwater recharge is equivalent to renewable groundwater resources”* (Döll & Fiedler 2007).

Major changes in land-use have occurred locally, regionally and globally over the last century. These will continue in the future too. The impact of urbanization on groundwater has a major concern to most urban area over past few decades, and in particular, to those involved in groundwater quantity and qualitative studies. Increased impervious area has been major factor in contributing to decreased infiltration, which results in decreasing groundwater storage. The impact of urbanization on groundwater and its improvement depends to a great extent not only on the level of urbanization but on the nature of urbanization as well. Thus, land – use changes has to be assessed properly. Large pressure of growing population, increased demands for food, fodder and fuel combined with industrial activities have essentially led to rapid change in land use patterns in developing countries. Since the beginning of human civilization, mankind has lived in close relationship with nature. While mankind interdependence on environment is

greater than that of any other organism, his restless pursuit of progress, comfort and security has resulted in increased stress on the environment, which led to land - use changes over a period of time. Planning for development of natural resources without endangering the environment is a crucial issue and the world is facing this task today. Information on the rate and kind of change in the land resources is essential for proper planning, management and regularizing the use of such resources. Land use information is needed in the analysis of environmental processes and problem. It is necessary to understand the surrounding at present conditions and standards to be improved or remained at current level. Information on existing land use, its spatial distribution and its changes are essential prerequisite for planning and management. Land - use planning and management strategies hold key for development of a region. One of the most devastating effects of land use changes are seen in tropical regions. The land use/land cover changes are significant in the tropical forests due to various reasons. However, very limited studies are available specific to tropical climates. Though there are number of studies conducted with specific reference to surface water availability, the studies related to groundwater are still in dormant stage and needs a boon from the funding organizations to take up field based studies.

## **1.2 BACK GROUND**

Tropical forest ecosystems generate multiple benefits to society, including goods such as fuel - wood, fodder, timber, leaf manure, food and medicines, and services such as carbons sequestration, habitat for wildlife and biodiversity. Watershed services, which include hydrological regulation (groundwater recharge, low - flow augmentation, flood control) and soil conservation, are considered to be one of the important benefits from forests. Thus, changes in forest condition are likely to have profound implications for society. This is particularly likely in densely populated, historically used river basins of South Asia, where forest cover is changing rapidly in quantity and quality, and where river flows are being increasingly harnessed for supplying scarce irrigation and drinking water.

In many ways, the hydrological service benefits of forests and associated ecosystems (such as grasslands) are perhaps the most poorly understood and contentious of all forest ecosystem benefits. Firstly, there are few rigorous studies of hydrological impact—even in physical terms—of different forest covers. Existing studies are limited to a few regions, and the insights that may have emerged from these studies cannot be safely extrapolated too the regions in the tropics. Secondly, the studies that exist do not provide

a consistent picture of the link between forests and hydrological regulation. What seems to emerge is that not all types of “forests” have equal or even unidirectional influence on hydrology, and neither are all “non-forest” land - uses deleterious to all these services. Thirdly, we understand even less about how physical changes in hydrological parameters might translate into social impact. In this section, we summarise briefly the current understanding and debates about the influence of tropical forest/land - cover on hydrological services and about the social significance of these services.

Popular belief is that forests perform extremely critical watershed functions, as they enhance rainfall, act as “sponges” that prevent floods during the monsoon and release water during the dry season, and prevent soil erosion. But after almost eighty years of watershed experiments (in mostly temperate regions), hydrologists had, by the mid-1980s, become rather sceptical of these popular “myths” (Hamilton, 1987; Hamilton, 1983). The growing knowledge of the higher consumption of water by trees compared to other vegetation such as grass was even used to question and reverse the traditional policy of afforesting non-forested catchments upstream of water-storage reservoirs in some temperate locations (Calder, 1979; Scott and Lesch, 1997; Finlayson, 1998). Strong evidence that flooding and sediment transport in flood plains downstream of young, geologically unstable mountain systems such as the Himalayas is often unrelated to “deforestation” upstream contributed to this process of myth deconstruction (Ives and Messerli, 1989). Subsequent research, however, showed that conclusions drawn from clear-cutting experiments in temperate ecosystems cannot be casually extrapolated to tropical ecosystems and the “clean” manipulations in the experiments bear little resemblance to the actual process of deforestation (Bruinjeel, 1991;1993). In the tropics, controlled experiments are few and far between, not covering the diversity of geomorphological conditions. Furthermore, they often are of short duration and/or do not accurately mimic the actual land-use that prevails after conversion of forests (Bonell, 1998). It is now accepted that the effects of tropical forest degradation, loss, or afforestation on watershed functioning will vary with spatial scale, precipitation characteristics (such as rainfall intensity), pedology, soils and of course the type of land-use that prevails after forest conversion (Calder, 1992; Bonell, 1993). In other words, simplistic statements that forests have positive (or negative) watershed benefits are no longer tenable; the relationship is likely to be highly contextual.

In the particular context of south Asia, research therefore needs to focus on two different ‘forest’ use systems. On the one hand, the use of forests by local communities has generated a complex mosaic of dense stands of secondary growth, tree savannahs,

seasonally protected grasslands, stunted scattered trees and shrubs, heavily grazed grasslands with exposed soils, or even closed canopy tree cover with no under-storey or leaf-litter. It has already been shown that from productivity or diversity point of view, the tendency to characterise all such forests as 'degraded' is without an adequate empirical basis (see, e.g., Lélé, 1993; Lélé, 1994, for the Western Ghats). The hydrological impacts of such heavy use, however, remain largely unknown (Bruijnzeel, 1989).

On the other hand, state forest agencies have followed the practice of converting natural forests or historically used grazing lands into monocultural plantations, earlier for production forestry and more recently for their supposed local and environmental benefits. But it is not clear that these strategies are indeed always beneficial from a watershed perspective. Recent evidence on this question is mixed. Firstly, soil erosion depends more on the groundcover than on tree canopy cover. Thus, high erosivities have been recorded in teak plantations, where the canopy is high, leaves are large, trees are deciduous and undergrowth is poor (Kusumandari and Mitchell, 1997). Rainfall erosivity in Java increased significantly under plantations of *Acacia auriculiformis*, mature oil palms, and bamboo after the canopy was established (Young, 1991). Secondly, hydrological changes are equally dependent upon earlier land-use, nature of plantation and pedological properties. Planting of eucalyptus on natural montane grasslands in the Nilgiris has been found to reduce water yield from catchments by up to 23 %, with implications for downstream hydropower projects (Sikka *et al.*, 2003). A reduction in water yield was also observed in a study of the hydrological effects of replacing natural forest with pine plantations in Chiang Mai, Thailand (Vincent *et al.*, 1995). Research on the impacts of monoculture afforestation is therefore also called for.

The social impacts of changes in hydrology due to forest cover changes are even less well understood or studied. From the few studies that are based on empirically established models of the forest-water relationship at that site, one finds that the impacts are highly context-dependent. While Vincent's study related to water availability for agriculture and urban areas, Aylward *et al.* looked at the impacts of converting forest to pasture on total flows and sediment load (Aylward *et al.*, 1998), Pattanayak's various papers analysed the impacts of deforestation on base flow used in agriculture in eastern Indonesia (Pattanayak, 2004; Pattanayak and Kramer, 2001b; a) and Kramer *et al.* (1997) examined the flood control benefits of forests. Not surprisingly, the 'economic value' of impacts ranged from 3cents/yr/ha of forest for flood control to about \$8/yr/ha for increased agricultural production in eastern Indonesia. Secondly, the beneficiaries of increased hydrological services may be quite different from those who bear the costs of

forest conservation (see, e.g., Xiaogang, 2001)—a point that tends to get glossed over in the economic valuation literature but which is of crucial importance in devising policies for forest and water management. This is particularly true in the south Asian context, where natural resources are used intensively by diverse groups. Thirdly, the impacts would clearly depend upon the technological and institutional context governing water use—something that has again received little attention so far.

### **1.3 STATEMENT OF THE PROBLEM**

Understanding impacts of land use/land cover (LU/LC) change on the hydrologic cycle is needed for optimal management of natural resources. The global impact of LU/LC change on the hydrologic cycle may surpass that of recent climate change (Vorosmarty et al., 2004). Impacts of LU/LC change on atmospheric components of the hydrologic cycle (regional and global climate) are increasingly recognized (Bonan, 1997; Pielke et al., 1998; Pitman et al., 2004). Impacts of LU/LC change on subsurface components of the hydrologic cycle are less well recognized, particularly groundwater recharge. The potential scale of subsurface impacts is large. Groundwater is Earth's largest freshwater resource. Reduced reliability of surface water supplies in the western US with projected climate change during the next century (Service, 2004) may result in increased reliance on groundwater. Widespread changes in LU/LC have occurred as a result of agricultural expansion. In the past 300 years, cultivated cropland has increased by factors of 70 in the US and globally (Richards, 1990). The projected global increase of agricultural lands is 20% over the next 50 years (Tilman et al., 2001). Agricultural areas are classified as irrigated or non-irrigated dry land or rainfed). Most recharge studies have been conducted in natural rangeland ecosystems (Cook et al., 1989; Phillips, 1994; Tyler et al., 1996; Izbicki, 2002); however, replacing rangeland with agricultural ecosystems alters many of the parameters controlling recharge, such as climate, soils, and vegetation. Increased evapotranspiration (ET) because of large-scale irrigation alters regional climate through precipitation recycling (Moore & Rojstaczer, 2002; Adegoke et al., 2003). Irrigation increases the amount of water applied to the system, generally enhancing groundwater recharge (Roark & Healy, 1998; McMahon et al., 2003). Tillage affects recharge by changing soil structure (Leduc et al., 2001). Agricultural conversion alters key vegetation parameters that affect recharge, including fractional vegetation coverage, wilting point, and rooting depth. Reducing fractional vegetation coverage to zero during fallow periods between crop rotations can increase recharge, as shown in the Northern Great Plains, US (Miller et al., 1981). Lysimeter studies indicate that devegetation can

increase recharge even in desert environments (Gee et al., 1994; Scanlon et al., 2005). The wilting point represents the minimum matric (pore-water-pressure) potential at which plants take up water. Increasing the wilting point from that typical of natural rangeland vegetation to much higher values typical of agricultural crops should increase groundwater recharge. Replacement of deep - rooted perennial Eucalyptus in Australia by shallow - rooted annual crops increased recharge by up to two orders of magnitude (Allison et al., 1990; Petheram et al., 2000). The situation is reversed in Argentina where shallow-rooted grasses are replaced by deep - rooted trees, decreasing recharge (Jobbágy & Jackson, 2004). Variations in recharge associated with LU/LC changes can have negative impacts on groundwater quality because thick unsaturated zones in semiarid and arid regions contain a reservoir of salts that accumulated over thousands of years (Allison et al., 1990; Phillips, 1994; Walvoord et al., 2003) and can be flushed into underlying aquifers. Increased recharge associated with agricultural development in south eastern Australia mobilized salts that had accumulated beneath native mallee eucalyptus vegetation, degrading groundwater quality (Allison et al., 1990). Miller et al. (1981) attributed saline seep development in the northern Great Plains to fallow periods in dry land agriculture, flushing salts from marine sediments in the unsaturated zone. Studies have shown that artificial recharge in southern California (US) can mobilize naturally occurring arsenic, chromium, and other salts impairing groundwater quality (Aiken & Kuniansky, 2002). Sustainable resource management planning requires considering the impacts of LU/LC changes on both the quantity and quality of groundwater.

## **1.4 OBJECTIVES OF THE STUDY**

1. To estimate the soil hydraulic properties such as infiltration, hydraulic conductivity and soil retention characteristics and to determine the variation of parameters with reference to changes in land use/land covers.
2. Modelling of soil moisture movement using Hydrus – 1D model.
3. To understand the impact of land use changes on soil physical and chemical properties.
4. To understand the relationship between plant richness and soil properties

## **1.5 SCOPE OF THE STUDY**

The major focus of the study was on the field experimentation in three micro-watersheds located in the Uttar Kannada District, Karnataka State, India. These experimental watersheds, each possessing a different land cover (forest, degraded and acacia) were established for long term monitoring of soil matric potential, climate

variables and runoff. Physical and hydraulic properties of the soil in the watersheds were characterised using in-situ and ex-situ procedures. Runoff was also measured at the outlet of the Biligihole catchment in which the watersheds are located. Observations were subject to various analyses aimed to test the hypothesis that reforestation reduces surface runoff and increases soil moisture content and nutrient within the root zone. To assess the socio - economic potential of various reforestation strategies in relation to the existing land use practices.

## CHAPTER-2

### LITERATURE REVIEW

#### 2.1 GENERAL

Numerous studies have been conducted in the past to examine the impact of forest degradation on the soil hydrological regime. There is a commonly held belief that degraded land have much reduced vertical percolation to the water table and in turn, much increased storm runoff, erosion and nutrient loss at the surface, consequently dry season base flow in streams essential for water supply in agriculture and domestic use would be substantially reduced. Further, one would expect to find a depletion of available soil moisture and nutrient status for plant grown. Such claims have not been scientifically quantified, possibly due to the limited duration and nature of earlier studies.

In India, Forest hydrology is still in an infant stage because, most of the studies conducted are in the scattered form which need collective efforts from various group of scientists. Literature on forest influences on hydrological parameters for a forested watershed is not yet available which could define the entire hydrological system and water budget of a particular forest. However, attempts were made by Pathak (1983) and Hewlett (1982), to study the apportionment of gross rainfall through different pathways, storage and losses.

Experimental studies have been conducted at various places in India to assess the effects of forests and forest management practices on water yield, peak flows and soil loss. Mathur et al. (1976) reported that reforestation of a small watershed (1.45 ha) by *Eucalyptus grand* and *Eucalyptus camaldulens* is reduced by volume and peak rate of runoff by 28 and 73% respectively from 1969 to 1973 by replacing the brushwood.

The effect of forest cover on groundwater storage can be inferred from, soil moisture and discharge relationships. It depends partly on the depth and proliferation of rooting system and on growing season length. Study carried out in the case of *eucalyptus camaldulensis* of 5 and 15 years age, root depth was less than 3m and lateral spread was upto 9 m and 20 m, respectively. This indicates that most of the water demand by this species was met from the surface layers rather than from the permanent groundwater table. Increase in the water table due to afforestation and other soil conservation measure in a watershed of 314 ha has been evidenced in C.R.Halli, Chithradurga. In the semi –

arid areas of Gujarat, the water levels of the wells of eucalyptus hybrid plantation did not go deeper than that of well in surrounding farms during periods of 7 years. Samraj (1984) observed that plantation of eucalyptus trees in Nilgiris has resulted in significant lowering of base-flow. Similarly a survey conducted by Gujarat Forest Department in April 1984 showed that out of 143 tube-wells in eucalyptus plantations of six districts, there was no drop of water table in four districts whereas in two districts the drop in level was less than that of control wells located outside the plantation area (Chandrasekharan, 1984). Singhal (undated) reviewed Indian experiments of effects of eucalyptus plantation on groundwater table. He concluded that the tap root of eucalyptus is not a major absorber of water from the water table in the low lying area, however, where the superficial root system is in contact with the capillary fringe of water tables direct absorption could be significant.

In the late eighties greater emphasis has been given for forest ecological and hydrological studies in India. In the latter years, National Institute of Hydrology has carried out few studies on Forest Hydrology. Detailed infiltration and runoff studies were carried out by Purandara et al. (2006), and Venkatesh et al., (2003). James et al. (2000) observed that in parts of Western Ghats the annual and monsoon stream flows from a unit area of the exploited watershed are much more than that from the dense forest watersheds. This study also indicated that in the forest watersheds, there is more storage of water and initialization by plants. Putty et al., (2000) also made efforts to understand the process of runoff generation mechanism in parts of Western Ghats.

Purandara et al. (2002) made an attempt to understand the impact of forest cover on groundwater. Investigations were carried out in Malaprabha sub-basin to estimate the ground water recharge under varied forest covers. The results indicated that forests and afforested areas have higher recharge capacity than the degraded and agriculture lands.

Later work using experimental catchments reported by Krishnaswamy et al., (2012) showed how land-cover change from native forest to heavily used forest and its subsequent reforestation have major effects on the rain-runoff process in the wet-season. They showed the highest proportions of rain converted to runoff being associated with the degraded forests whereas the natural forests showed the lowest runoff yields. Using stream hydrograph separation, they also reported much higher quick flow volumes from degraded forest and reforested, former degraded land in the form of *Acacia auriculiformis* plantations when compared to the less disturbed natural forest. Furthermore, time series analysis showed much shorter rainfall-runoff time lags for the degraded forest and *Acacia auriculiformis* plantations when compared to natural forest. This characteristic of faster

rainfall-runoff responsiveness supports the notion of the frequent occurrence of IOF within the former two, more human-impacted land covers. The study carried out by Krishnaswamy et al., 2012, clearly indicates that even assuming the maximum measured annual evapo – transpiration (AET) for humid forests globally (say 1500 mm) the estimated water available for recharge from natural forest catchments annually after accounting for both measured runoff and AET was 259 mm (rainfall of 2252 mm) and 978 mm (rainfall of 4016 mm). Thus it was concluded that (i) a significant amount of rainfall was potentially available for recharge to groundwater and for downstream base-flow and dry-season flow, (ii) deeper subsurface water or groundwater of possible large capacity, had a significant role in the storm runoff generation process and (iii) the continuation of a secondary, longer rainfall-runoff time lag in the intensely, disturbed land covers indicated that there was a retention of ‘memory’ of the previous natural forest response. Therefore, from the above discussion it is clear that the forests play a significant role in water management and need much more exploration based studies to bring out some concrete conclusions.

## **2.2 INTERNATIONAL SCENARIO**

Over the last few decades, dramatic land use (LU) and land cover (LC) changes (defined and described in Drigo, 2006) have taken place in the humid tropics (Chang & Lau, 1993) which have resulted in rapid rates of deforestation. In response, Giambelluca (2002) remarked that hydrologists have traditionally focused on the hydrological impacts of forest conversion to cleared, actively used land, that is, at the respective extremes of this LC taxonomy (e.g. Bruijnzeel 2004; Costa, 2004; Grip *et al*, 2004). The LC of the tropics is now becoming more fragmented and highly complex, and secondary forest is now emerging as the dominant forest type interspersed with remnants of old-growth forest and other LCs (Giambelluca, 2002 ; Drigo, 2004 ; Holscher et al, 2004). The storm runoff hydrology of these intermediate LCs such as ‘altered ‘secondary forest, ‘degraded’ (Scott et al., 2004) LC from multi-decades of human occupancy and ‘forestation’ (afforestation – reforestation, defined in Scott *et al*, 2004) of land in various states of degradation have been much less studied across a range of soils and scales (Giambelluca, 2002 Bruijnzeel, 2004 ; Holscher et al, 2004; Scott *et al*, 2004; Ilstedt et al, 2007). The need for such an attention is emphasized when one considers that globally an increasing proportion of the population in the humid tropics are becoming dependent on these intermediate LCs for their livelihoods because of decreasing availability (and access to) of primary tropical forest (Drigo, 2004). For example within South and Southeast Asia, it was estimated that about 45% of the total land area has been affected by human – induced

soil degradation (Eswaren *et al.*, 2001; Scott *et al.*, 2004). At the small scale (~1Km<sup>2</sup>), Ziegler *et al.* (2004, 2007) presented a case study from northern Vietnam which highlighted this issue.

There are reports (Scott *et al.*, 2004) from long-term, degraded landscapes in the tropics where a significant reduction in infiltration capacity has occurred from human disturbance such as intensive over-grazing and shifting cultivation following forest conversion *a priori* at multi-decadal time scales. There are reports of these circumstances leading to the occurrence of Horton-type (infiltration-excess) overland flow ( HOF, Chorley, 1978) ) across various scales of investigation ( Zhou *et al.*, 2001; Costa *et al.*, 2003; Bruijnzeel, 2004 ; Ziegler *et al.*, 2004; de Moraes *et al.*, 2006; Chaves *et al.*, 2008).

Such evidence is contrary to results from controlled, paired experimental research basins (Hewlett & Fortson, 1983; Bruijnzeel, 2004) which show that the largest increase in the stream hydrograph is within the delayed flow ( Chorley, 1978) component arising from the savings in ET following forest conversion. The latter however, relate mostly to the two-class land-cover taxonomy of Giambelluca (2002) where the various states of resilience of different soils to disturbance have remained high. Thus soils have retained comparatively high infiltration rates towards those of pre-disturbed conditions, and so LC change has had a minimal effect on quick-flow. Most important, the short duration of these experiments has not captured the hydrological responses to multi-decadal degradation (Bruijnzeel, 2004; Sandstrom, 1998). For selected soils in the tropics, the surface fabric is particularly vulnerable to collapse from human disturbance (e.g. Gilmour, 1977; Schack- Kirchner, *et al.* 2007). Also the exposure of such soils to the prevailing higher, rainfall intensities (Bonell *et al.*, 2004) compared with the temperate latitudes which can lead to raindrop compaction and sealing. (Sandstrom, 1998; Grip *et al.*, 2004; Scott *et al.*, 2004). This led to Bruijnzeel (2004) proposing the '*infiltration trade off hypothesis*' linked more with low flows, but it is also relevant here. If the surface infiltration characteristics are not significantly reduced following conversion due to soil aggregates being stable and resilient to dispersion (or if soil conservation measures exist) then percolation towards deep groundwater will be maintained, i.e. the 'non-degraded scenario'. Further, although not stated by Bruijnzeel (2004), no substantial change in the dominant flow pathways would be expected. Conversely if the surficial, soil fabric easily collapses on disturbance then a corresponding reduction in permeability (and thus infiltration) will affect the vertical percolation (VP) flux in the uppermost soil layers, i.e. 'degraded scenario'. Consequently there will be reduction in groundwater recharge.

Moreover this reduced infiltration capacity could facilitate the occurrence of HOF depending on such factors as rainfall intensity and duration , the hydraulic conductivity of the soil at different depths , slope morphology and the surface hydraulic resistance by biomass.

From the forgoing discussion it is evident that there is a lack of controlled, paired experimental research basins (Bruijnzeel, 2004; Scott *et al*, 2004) which have addressed any changes in the soil hydraulic properties and associated storm flow pathways in connection with the long-term impacts of 'forestation' of landscapes in various states of degradation. Particular emphasis was given to such forestation impacts when concerning severely degraded landscapes linked with the '*infiltration trade off hypothesis*' and the consequences on low flows above (Bruijnzeel, 2004). However, this research question applies as much to the other intermediate, land-cover taxonomy highlighted by Giambelluca (2002) and elsewhere (Godsey and Elsenbeer, 2002; Holscher et al, 2004; Ilstedt et al, 2007).

The above discussion clearly indicated the issues related data availability as most of the data is based on the point scale of measurement. Field saturated hydraulic conductivity,  $K^*$  (Bouwer, 1966; Talsma and Hallam, 1980) at various soil depths are linked with rainfall intensities to infer any changes in dominant storm-flow pathways. Particular focus has concerned comparisons between old growth forest and pasture for grazing, and also with secondary forest notably within the Amazon basin (Tomasella and Hodnett, 1996; Godsey and Elsenbeer, 2002; de Moraes et al, 2006; Zimmermann *et al*, 2006; Chaves *et al*, 2008) which incorporated mostly Ferrasols and Acrisols (FAO-UNESCO, 1974; 1988). The geometric mean or median values of  $K^*$  at the surface were shown to be up to two (2) orders of magnitude lower under pasture ( from cattle trampling) in comparison with adjacent forest. Not all these studies however suggested HOF would become dominant following disturbance due to the resilience of these soils. Instead both SSF (subsurface storm-flow) and SOF(saturation overland flow, SOF,) (Chorley, 1978) were indicated (e.g. Zimmerman *et al*, 2006) for a 20-year old pasture and 10-year old teak plantation. Similar conclusions emerged when comparing primary forest with ~5years secondary forest (Godsey and Elsenbeer, 2002).

Further the acceptance that surface compaction causes an 'inflection' in  $K^*$ ( as shown by Tomasella and Hodnett, 1996 in central Amazonia) so that  $K^*$  increases below the near-surface compaction, and then subsequently resumes its progressive decline in trend with increasing depth was challenged by Elsenbeer et al ( 1999). In their Rondonia

work, these writers noted no such inflection in  $K^*$  under pasture. Instead the trend was a more gradual decrease with depth.

Elsewhere Ziegler *et al* (2004) took  $K^*$  measurements across a range of land covers within the fragmented landscapes of two (2) upland drainage basins (0.91 Km<sup>2</sup>, 1.23 Km<sup>2</sup>) in northern Vietnam. Whilst small in area, compaction from walking paths, dwelling sites and roads contributed a disproportionate increase in HOF when compared with secondary forest. Otherwise the most prolific producer of HOF (and the next lowest  $K^*$  by LC) was from recently abandoned fields following cultivation due to the non-consolidation of the topsoil. These writers then showed a progressively increasing  $K^*$  following secondary growth succession and grassland, c.f. the Amazon basin studies. Moreover Ziegler *et al* (2004) reported an even more rapid decrease in  $K^*$  with depth under the more recently disturbed LCs (connected with upland field and intermediate secondary vegetation, mostly of bamboo) than with the reported trends from the Amazon basin studies. Such anisotropy Ziegler *et al* (2004) suggested would enhance the occurrence of SSF and return flow (RF) during monsoon events within these land covers. Paradoxically the noted inflection in  $K^*$  with depth *existed under sites not recently disturbed*, that is, beneath the secondary, evergreen – broadleaf forest (the least disturbed land cover), c.f. Tomasella and Hodnett (1996), as well as young secondary vegetation (mixed evergreen broadleaf bush).

The previous paragraphs described the various studies on going in various parts of the world and stressed the need for a field based integrated study to understand the impact of forest cover changes on hydrological regime.

### **2.3 REPORTED FINDINGS ON THE RELATIONSHIPS BETWEEN THE SOIL MOISTURE AVAILABILITY AND PLANT RICHNESS**

Several investigations have been undertaken on changes in plant richness along moisture gradients, but to date no consistent general relationships have been found. A number of researchers reported a positive relationship between plant species richness and rainfall (Richerson and Lum, 1980; Knight et al., 1982; Gentry, 1988; O'Brien, 1993). Richerson and Lum (1980), for example, investigated the effect of annual rainfall on species diversity in California, and found rainfall to be the strongest single variable controlling total species diversity as well as tree and herb diversity. The effect of precipitation on shrub diversity was small, but also significant. Minchin (1989) also found a significant positive correlation between species diversity and moisture

availability, while Leathwick et al. (1998) found that humidity is one of the most important predictors for biodiversity. By contrast, Cody (1989, 1991) found negative relationships between moisture availability and biodiversity in North American deserts. He reported that life form diversity peaked in climates characterized by low rainfall, high temperatures, and low seasonality of these factors.

These conditions enabled the coexistence of the widest range of plant life forms and the highest numbers of species. Montana (1990) also found that maximum plant richness occurred where water availability was low.

Contrary to these observations, some researchers have reported no correlation between plant richness and precipitation. Barbour and Diaz (1973) found no correlation between rainfall and species diversity in Arizona, USA and Argentina, and Currie and Paquin (1987) found a weak relationship between plant richness and precipitation.

### **2.3.1 FACTORS MODIFYING THE EFFECT OF SOIL MOISTURE ON PLANT RICHNESS**

The contradictory findings regarding the water received and plant richness can potentially be attributed to factors that modify soil moisture. A number of scientists used rainfall as a measure for moisture availability (Barbour and Diaz, 1973; Richerson and Lum, 1980; Currie and Paquin, 1987). Soil moisture, however, depends not only on precipitation, but also on soil infiltration and runoff factors. Other factors influencing moisture availability that should also be considered include: landscape position, slope, soil structure and texture, seasonality of precipitation and temperature.

Peet (1978) reported that moisture effect on diversity was modified by elevation in forest vegetation of the northern Colorado Front Range. At high elevation, the richest forests were on wet sites, and richness decreased toward the xeric end of the gradient. At middle elevations lowest richness was found near the central portion of the moisture gradient, and the highest diversity sites occurred near the moist end. With decreasing elevation the lowest diversity was observed at the moist end of the gradient.

Sala et al. (1997) reported that plant richness was more influenced by soil texture than by rainfall, and suggested that soil texture has a large influence on the location at which water is stored. Fine textured soils store more water near the surface layers than coarse-textured soils. Therefore fine-textured soils are more favourable for grassy vegetation with shallow root systems, compared to woody vegetation with deeper roots.

The seasonality of precipitation also affects soil moisture availability. Precipitation falling during the cold season has a higher probability of being stored in deep soil layers, because evaporation is relatively low. In deep soil layers grasses are less effective because of shallower root systems and therefore these conditions should favour woody plants. Areas with maximum precipitation during the warm season would have high evaporation and lower net water balance compared to the areas with precipitation during the cold season. These conditions should support grasslands (Sala et al., 1997).

Temperature can also modify the effect of moisture availability on plant biodiversity. Austin et al. (1996) in their research in New South Wales, Australia, found that at low temperatures, tree richness was constant along the rainfall gradient, while at high temperatures a humped response was observed, with the maximum richness occurring between 900 and 1200 mm rainfall.

Pausas (1994) used an integrative approach for an investigation of the relationships between moisture availability and richness of understorey of *Pinus sylvestris* forest in the eastern Pyrenees. He used a moisture index based on soil and site parameters (topographic position, slope, soil texture, stoniness and soil depth) and found a humped curve for moss species richness.

## **2.4 RELATIONSHIPS BETWEEN ENVIRONMENTAL FACTORS AND PLANT RICHNESS**

A correlation between environmental factors and plant species richness (here after referred to as plant richness) has been reported (Lavers and Field, 2006). This is due to the profound effect extended by environmental factors on plant growth. No species are suited to every environment. Different plant species differ for moisture, soil nutrient content and amount of radiation received. Furthermore, environmental factors, such as energy and nutrient availability, control population growth. Conditions leading to an increase in growth rates of competing species result in monopolisation of resources by well-adapted species, and extinction of less-adapted species, which are unable to withstand competition. These processes are assumed to affect biodiversity negatively, i.e., reduce plant richness (Huston, 1979).

Numerous studies have reported hump-shaped relationships between plant richness and environmental factors (Grime, 1979; Tilman, 1982; Vermeer and Berendse, 1983; Janssens et al., 1998; Pausas and Austin, 2001). This pattern has been interpreted

by a number of researchers (Grime, 1979; Huston, 1979; Austin, 1982; Tilman, 1988), whose theories can be summarised as follows. When resource availability is limited only a few species can survive these stressful conditions. As resource availability increases, more species can survive and hence plant richness rises. With a further increase in resource availability a few highly competitive species become dominant, leading to extinction of other, less-competitive, species. This competitive exclusion causes a decline in plant richness.

#### **2.4.1 FACTORS WHICH SHOULD BE TAKEN INTO ACCOUNT WHEN INVESTIGATING THE EFFECTS OF ENVIRONMENTAL FACTORS ON PLANT RICHNESS**

Investigations into the relationships between plant richness and environmental factors have resulted in recommendations for conducting studies on richness-environment relationships. These can be grouped as follows: 1) the scale of the environmental gradient should be taken into account; 2) the patterns for different life forms of plants should be compared; 3) multivariate gradients, not single variables should be investigated, and 4) variables related to the growth of plants should be explored (Pausas and Austin, 2001).

##### **2.4.1.1 Scale of Environmental Gradient**

A consideration of scale is of critical importance when investigating plant richness in relation to environmental factors (Austin et al., 1996). Plant richness is controlled over large scales by climate and over small scales by environmental heterogeneity. Climate affects the input of the resources needed for plant growth, such as moisture, solar radiation, and temperature, while environmental heterogeneity (topography, aspect, infiltrability) determines the number of “realized environmental gradient combinations” in a particular landscape. It is theorised that the greater the number of the combinations, the greater the number of richness for plant growth, which enables more plant species to co-exist.

##### **2.4.1.2 Life Form Richness**

A number of researchers have reported that environmental “predictiveness” increases when plant life forms are investigated separately.

Austin et al. (1996) investigated the effect of environmental factors on life form richness (number of species within life forms) in Australia. Each life form showed a different response to the environmental predictors. Maximum richness of Eucalyptus

species occurred at high temperatures, intermediate rainfall and radiation conditions on ridges with a seasonal rainfall and intermediate nutrient levels. By contrast, maximum richness of rainforest species occurred at high temperatures, intermediate rainfall and low radiation in gullies with summer rainfall and high nutrient levels.

Minchin (1989) also found different patterns of richness for different life forms (namely, trees, shrubs, herbs, graminoids and ferns) in sub-alpine environments of Tasmania. These patterns related to two-factor gradients of soil drainage and altitude. In Minchin's (1989) research, trees attained their maximum richness on moderate to excessively drained sites, while shrub richness peaked on well-drained sites. The maximum richness of herbs was on poorly drained and waterlogged sites.

#### **2.4.1.3 Effect Of The Combination Of Factors On Plant Richness**

Plant richness is likely to be governed by two or more environmental factors. Most environmental factors are complex (Whittaker, 1967). They involve a number of variables, only some of which exert a direct effect on the performance of species. A one-dimensional environmental gradient is meaningless unless defined in terms of other environmental conditions, and generalisations about single gradients are conditional upon other variables. Huston (1997) wrote that mistakes in conclusions about environmental factor's effect on species diversity might lie in "hidden treatments". These "hidden treatments" may be abiotic or biotic conditions, which are not taken into account during experiments. Pausas and Austin (2001) also emphasized the importance of multi-factor studies and the use of non-linear statistical techniques. The length of the nutrient gradient, the correlation with other nutrients present and the influence of pH on nutrient availability may all influence the shape of the response of plant richness to a nutrient (Pausas and Austin, 2001). Among the soil properties affecting plant growth, soil pH, electrical conductivity (EC) and moisture availability play the most important role.

## **2.5 MATHEMATICAL MODELLING IN FOREST HYDROLOGY**

Large number of process studies and catchment experiments has been made on effects of land use changes on the hydrological and other resources in forest ecosystems. Information from these investigations is invaluable and should be enlarged upon. However, source data that are obtained from one location seldom can be applied directly to estimate impacts at other locations. Alternative means of predicting consequences of land use on forested areas are required in many instances. One such means is the

application of forest hydrological and watershed management through computer simulation models.

It is a fact that in most of the cases empirical formulae does not work well in forested catchments. Therefore, it is necessary to develop physically based models to estimate various components of the hydrological processes. Since 1980s, increasing attention has been devoted to the development and testing of more physically based models to address the practical issues of predicting the future of hydrological effects of land use and climatic change, especially in ungauged drainage basins where no data are available for model calibration or recalibration (Beven,1992). Probably the two best known distributed models of this type are the System Hydrologique European model (SHE) (Bathurst, 1986a, b; Abbott et al., 1986a, b) and the Institute of Hydrology Distributed Model (IDM) reviewed by Beven (1985)). To avoid the excessive computational burden of simulations, certain simplifications are made in both models so that neither of them can be considered fully three dimensional in their approach (Binley and Beven, 1992;Jain et al;1992). The attraction of these models is that they intend to use variables that have physical interpretation. Furthermore, they have apparent theoretical rigour when related to the environment in terms of scientific physical understanding of the hydrological processes involved. Both models are based on numerical solutions (finite difference, SHE; finite element IDM) of the partial differential equations describing surface and subsurface processes which involve differently designed grid systems. Selected variable values which have a physical meaning are allocated for each grid element (Bathurst and O'Connell, 1992; Jensen and Mantaglu, 1992). In addition, calibration can be undertaken using only a short period of hydrological and climatological record supported by a short field survey. Subsequently, values of variables can be changed for specified land use conversions to determine their hydrological impact; this emphasises the apparent ability of 'Physically based' models to be applied with more confidence outside the range of the data previously used in their calibration (Bathurst and O'Connell, 1992).

### **2.5.1 DIGITAL TERRAIN MODELS FOR RUNOFF PROCEDURE**

The current status of digital terrain modelling for runoff production was reviewed by Moore et al. (1991), and comprehensive details on particular models have been presented by the workers concerned (for TOPMODEL, Beven (1986a, b), Beven et al.(1988); Quinn et al. (1988 ); Quinn et al. (1989, 1991) and Robson et al. (1992b); for TOPOG, O'Loughlin (1986,1990a) and O'Loughlin et al. (1989); for THALES, Grayson

et al. (1992a). Comparisons between TOPMODEL and TOPOG were provided by O'Loughlin (1990b), and by Bonell with Balek (1993), during the process of evaluating their applicability in the humid tropics where baseline data are commonly deficient. Consequently, only some of the recent experiences in using these models will be mentioned here.

TOPOG has ability to predict a range of wetness functions in the absence of a hydrological data base (O'Loughlin, 1986,1988). As noted by O'Loughlin (1988), this function effectively determines the areas that are most liable to soil water logging controlled by topographic convergence and divergence areas. The identification of these vulnerable areas is an important consideration in decision-making on alternatives in forest land management, especially where agencies (in particular, those in developing countries) do not have access either to supporting scientific infrastructure or to any data bases apart from a topographic map. TOPOG showed considerable success in simulating storm hydrographs (Moore et al., 1986) through the use of a lumped variable model to calculate rapid storm runoff. The latter was based on the saturated areas predicted by TOPOG being effectively impermeable to rainfall and supplied with rapid subsurface storm flow from upslope. In addition, both Moore et al.(1986) and Burch et al.(1987) showed how the effective transmissivity of both small forested and grassland catchments could be estimated by using the wetness index vs. percent saturated source area analogy with Theis (1935) graphical method for determining the transmissivity of a groundwater aquifer under conditions of unsteady flow. For the forested Myrtle II catchment near Melbourne, Vertessy et al. (1991) reported that the transient version (TOPOG-YIELD) modelled runoff (and interception) satisfactorily over a 4-year period. The predicted total evaporation rates, however, were too high. Among the improvements suggested was the incorporation into the model of a facility to handle layered soils (Vertessy et al.,1991). On the other hand, a 20 year simulation of the hydrological response of forest regeneration after fire was successful using a variant (TOPOG-IRM) of the transient model.

In contrast to the steady-state version of TOPOG, TOPMODEL has always been a dynamic model (Beven, 1986a), originally developed for application to flood runoff studies and total runoff area, rather than to the spatial distribution of soil moisture (and runoff production areas). As Quinn et al. (1989) showed, however, TOPMODEL has these capabilities during the prediction of local storage deficits across hill sides. TOPMODEL also has an infiltration-excess overland flow option (Beven, 1986a,b), which was not used in the application of the model to the Wye catchment (UK) because

of the high transmissivities and weak rainfall intensities. Quinn et al.1991, introduced the concept of a reference level to cater for the deviation of water table levels from the soil surface at locations such as upper slopes, where deeply weathered soil profiles encourage deep unsaturated zones. In these circumstances, the assumption that subsurface storm flow rates and pathways are proportional to a hydraulic gradient approximating the surface slope is not always correct. The inclusion of the multiple flow direction algorithm and smaller grid scale also improves TOPMODEL for simulating the hydrological behaviour of two sub-Mediterranean montane catchments. A deep groundwater system was thought to exist beneath the forested catchment; its interactions with the stream could not be modelled adequately and therefore, anomalies occurred in the simulations. The fact that bedrock surface was not parallel to the surface topography, coupled with an irregular thickness of regolith, also affected the assumption that the water table's hydraulic gradient was parallel to the local slope. This simple version of TOPMODEL was also affected by storms when either infiltration-excess (Hortonian) overland flow dominated flood peaks or the available soil storage estimates were affected by the hydrophobic properties of the soils (Durand et al., 1992; compare with Burch et al., 1989). Despite these imperfections, Durand et al. (1992) considered that the basis of hydrological behaviour of the catchments was modelled satisfactorily.

### **2.5.2 SOIL EROSION AND SEDIMENTATION MODELS**

Mathematical models are numerical representations of conceptual models and provide behaviour of a system. Models are invariably simpler than the system behaviour. Wide range of model types exist, they may be conventionally divided in lumped parameter models, distributed process models and hybrids. Lumped parameter models are those in which complex system behaviour is averaged or integrated over space and time and represented by a few mathematical functions. The calibration is usually carried out by using fitting or optimisation procedures which change parameters values until observed and modeled outputs match. Lumped parameter models must therefore be used on drainage basins for which sediment data already exists. This restricts their usefulness forecasting in situations where data not available for calibration.

Distributed process models such as those used for catchment or channel sediment routing, attempt to reproduce the spatial and temporal behaviour of a system by modelling it from physical considerations. The basic relationship in these models is analytically based mathematical descriptions of physical laws.

Hybrid or quasi- analytical models are those which contain both distributed and lumped parameter elements. They typically apply to situation in which only part of the process to the modeled is well understood or described by physically based mathematical relationships. Other processes may not be understood so well and have to be represented by stochastic processes or relationships which approximate their behaviour without being analytically based.

### **2.5.3 LUMPED PARAMETER SEDIMENT YIELD MODELS**

The sediment rating curve is an empirically derived relationship between water discharge and suspended sediment concentration at some point along a stream. Water discharge is obtained either by gauging or from a stage discharge rating curve. Sediment concentration is measured by collecting sample of the water sediment mixture which are then analysed for sediment content. Sediment rating curves are traditionally present in the following form:

$$C = aQ^j$$

Where,

C = Sediment concentration

Q = water discharge a and j = empirical coefficients derived by regression. The exponent j usually lies between 1.0 and 2.0 with the higher values associated with smaller catchments.

### **2.5.4 COMPLEX RESPONSE MODELS**

Moore (1984) developed the best complex response model which is called Dynamic Basin (DB) sediment yield model. This is a lumped parameter scheme developed to resemble the physical processes involved in catchment sediment transport yet still remain simple enough for gradient based automatic calibration. All function within the model is smooth and twice differentiable. The DB model is an improvement on time series model which have relatively simple time invariant response functions and cannot handle the complex behaviour observed in sediment yield data. The DB model uses three relationships to describe the variation in suspended sediment yield from a catchment over time are a sediment availability function, a sediment removal function and a sediment translation function.

### **2.5.5 Catchment Sediment Routing Models (CSR)**

Catchment sediment routing is a mathematical procedure for calculating erosion rates within a catchment and transporting the eroded sediment to the catchment outlet. The main aim in developing CSR models has been to predict the impact of landuse changes on sediment yield. Most CSR models use the Universal Soil Loss Equation or its variants for the determination of on - site erosion (Wischmeier and Smith, 1965, 1978, Wischmeier, 1976 and USDA, 1982).

The USLE may be stated as:

$$A = RKLSCP$$

where,

A = average predicted annual soil loss per unit area,

R = rainfall and runoff erosivity index for a specific location.

K = Soil erodibility factor for a specific soil horizon,

L = Dimensionless slope-length factor, expressed as the ratio of soil loss from a given slope length to that from a 72.6 feet length under the same condition.

C= dimensionless cover management or cropping management factor expressed as ratio of soil loss from the condition of interest to that from tilled continuous fallow.

P= Dimensionless erosion control practices factor expressed as a ratio of the soil loss with practices such as contouring, strip cropping, or terracing to that with farming up and down slope.

### **2.5.6 CHANNEL SEDIMENT ROUTING MODELS**

Channel sediment routing is the mathematical procedure by which inflowing sediment load is passed along the channel to the catchment outlet during a sequence of flow events. It is normally carried out when information is required on the effects of a change in sediment input, water discharge or channel geometry, all of which affect the rate of sediment transport equations usually do not handle wash load. Sediment routing requires a model describing the system and the events to which it is subjected. The input data usually consists of :

(a) a sequence of flow events representing a hydrograph or flow duration curve,

(b) a series of cross-sections and roughness coefficients which describe the channel system,

(c) the size distribution and amount of the inflowing sediment load,

(d) the size distribution and amount of sediment available for transport in the channel bed and banks.

A wide range of sediment routing models are available as a computer programs. These includes analytical solutions, finite difference approaches (HEC-6 , Pone et al. 1979) using the known discharge and sequential routing methods (Bennett and Nordin, 1977; Alonso et al 1981), and the moving wave or dispersion approach (Braided river model, Pickup and Higgins, 1979), Pick up et al 1983).

Because of the lack of sufficient data from experimental watersheds and the resulting inability to characterize universal process response from the experimental data available, process simulation has been widely used as the basis for quantifying the hydrologic impact. Over the past 50 years, many attempts have been made to identify soil and site characteristics that can be used as parameters to quantify the amount of accelerated soil erosion on agricultural and forest lands. Most of the models that have been developed are unique to the areas where they were tested and may not be applicable to other locations. Models which estimate the movement of eroded material through a forest environment to a stream channel have not been extremely tested. The most acceptable model that is used to estimate surface soil erosion on agricultural lands is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965). Since this equation is not universally applicable to forest environment conditions, attempts have been made to develop a Modified Soil Loss Equation (MUSLE). To adapt the USLE to forest conditions, the cropping management factor (C) and the erosion control practice factor (P) have been replaced by a vegetation management factor (VM) in the MUSLE.

The various models for predicting sediment yield are available. A few models have been tested at various places in United States for forested catchments. The following models have been applied under forests:

(a) R1R4 SED model

(b) PRMS model

(c) WEPP model

(d) SEDEL

- (e) Wisconsin Hydrologic Transport model
- (f) LUMOD
- (g) WASED
- (h) STORM
- (i) MUSLE
- (j) NPS
  
- (k) HYMO model
  
- (l) EUROSEM
  
- (m) SWIM

#### **2.5.6.1 R1R4 model**

The model was developed for predicting sediment yield from forest lands for use in land management planning which is urgently needed to respond the requirement of National Forest Management Act (NFMA). This provides a basic set of assumptions, procedures and a quantitative starting point from which to develop locally applicable estimates of natural (undisturbed) sediment production characteristics and response to management activities on a variety of lands. The procedure considers both on site erosion and downstream sediment yield. Because the model relates the effects of land disturbing activities to downstream sediment yield, best management practices can be evaluated to protect water quality conditions.

#### **2.5.6.2 PRMS model**

Leavesley et al (1983) developed the 'Precipitation Runoff Modelling System'. It is a modular design, deterministic, distributed- parameter modeling system developed to evaluate the impacts of various combination of precipitation, climate and landuse on streamflow, sediment yields and general basin hydrology. Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water balance relationships, sediment yield and ground water recharge. Parameter optimization and sensitivity analysis capabilities are provided to fit selected model parameters and evaluate their individual and joint effects on model output.

Input variables include descriptive data on the physiography, vegetation, soils and hydrologic characteristics of each 'Hydrologic Response Unit (HRU) and on the variation of climate over the watershed. The minimum driving variables required to run in the daily

flow mode are (a) daily precipitation, (b) maximum and minimum daily air temperatures. Daily Pan Evaporation data can be substituted for air temperature for situations where snowmelt simulation is not required, daily solar radiation data are recommended when snow melt will be simulated. To simulate storm flow hydrograph, rainfall depths for time interval of 60 minutes or less are required.

#### **2.5.6.3 WEPP model**

Based on modern hydrology and erosion science, water erosion prediction Project (WEPP) model is a new technology in erosion prediction. Three versions are included in WEPP: a hill slope profile version, a watershed version, and a grid version. WEPP was developed primarily to be executed as a continuous simulation, reflecting changes with time, due to impact from management or climate. WEPP hillslope profile version can also be run on a single storm event and estimates spatial and temporal soil loss distributions without concentrated flow channels. Fundamental of infiltration theory, Hydrology, Soil Physics, Plant Science, Hydraulics and erosion mechanics form the basis of the model. The parameter estimation technique was derived from a broad base of experimental data. Four input files are required to run the model: Climate, slope, soil, and management. The output includes two sections, one for onsite effects of erosion and one for off-site effects. The onsite effects contains time integrated soil loss deposition over the hill slope. The model has climate, infiltration, water balance, crop growth and residue decomposition, surface runoff and erosion as major components.

#### **2.5.6.4 SEDEL model**

Boyce (1975) developed Sediment delivery (SEDEL) model. The model estimates river basin sediment yield by sub-basins, sheet erosion by Universal Soil Loss equation, channel types of erosion by unit rates. Routes through existing or proposed impoundments, computes sediment storage requirements for proposed dams. Parallel computations for suspended load and bed load. The model has been used in North east and Mid-west for all types of land use.

#### **2.5.6.5 Wisconsin Hydrologic Transport model**

Patterson et al (1974) has depicted 'Wisconsin Hydrologic Transport Model' as developed by Huff, D.D. The model is based on the Stanford Watershed model' and forms a major component by the unified transport model. It includes the hydrologic transport of a trace contaminant by entrainment in overland flow, infiltration, impervious

area runoff and sub-surface flow. Chemical exchange is designed to interface with atmospheric transport and transport modules. The model has been used for all types, of land use for the southeast and midwest.

#### **2.5.6.6 Landuse model (LUMOD)**

Leaf et al (1975) developed 'Land use model' to simulate the short and long term hydrologic impacts of combinations of timber harvesting and weather modification to develop management strategies for planning intervals which can vary from a few years to the rotation age of sub-alpine forests (120 yr. and longer). The model contains time trend functions which compute changes in evapotranspiration, soil water, forest cover density, reflectivity, interception, snow redistribution and sediment yield as the forest stands respond to timber harvesting.

#### **2.5.6.7 WASED model**

Simons et al (1975) have developed the model which allows user to stratify watershed into homogeneous land and channel units. It is an individual storm model which includes water balance, loose soil detachment by raindrop impact and by moving water, water and sediment routing for both overland and channel flow systems. Flow routing is by non-linear kinematic wave approximations. The model has been used for forested areas of the southwest.

#### **2.5.6.8 STORM model**

Water Resources Engineers at Hydrologic Engineering Centre (1976) have developed a Storage-Treatment-Overflow-Runoff model (STORM). The model provides continuous analysis of quantity and quality of storm runoff from urban and non-urban watersheds. It is mainly used for prediction of wet weather pollutant graphs for use in receiving water assessment models and preliminary sizing of detention reservoirs and treatment plant capacities. The model has been used for all types of land use all over the United States.

#### **2.5.6.9 MUSLE model**

Williams(1975) modified the USLE as developed by Wischmeier and Smith (1960) by replacing the rainfall energy factor with a runoff factor. Modified Universal Soil Loss Equation (MUSLE) does not require a delivery ratio and is capable to individual storms. Daily sediment yield is predicted for ungauged watersheds by

attaching MUSLE to the SCS curve number with water yield model and HYMO. The model has been used in forest, range and agricultural lands in all parts of the country.

#### **2.5.6.10 NPS model**

Donigian et al (1976) developed the NPS model to simulate hydrologic processes (including snow accumulation and melt), erosion processes and surface non-point source pollutants. The hydrologic model is based on the Stanford Watershed Model. The model can simulate up to five different user specified pollutants from up to five different land uses in a single operation. All pollutants are simulated as a function of the eroded sediment.

#### **2.5.6.11 Sediment Routing Model**

Williams(1975) developed this model. The model routes sediment yields from small watersheds through streams and valleys to the outlet of large watersheds. The technique is based on MUSLE and a first order decay function of travel time and particle size. Sediment routing allows determination of sub watershed contributions to the total sediment yield. Also, the locations and amount of flood plain scour and deposition can be predicted.

#### **2.5.6.12 EUROSEM**

Morgan et al (1989) presented a process based European Soil Erosion Model(EUROSEM). The model calculates the volume of rainfall reaching the ground surface as direct throughfall, leaf drainage and stream flow, the volume of a surface depression storage in relation to micro topographic roughness, the rate of detachment of soil particles by raindrop impact as a function of the energy of the direct throughfall and leaf drainage, the flow and thereby made available for transport, the rate of detachment of soil particles by surface flow and transport capacity of the runoff. Net erosion and deposition are calculated during the storm and changes in the micro topographic surface are simulated.

#### **2.5.6.13 SWIM model**

A soil water infiltration and movement (SWIM) model was developed by CSIRO unit of Soil Science, Australia. This is one dimensional vertical flow model based on Richard's equation. This can be used for water balance as well as for solute transport through the unsaturated zone.

## **2.6 GAPS IN UNDERSTANDING THE IMPACT OF FOREST COVERS ON SOIL MOISTURE AND GROUNDWATER RECHARGE**

Understanding impacts of forest and land use/land cover (LU/LC) change on the hydrologic cycle is needed for optimal management of natural resources. The global impact of forest cover and LU/LC change on the hydrologic cycle may surpass that of recent climate change. Impacts of LU/LC change on atmospheric components of the hydrologic cycle (regional and global climate) are increasingly recognized. However, it is quite important to note that the impacts of forest cover change on subsurface components of the hydrologic cycle are less well recognized, particularly groundwater recharge. The potential scale of subsurface impacts is large. Groundwater is Earth's largest freshwater resource. Reduced reliability of surface water supplies in the world with projected climate change during the next century may result in increased reliance on groundwater. Widespread changes in LU/LC have occurred as a result of agricultural expansion. In the past 300 years, cultivated cropland has increased by factors of 70 in the US and globally. The projected global increase of agricultural lands is 20 % over the next 50 years. Most recharge studies have been conducted in natural rangeland ecosystems; however, replacing rangeland with agricultural ecosystems alters many of the parameters controlling recharge, such as climate, soils, and vegetation. Variations in recharge associated with LU/LC changes can have negative impacts on groundwater quality because thick unsaturated zones in semiarid and arid regions contain a reservoir of salts that accumulated over thousands of years and can be flushed into underlying aquifers. At the outset, it is imperative that a systematic investigation on surface runoff and groundwater recharge under varying forest cover conditions is a pre-requisite for developing water resources management. The study also attains significance with respect to on-going climate change implications which will contribute to understand, how the local changes in forest cover will influence the water availability.

# CHAPTER 3

## STUDY AREA

### 3.1 INTRODUCTION

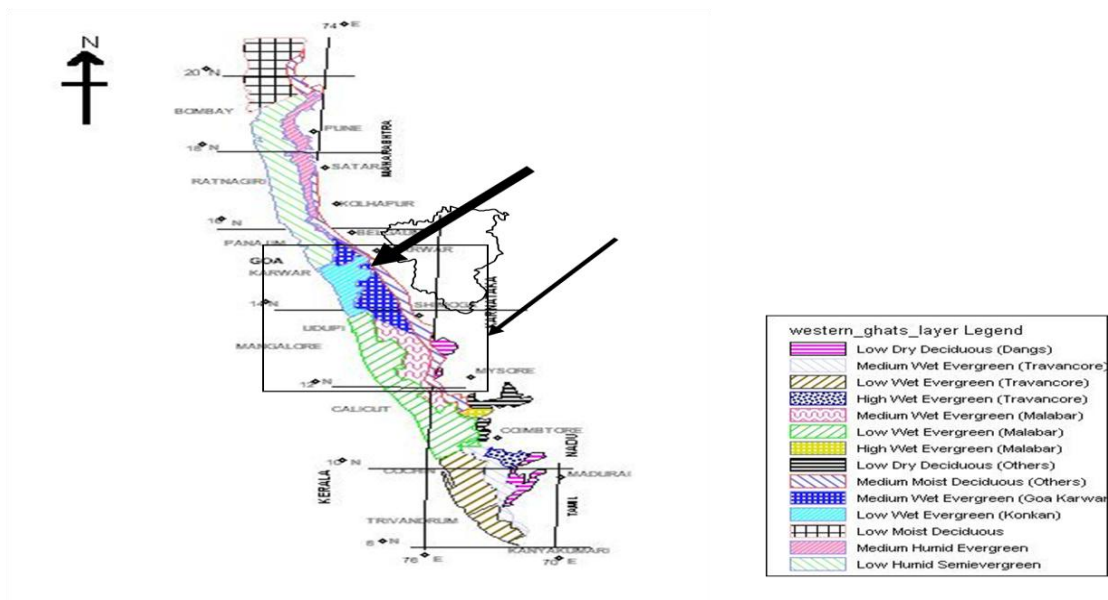
The primary focus of the present research was to characterize the hydrologic regime of small catchments (here in after referred to as watersheds) located in the Sahayadri mountains of Uttara Kannada district of Karnataka through long term measurements of relevant hydrological variables. The intention was to understand the effect of different land covers on the hydrological processes at the watershed scale and to develop appropriate methodologies to up-scale this knowledge to larger watersheds (here in after referred to as catchment).

In this chapter, a description of the study area, the characteristics of the selected catchment and watersheds and details of hydro-meteorological measurements and monitoring is enumerated.

### 3.2 UTTAR KANNADA DISTRICT

The Sahayadri Mountains (fig 3.1) run parallel to the West Coast of India extend from the southern tip of the peninsula to the river Tapti located in Gujarat state in the north-west region of the country. The mountain ranges have a geographical area of nearly 14Mha, and cover five Indian states, these mountains cover 7 districts including the Uttara Kannada district which formed the focus of this study.

A brief description of important hydrogeoclimate characteristics of Uttara kannada is given in the following sections.



**Fig 3.1 Location map of Sahayadri mountain (Source: Centre for Environmental Studies, IISc. Bangalore, India)**

The Uttara Kannada district in Karnataka is located between 13° 55' to 15° 32' N Latitude and 74°05' to 75° 05'E Longitude. It is the only district in Karnataka which has over 80 % forest cover (Ramachandra 2007). The forest resources of the district are under pressure as large portions of the forested area have been converted into non-forestry activities owing to the increased demands from human and animal population. This has resulted in degradation of the forest ecosystem. Poor productivity and regenerative capacity is evident in the form of barren hill tops on the eastern side of the Sahayadri Mountains.

### **3.3 BILIGIHOLE CATCHMENT AND WATERSHEDS**

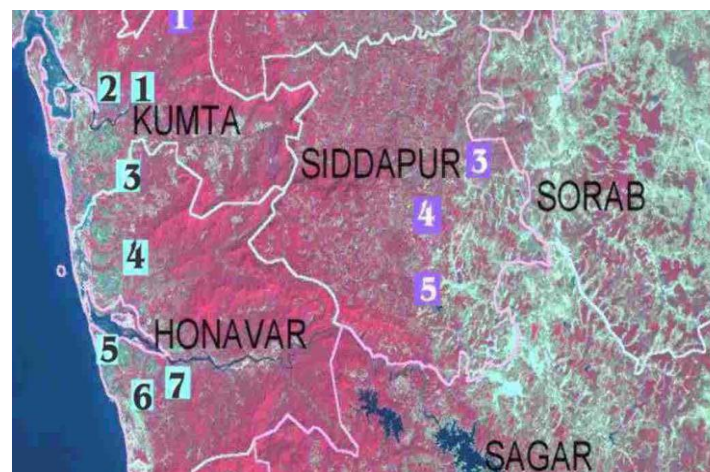
Keeping in mind the main objectives of the present research, it was decided to identify a catchment of reasonable size (<50 km<sup>2</sup>) in the Uttara Kannada portion of the Sahayadri mountains. The intention was to carry out detailed experimental investigations on the hydrology of the catchment with specific reference to the effect of different land covers on catchment runoff. Since experimental studies at the catchment scale can be time-consuming and expensive, it was decided to identify small watersheds within the catchment, which possessed homogeneous land covers which are characteristic of the region. Such a nested approach permits detailed hydrologic investigations to be carried out to characterize hydrological processes and parameters at the watershed scale. This knowledge may be subsequently up scaled to the catchment scale to model runoff and evaluate the hydrologic impacts of anthropogenic activities.

Accordingly, from an analysis of Survey of India toposheets, the Biligihole catchment was identified as most appropriate for the present study. The Biligihole stream originates near Vajgar village of Siddapur taluk at an elevation of 680 m (amsl). It flows westward before it joins Somahalla downstream of Biligi village, which is a tributary of river Aghinashini, one of the major west flowing rivers.

The catchment of Biligihole lies between 74°47'30" to 74°52'30" E Longitude and 14°20' to 14°22'30" N Latitude. The drainage area is 28 km<sup>2</sup>. The catchment outlet is located about 3km southwest of Kodigibail village (Fig. 3.7). A road bridge exists at the outlet and provided a convenient location for measuring stream-flows during this study.

Biligihole catchment is comprised of three major land covers – natural forest, degraded forest and acacia plantations. In the catchment, three small watersheds will be identified possessing relatively homogeneous land covers of natural forest, degraded forest and acacia. In order to isolate the effects of only land cover on hydrological processes, it was imperative that the selected watersheds were similar with regard to other hydrogeoclimatic characteristics.

Accordingly, three watersheds were selected based on the above criteria. These are located in the Siddapura Taluk of Uttara kannada district of Karnataka State. The selected watersheds are under natural forest (considered as the control watershed), degraded forest and acacia plantation and covers. These watersheds drain first order streams and are located on the head-water of the Biligihole stream (Fig 3.3). Being located within a 1 km radius, the three watersheds possess more or less similar soils, geology and morphological conditions and differ only in type of land cover.



**Fig 3.2 Map of Siddapur Taluk**



**Fig 3.3 Bilgihole Catchment**



**Fig 3.4 Natural forest**



**Fig 3.5 Degraded forest**



**Fig 3.6 Acacia**

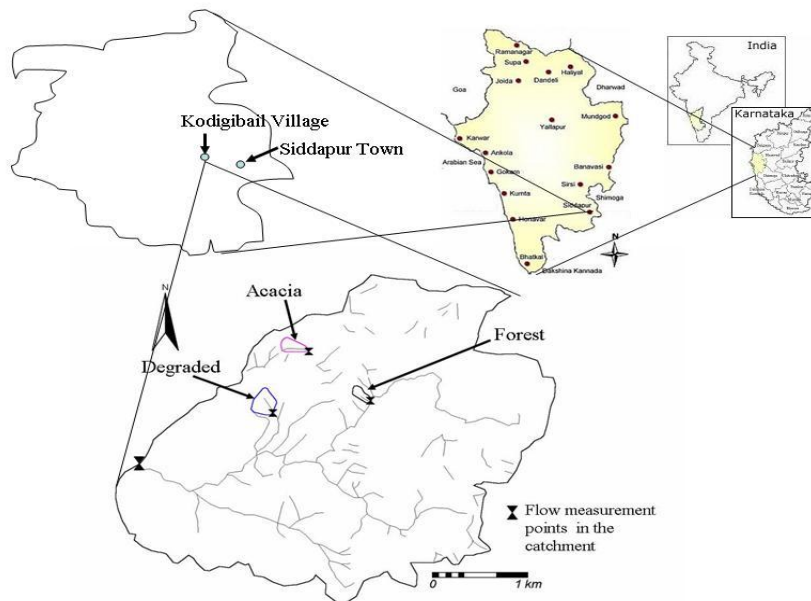
### **3.4 APPROACH TO SITE SELECTION**

There are various methods of studying the effects of land use changes on stream flow. The paired catchment study is the common method for this objective and is based on the two catchments of similar size, geology, exposure and vegetation, which are monitored during an initial calibration period. One catchment is then altered by removal of vegetation, while one is left as control. The disadvantage is that, the experiments required for longer duration of time incurring high expenses, plus local applicability of the results (due to change in the soil, geology, and location etc.). To avoid this, another approach is to record the hydrological responses of a catchment before and after land use changes (Mwendera, 1994), but the effects of climatic fluctuations are then intermingled with the effects of the changed land use, heterogeneous geology, soil etc. The data obtained by the experiments, will then be used in a mathematical model which describes the problem well, for simulating the impact of changing land cover and climatic conditions.

This study was originally planned to choose a set of catchments in accordance with selection procedure such as ‘paired catchment’ approach. The ideas of the paired catchment approach are to use catchments that are proximate (and hence experiencing similar rainfall) and are similar to each other in terms of shape, size and geology. Hence, the effects of these compounding factors are minimized in the hydrological studies.

In light of the above, it was decided to largely abandon the paired-catchment approach and instead the watersheds were selected based on the less heterogeneity of the land use. That is, the selected watersheds were predominantly covered by the land-use, which are of our interest. Finally watersheds were selected based on the above criteria are

located at Kodigibail, which is a village in the Siddapura Taluk of Uttarakannada district of Karnataka State. The selected watersheds are under Forest (considered as the control watershed), degraded forest and acacia plantation watershed. These watersheds can be classified as the first order watersheds and are located on the head-water of a fourth order stream namely, Biligi Hole (Figure. 3.7). The selected watersheds are more or less possess similar soil, geology and topographic features and are located within one kilometer radius.



**Figure 3.7 Index map of Study area showing the spatial distribution of the selected watersheds and flow measuring points.**

### **3.5 DESCRIPTION of SELECTED WATERSHEDS**

#### **3.5.1 RAINFALL REGIME OF THE STUDY AREA**

Western Ghats, which forms a range of hills bordering the west coast in the Indian Peninsular, has been the head-water catchment for most of the rivers. Numerous studies have reported the spatial variation of the rainfall across the Western Ghats. Also, it is essential to know the rainfall characteristics (shorter and daily time scale) of the area which can be used for various hydrological purposes. Thus, magnitude of rainfall is one of the principal drivers in accounting for the much wider range of preferred pathways of storm runoff in tropical forests.

### 3.5.2 LOCATION, TOPOGRAPHY AND CLIMATE

Siddapur is one of the 11 talukas in Uttara Kannada district, and along with Sirsi and Yellapur to its north, constitutes the heartland of the 'Malnaad' (hilly) portion of this district, characterized by mixed areca and spice orchards and paddy cultivation. The village of Kodgibail is located about 7.5 km northwest of Siddapur town (see Figure.3.7). The area is characterized by a dense stream network in an undulating terrain, although hills seldom rise more than a 100 m. The long-term average rainfall is around 2900mm, although in good years it may go above 3500 mm. The rain comes from the south-west monsoon, and therefore has a unimodal distribution within the year, and most of rainfall period is concentrated during May- November period, with the bulk falling during June-September.

Geologically, these watersheds consist of pre-Cambrian formations with gneiss and intrusive granites concentrated mostly along the coastal tracts and adjoining areas towards east. The major soil type found in the study area is red or yellowish-red lateritic soil, with gravely-clay texture. Forest soils are deep to moderately drained, dark brown to dark yellowish brown with sandy-clay to sandy-clayey-loam texture. They are rich in humus, acidic and usually deep.

**Table. 3.1. Characteristics of the selected watersheds**

| Land-use type | Catchment area (Ha) |
|---------------|---------------------|
| Acacia        | 7                   |
| Degraded      | 9                   |
| Forest        | 6                   |

#### 3.5.2.1 Geology and Soils

Geologically, the study area consists of Pre-Cambrian formations with gneiss and intrusive granites. The major soil type found in the study area is the Laterites. The forest soils are rich in humus and more porous. The depth wise soil characteristics (particularly percent of Sand, Silt and Clay) for the selected watersheds.

### **3.5.2.2 Physiography**

A major part of the district is covered by hilly areas belonging to Sahayadri mountain ranges, except for the narrow coastal strip on western side and plain tabled land areas to the eastern part of the district. Land elevations in the district range between 0 to 800 m above mean sea level (msl).

### **3.5.2.3 Climate**

Gunnel (1997) outlined the climatic features of the Western Ghats in some detail indicating that it is distinctly monsoonal. The rainfall is dominated by the orographic uplift of moist, southwest monsoon airflow with the topographic barrier of the “Western Ghats - Central Sahayadri” during the months June-September (Pascal 1982; Gadgil and Joshi 1983; Singh 1986). Spatially annual rainfalls are highly variable and range from 1150 mm to greater than 5000 mm over the highest topography. There is a distinct drying gradient on the eastern slopes and onwards towards the Deccan plateau.

The region has a tropical climate with mean monthly temperature ranging from 20° - 27°C. About 70-80 % of the rainfall is received between June to September due to the south-west monsoon phenomenon. The number of rainy days during June- September is about 100-110.

Various authors (Patwardhan and Asnani 2000 and Gadgil et al. 1988) have made attempts to identify the homogeneous rainfall regions within Sahayadri Mountains. In one such attempt Venkatesh and Jose (2007) have delineated homogeneous rainfall regions in Uttara Kannada district. The study area of the present research is characterised by mean annual rainfall of 2932 mm with standard deviation of 405 mm and coefficient of variation of 0.21.

## **CHAPTER - 4**

### **MATERIALS AND METHODOLOGY**

#### **4.1 METHODOLOGIES USED IN THE ESTIMATION OF HYDROLOGICAL COMPONENTS**

##### **4.1.1 RAINFALL ANALYSIS**

Data on rainfall intensity, duration and recurrence interval have been compiled for the rainfall stations located in the catchment. The data is available for a period of 18 years was used for the study.

From the available Self Recording Raingauge Charts, the storms having duration of 3 hours or more were selected. The rainfall intensity values for the durations of 1 hr, 2 hr, 3 hr and 5 hr were calculated for the selected storms. The rainfall intensity values, thus calculated for each duration were used to fit the gumble frequency distribution with the method of probability weighted moments and plotted on Gumble frequency distribution curve. In order to establish a relationship between rainfall intensity - duration - frequency, the rainfall intensity values were regressed against duration for the set of data available.

$$I = a t^b T^c \quad \text{Eq..... (4.1)}$$

where I = intensity of the rainfall mm/hr

t = duration in minutes

T = return period in years

a,b,c are the empirical constants

A comparative analysis will be done to find out which method is more suitable for this region.

#### **4.1.2 PROBABILITY DISTRIBUTIONS USED IN THE STUDY**

There is no theoretically sound reason for selecting a rainfall distribution model in preference to another. It is therefore, practical to assess competing models in terms of empirical fit of available data, computational ease, and consistency with various sample sizes. However, the present study is carried out using the most commonly used distributions like Gumbel (EV-I) distribution to the corresponding annual maximum series of the available rainfall data.

The density function is defined by:

$$P(x) = \exp[- \exp - (x-u)/\alpha] \quad \text{Eq..... (4.2)}$$

Where P(x) is the probability of an event not exceeding x, and u and  $\alpha$  are the location and scale parameters of the distribution. The above equation may be written conveniently in terms of a reduced variate y:

$$P(x)=\exp[-\exp(-y)] \quad \text{Eq.....(4.3)}$$

where

$$x = u + \alpha y \quad \text{Eq.....(4.4)}$$

By inversion of above equation, the relationship may be written in terms of the return period T ( the reciprocal of the probability of exceedence):

$$y = -\ln[ \ln\{T/(T-1)\}] \quad \text{Eq..... (4.5)}$$

The Probability Weighted Moments (PWM) method of parameters estimation of Gumbel distribution found to be superior in many respects to the conventional moment and maximum-likelihood estimators (Landwehr et al, 1979). Hence, this method is employed for the determination of parameters in the distribution.

## 4.2 MEASUREMENT OF SOIL HYDRAULIC PROPERTIES

### 4.2.1 WATER CONTENT

Measurements of water content are needed in hydrological studies for direct knowledge of the quantity of the available soil water for interpretation of physical and chemical measurements, and for determination of water retention and hydraulic conductivity curves. Soil water content can be expressed as a dimensionless mass or volume ratio. The gravimetric content is mass ratio.

$$V_m = M_w / M_s \quad \text{Eq .....(4.6)}$$

where,  $V_m$  is gravimetric water content,  $M_w$  is water mass (mg) , and  $M_s$  is dry soil mass (mg) the volumetric water content is based on the volume ratio.  $= V_w / V$  where is volumetric water content,  $V_w$  is volume of water(cu. m)  $V$  is total soil volume. Gravimetric and Volumetric soil water content are related to each other as  $= r_s \times V_m$  where  $r_s$  is dry bulk density of the soil ( mg/cu. m) soil water content can be measured by direct methods such as oven or microwave dry, or by indirect ones based on neutron thermalisation, gamma ray attenuation or electrical conductivity and capacitance.

### 4.2.2 DISC PERMEAMETER

The disc permeameter has become a popular apparatus for measuring in situ the soptivity, S, and hydraulic conductivity, K, of the soil at some prescribed potential.

Measurements of sorptivity,  $S$ , (Philip 1957) and hydraulic conductivity,  $K$ , are important for predicting how water will enter, redistribute within, and drain from soils. Methods that can rapidly and accurately measure  $S$  and  $K$  are valuable. The disc permeameter (Perroux and White 1988) is a relatively new method that has gained popularity because of its simplicity, the speed at which measurements can be made, and because it does not greatly disturb the soil surface being measured (White and Sully 1987 ;) White and Perroux 1987 and 1989; Smettem and Clothier 1989; Ankeny et al 1991). Different methods have been devised for calculating  $S$  and  $K$  are compared using same set of data. Two methods those of Ankeny et al. (1991) and Scotter et al. (1982), require the steady-state flow rate from rate from the disc permeameter to be known. A third method, that of White et al (1992) , requires both the flow rate at early time and the Steady state flow rate to be known. These three methods are all based on the approximate, but usefully accurate, solution of flow from a disc source found by Wooding (1968). This linearized solution uses a hydraulic conductivity ( $K$ ) function of the exponential form (Gardner 1958):

$$K = K_s \exp (\psi / \lambda_c) \quad \text{Eq 4.7}$$

where  $K_s$  is the saturated hydraulic conductivity ( $\text{m s}^{-1}$ ),  $\lambda_c$  is the macroscopic capillary length scale (m) (Philip 1985; White and Sully 1987), and  $\psi$  is the matric potential (m).

Warrick (1992) showed that a solution for flow from a disc source at early- to medium time, based on the concept of linear diffusion, was only dependent on the sorptivity and water content. This solution can be used to obtain a method for calculating  $S$ .

A method for calculating  $K$  that uses the flow rate data from the early- to medium-time was proposed by Youngs (1987). It uses the ratio between microscopic length scales of  $S$  and  $K$  to obtain a solution for  $K$ . Although this method does not rely on any functional form for the hydraulic conductivity function, consideration of the microscopic length scales of  $S$  and  $K$  . Further, White and Perroux (1989) suggested that  $K$  could be calculated from  $S$  measured at two different matric potentials. Although not directly reliant on the disc permeameter, their method has been included in this comparison as it could provide a rapid means of easily characterizing the hydraulic properties of soil when used in conjunction with the disc permeameter.



**Fig 4.1 Disc Permeameter**

#### **4.2.2.1 Principles of Operation**

When a source of water, such as a wet circular disc or shallow pond, is placed on the soil surface, the initial stages of flow into the soil are dominated by the soil's capillary properties. As time progresses, both the size and geometry of the water source and the force of gravity influence the water flow rate. For uniform soils a time is eventually reached where the flow rate from the source becomes steady. This steady state flow rate is governed by capillarity, gravity, the size of the disc and the pressure at which water is supplied to the soil surface.

In this technique we make use of both the initial and steady-state flow rates to separate the capillarity and gravity contributions to soil water flow. In addition, by selecting the water supply pressure we can dictate the sizes of pore sequences or fissures which participate in the flow process.

#### **4.2.2.2. Hydraulic conductivity and Sorptivity**

The method for determining soil hydraulic properties from disc permeameter measurements in the field is given by White, Sully and Perroux (1989) and is based on an analysis (Wooding, 1968) of the three-dimensional flow from a shallow circular pond or surface disc. The situation is illustrated in fig .

For a pond or disc of radius  $r_0$ , on a homogeneous soil, Wooding showed that when water is supplied at a potential of  $\psi_0$  the steady state volumetric flow rate  $q$  is

$$q = \pi r_0^2 (K_0 - K_n) + 4r_0 \phi \quad \text{Eq.....(4.8)}$$

The first term on the right essentially represents the contribution of gravity to the total flow from the surface disc and the second term contains the contribution due to capillarity. In the gravity term  $K_0$  is the hydraulic conductivity at the supply potential  $0$ , and  $K_n$  is the hydraulic conductivity at the initial soil water potential  $n$ . For relatively dry materials  $K_n$  is much smaller than  $K_0$  and we can safely ignore its effect. The capillarity term contains the matric flux potential, which is related to the conductivity by  $\psi = Kc$

The macroscopic capillary length is related to the sorptivity,  $S_0$ , and the hydraulic conductivity (White and Sully, 1987), is the initial moisture content at is the moisture content at the supply potential,  $S$  is the sorptivity at with supply potential and is a dimensionless constant whose value lies between  $1/2$  and  $1/4$ . For field soils a good mean value for  $b$  is  $0.55$ . We can now rewrite (1) as

Dividing by the area of the disc, we find the steady-state flow rate per unit area

$$q = K_0 + \frac{4b S_0^2}{\theta_s - \theta_r} \quad \text{Eq. (4.9)}$$

Rearranging (Eq.13) to find the conductivity, we have

$$K_0 = q - \frac{4b S_0^2}{\theta_s - \theta_r} \quad \text{Eq.(4.10)}$$

During the early stages of flow from the disc, capillarity dominates flows irrespective of the disc. At short infiltration times the system behaves as if it were one-dimensional. In this case the cumulative infiltration is given by (Philip, 1969). Where  $Q$  is the total volume of water infiltrated and  $t$  is time from the commencement of infiltration. Sorptivity, then is the Slope of the cumulative infiltration vs  $t^{1/2}$  plot.

To calculate the hydraulic conductivity from (4), the measurements required are the sorptivity, the steady state flow rate, the initial volumetric moisture content at the supply potential.

### 4.3 SOIL MOISTURE ANALYSIS

#### 4.3.1 DEVELOPMENT OF SOIL MOISTURE RETENTION CURVE USING PRESSURE PLATE APPARATUS

This is a standard method for obtaining the soil moisture retention curve. Pressure plate apparatus consists of a pressure chamber in which a saturated soil sample is placed on a porous ceramic plate through which the soil solution passes but no soil particle or air can pass. The soil solution which passes through the membrane is in contact with atmospheric pressure. As soon as the air pressures inside the chambers are raised above the atmospheric it takes excess water from the soil out of the chamber through the membrane outlet. Soil water will flow out from the soil sample until the metric potential of the unsaturated flow is same as the applied air pressure. The air pressure is then released and the moisture content of the soil is gravimetrically determined.

During a run, soil moisture will flow from around from each of the soil particle and out through the ceramic plate until such time as the effective curvature of the water film throughout the soil are the same as at the pores in the plates. When this occurs equilibrium is reached and the flow of moisture ceases. When air pressure in the chamber is increased, flow of water from the samples starts again and continues until a new equilibrium is reached. A source of regulated gas pressure is required for all extraction work. Compressed air from a compressor is the most efficient source of supply.

The ceramic plates are available in different range. Each ceramic pressure plate cell consists of a porous ceramic plate, covered on one side by a thin neoprene diaphragm sealed to the edges of the ceramic plate. An internal screen between the plate and diaphragm provides a passage for flow of water. An outlet stem running through the plates connects this passage to an outflow tube fitting which to the atmosphere outside of the extractor. To use the ceramic pressure plate cell, one or more soil samples are placed on the porous ceramic surface held in place by retaining rings of appropriate height. The soil samples together with the porous ceramic plate are then saturated with water. This is usually done by allowing an excess of water to stand on the surface of the cell for several hours. When the saturation is complete, the cell can be mounted into the pressure vessel. Air pressure is used to effect extraction of moisture from the soil samples under controlled conditions. The 1 bar ceramic plates are ideal for the routine determination of the 1/10 bar and 1/3 bar range of the soil suction. The 3 bar pressure plate cells are used in the range of 0 - 3 bars. The 15 bar ceramic cells are commonly used for measurement of soil moisture suction in the range of 5 - 15 bars of soil suction.

The moisture retention curve of a soil sample can generally be determined by equilibrating a soil sample at a succession is known tension value and each time determining the amount of moisture. The graph is plotted between the tension and

corresponding soil moisture value to obtain the soil moisture retention curve. Different types of soil represent different retention curves.



**Fig 4.2 Pressure Plate Apparatus**

## **CHAPTER 5**

### **RESULTS AND DISCUSSION**

#### **5.1 HYDROLOGICAL ANALYSIS**

The present study was focussed on field experimentation aimed at characterising hydrological processes as influenced by land cover at the watershed scale. This study provides a detailed description of the manner in which measured data was analysed with the objective of gaining on improved understanding of the effect of land cover on hydrological processes and parameters.

The present chapter addresses the following aspects:

- 1) Analysis of rainfall in the study area.
- 2) Detailed analysis of measured runoff.

#### **5.2 RAINFALL CHARACTERISTICS OF THE STUDY AREA**

Rainfall is the major driving force in determining the overall climatic conditions and to understand the hydrological regime of a given region. Variations of rainfall in time and space exert a significant influence on the magnitude and characteristics of various

hydrological processes. In this regard, rainfall analyses of daily, monthly and annual basis has been carried out. This will help to estimate the water availability of the region.

### 5.2.1 ANNUAL, MONTHLY AND DAILY RAINFALL

24-Hour (daily) rainfall (mm) was measured using a non- recording rain - gauge installed in the climate station established at Kodigibail close to the experimental watersheds. Rainfall data (2004 onwards), has been collected from NIH, Belgaum and subjected to annual, monthly and daily time periods.

For the annual time period, annual rainfall totals were compared with the long-term normal annual rainfall at the neighbouring Siddapur climate station maintained by Water Resources Development Organisation [WRDO], Govt. of Karnataka.

Monthly rainfall totals are shown in tables. Yearly rainfalls were divided into three classes based on the long term rainfall data of Siddapur taluk. The selected group of rainfall data falls under three categories Below Normal (< 3000 mm), Normal (3000 – 3500 mm) and Above Normal (3500- 4100 mm). Results of this analysis are tabulated in Table 5.1, Table 5.2, and Table 5.3.

**Table 5.1 Daily rainfall Characteristics of the Study Area for Below Normal Rainfall**

| Rainfall Class by depth (mm) | No. of Rainy Days | Rainfall Amount (mm) | % of Total Rainy Days | % of time | Cumulative % Annual Rainfall |
|------------------------------|-------------------|----------------------|-----------------------|-----------|------------------------------|
| >80                          | 6                 | 873.60               | 29.36                 | 29.36     | 29.36                        |
| 40.1 to 80                   | 27                | 880.60               | 29.60                 | 29.60     | 58.96                        |
| 20.1 to 40                   | 27                | 833.00               | 28                    | 28        | 86.96                        |
| 10.1 to 20                   | 20                | 284.20               | 9.55                  | 9.55      | 96.52                        |
| 5.1 to 10                    | 9                 | 72.00                | 2.42                  | 2.42      | 98.94                        |
| <5                           | 11                | 31.60                | 1.06                  | 1.06      | 100                          |
| Annual Total                 | 89                | 2975.00              |                       |           |                              |

**Table 5.2 Daily rainfall Characteristics of the Study Area for Normal Rainfall**

| Rainfall | No. of | Rainfall | % of Total | % of Annual | Cumulative |
|----------|--------|----------|------------|-------------|------------|
|----------|--------|----------|------------|-------------|------------|

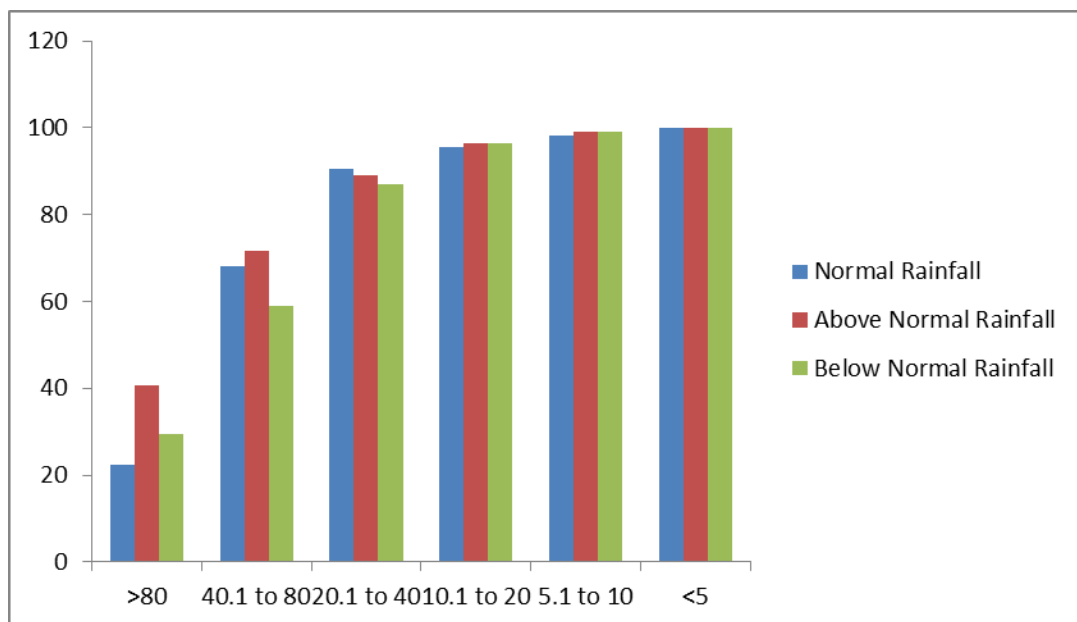
| Class by depth (mm) | Rainy Days | Amount (mm) | Rainy Days | Rainfall | % Annual Rainfall |
|---------------------|------------|-------------|------------|----------|-------------------|
| >80                 | 6          | 749.60      | 5.88       | 22.40    | 22.40             |
| 40.1 to 80          | 27         | 1531.60     | 26.47      | 45.76    | 68.16             |
| 20.1 to 40          | 26         | 749         | 25.49      | 22.37    | 90.53             |
| 10.1 to 20          | 11         | 168.20      | 10.78      | 5.03     | 95.56             |
| 5.1 to 10           | 11         | 86.00       | 10.78      | 2.57     | 98.13             |
| <5                  | 21         | 62.60       | 20.59      | 1.87     | 100               |
| Annual Total        | 102        | 3346.80     | 100        | 100      |                   |

**Table 5.3 Daily rainfall Characteristics of the Study Area for Above Normal Rainfall**

| Rainfall Class by depth (mm) | No. of Rainy Days | Rainfall Amount (mm) | % of Total Rainy Days | % of Annual Rainfall | Cumulative % Annual Rainfall |
|------------------------------|-------------------|----------------------|-----------------------|----------------------|------------------------------|
| >80                          | 12                | 1631.80              | 11.21                 | 40.56                | 40.56                        |
| 40.1 to 80                   | 22                | 1248.80              | 20.56                 | 31.04                | 71.60                        |
| 20.1 to 40                   | 24                | 708.10               | 22.43                 | 17.60                | 89.20                        |
| 10.1 to 20                   | 20                | 293.60               | 18.69                 | 7.30                 | 96.50                        |
| 5.1 to 10                    | 14                | 101.30               | 13.08                 | 7.30                 | 99.02                        |
| <5                           | 15                | 39.40                | 14.02                 | 7.30                 | 100                          |
| Annual Total                 | 107               | 4023                 |                       | 0.98                 |                              |

It is interesting to compare the intra - annual distribution of daily rainfall depths for above normal rainfall, which was an exceptionally on wet year, with below normal rainfall which received close to normal rainfall. It can be seen from table 5.3 and 5.1 that the cause for substantial difference in the annual totals for these two years was on account

of contribution from rainfalls of larger depths. For the above normal rainfall, 12 days received rainfall depths in excess of 80 mm while the corresponding figure for below normal rainfall was only 6. Similarly, while 16 days below normal rainfall received rainfalls depths between 40.1 – 80 mm, there were 22 such days for above normal rainfall. The difference in total number of rainy days for these two years (107 versus 89) was almost entirely on account of the increased number of rainfall events (134 versus 22) in these two classes during above normal rainfall. This phenomenon has induced significant differences in the annual totals and also the relative contributions of high magnitude events between above normal rainfall and below normal rainfall. The overall contribution of rainfall events > 40 mm was 71.60% for above normal rainfall (Table 5.3) compared to 58.96% in 2013 (Table 5.1). The corresponding contribution during the normal rainfall which is not exceptionally wet year, was 68.16% (Table 5.2).



**Fig 5.1 Daily rainfall characteristics for the study area**

In conclusion, it may be said that in a tropical monsoon environment, the difference between a high rainfall year and an average year may be entirely on account of a few high magnitude rainfall events. However, the few events can have a significant impact of not only total water yield, but also on runoff generation mechanism producing flash floods and causing erosion. This analysis highlights the importance of investigating intra - annual variability of rainfall while classifying years as above or below normal rainfall.

### **5.2.2 HOURLY RAINFALL INTENSITY**

A key facet of the hydrology and climatology of the humid tropics is the occurrence of more persistent high rainfall intensities compared with those occurring in the temperate regions. The equivalent hourly intensities of short term rainfalls, for example, over one minute, are commonly one or two order of magnitude higher than those experienced in humid temperate areas. Thus, the magnitude of rainfall is one of the principal drivers in accounting for the much wider range of preferred pathways of storm runoff in tropical forests. It is also a principal cause for a much greater range of dominant runoff pathways observed in hill slope hydrology, both temporally and spatially, during tropical storm events compared with non tropical areas.

The Sahayadri region is characterised by higher annual rainfalls due to long duration low intensity rainfall. It is reported that the 15 minute intensities often exceed 40mm/hr contributing about 15 % of total annual rainfall. Venkatesh et al (2006) analysed hourly rainfall data of 12 recording stations covering Uttara Kannada district of Karnataka. The study was carried out by dividing the district into three geographical units namely coastal, up - ghats and the plains. In the present analysis, hourly rainfall data recorded at Kodigibail using a recording type of raingauge was analysed to understand inter - annual and intra - annual variabilities. Rainfall intensities of hourly rainfall were extracted from the rain gauge charts and categorised under 6 classes depending on the magnitude of intensities. Results of this analysis are presented in Table 5.4, Table 5.5 and Table 5.6.

**Table 5.4 Rainfall intensity characteristics of the Study Area for Below Normal Rainfall**

| Rainfall Class by depth (mm) | Duration of rainfall events(hrs) | Amount of rainfall (mm) | % of total duration | % of Annual Rainfall | Cumulative % Rainfall | Equivalent days |
|------------------------------|----------------------------------|-------------------------|---------------------|----------------------|-----------------------|-----------------|
| >25                          | 3                                | 102.20                  | 0.46                | 3.46                 | 3.46                  | <1              |
| 20-25                        | 5                                | 108.80                  | 0.77                | 3.69                 | 7.16                  | <1              |
| 15-20                        | 10                               | 250.80                  | 1.54                | 8.51                 | 15.65                 | <1              |
| 10-15                        | 33                               | 410.80                  | 5.10                | 13.94                | 29.61                 | 1.38            |
| 5-10                         | 116                              | 936.50                  | 17.95               | 31.78                | 61.40                 | 4.83            |
| <5                           | 479                              | 1137.00                 | 74.14               | 38.59                | 100                   | 19.96           |
| Annual                       | 646                              | 29946.10                |                     |                      |                       |                 |

|       |  |  |  |  |  |  |
|-------|--|--|--|--|--|--|
| Total |  |  |  |  |  |  |
|-------|--|--|--|--|--|--|

**Table 5.5 Rainfall intensity characteristics for the Study Area for Normal Rainfall**

| Rainfall Class by depth (mm) | Duration of rainfall events(hrs) | Amount of rainfall (mm) | % of total duration | % of annual rainfall | Cumulative % Rainfall | Equivalent days |
|------------------------------|----------------------------------|-------------------------|---------------------|----------------------|-----------------------|-----------------|
| >25                          | 1.00                             | 25.60                   | 0.09                | 0.77                 | 0.77                  | <1              |
| 20-25                        | 3                                | 62.10                   | 0.26                | 1.88                 | 2.65                  | <1              |
| 15-20                        | 7                                | 111.50                  | 0.61                | 3.37                 | 6.01                  | <1              |
| 10-15                        | 53                               | 603.50                  | 4.65                | 18.21                | 24.22                 | 2.21            |
| 5-10                         | 138                              | 989.00                  | 12.11               | 29.86                | 54.09                 | 5.75            |
| <5                           | 938                              | 1520.53                 | 82.28               | 45.91                | 100                   | 39.08           |
| Annual Total                 | 1140                             | 3311.73                 |                     |                      |                       |                 |

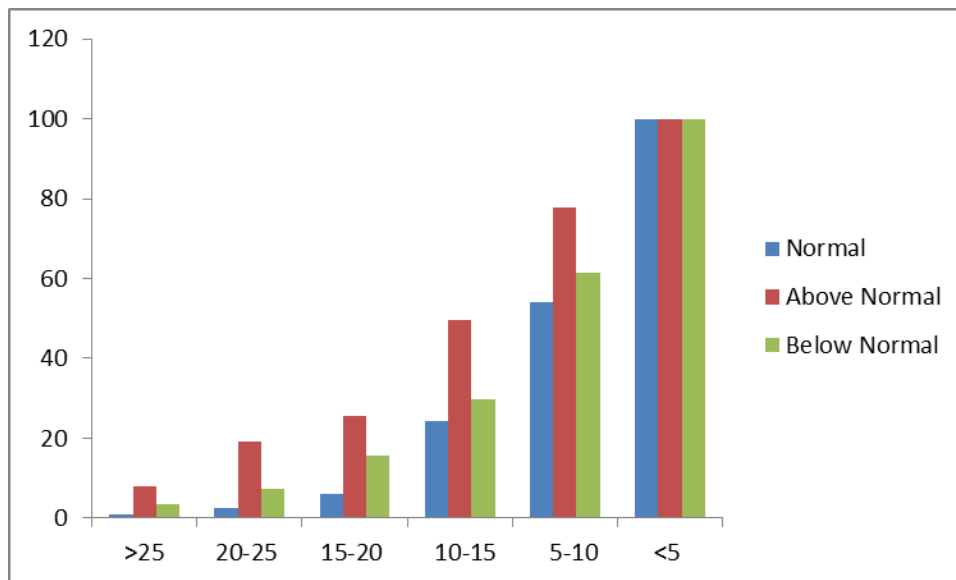
**Table 5.6 Rainfall intensity characteristics for the Study Area for Above Normal Rainfall**

| Rainfall Class by depth (mm) | Duration of rainfall events(hrs) | Amount of rainfall (mm) | % of total duration | % of Annual Rainfall | Cumulative % Rainfall | Equivalent days |
|------------------------------|----------------------------------|-------------------------|---------------------|----------------------|-----------------------|-----------------|
| >25                          | 6                                | 323.20                  | 0.88                | 8.05                 | 8.05                  | <1              |

|                 |     |         |       |       |       |       |
|-----------------|-----|---------|-------|-------|-------|-------|
| 20-25           | 15  | 441.90  | 2.20  | 11.01 | 19.06 | <1    |
| 15-20           | 15  | 260.00  | 2.20  | 6.48  | 25.54 | <1    |
| 10-15           | 72  | 972.00  | 10.56 | 24.29 | 49.54 | 3.00  |
| 5-10            | 145 | 1122.50 | 21.26 | 27.97 | 77.79 | 6.04  |
| <5              | 429 | 891.30  | 62.90 | 22.21 | 100   | 17.88 |
| Annual<br>Total | 682 | 4013.70 |       |       |       |       |

From the analysis of the hourly rainfall intensities during below normal rainfall, normal rainfall and above normal rainfall, it was noted that the recorded maximum hourly intensity was of the order 50.5 mm/hour during above normal rainfall. The total number of rainfall hours varied from 1140 hr (47.5 equivalent days) for normal rainfall category to a minimum of 646 hr (27 equivalent days) for below normal rainfall category showing large inter annual variation. The corresponding percentage of days (in comparison to the total number of rainy days) for normal rainfall and below normal rainfall were 47 % and 30 % respectively. During above normal rainfall received higher rainfall within 682 hrs. This suggest that the intensity of rainfall was very high with an average hourly intensity of 5.88 mm/hr in comparison with other two years (2.90 mm/hr for 2011 and 4.56 mm/hr for below normal rainfall).

Table 5.4 to 5.6 show that the major contribution to total annual rainfall comes from intensities less than 10 mm/hr. All it was observed that intensities less than 5mm/hr were recorded for maximum duration during the period of analysis. In above normal rainfall category, the rainfall intensity >10mm/hr contributed about 42% towards annual rainfall total. The contribution in the same intensity class during other two categories of rainfall i.e normal rainfall and below normal rainfall are comparatively lower the major portion of rainfall in the Sahayadri regoin is contributed by 4 to 5 spells each lasting 8 to 10 days but with relatively moderate rainfall intensities.



**Fig 5.2 Hourly rainfall intensity for the study area**

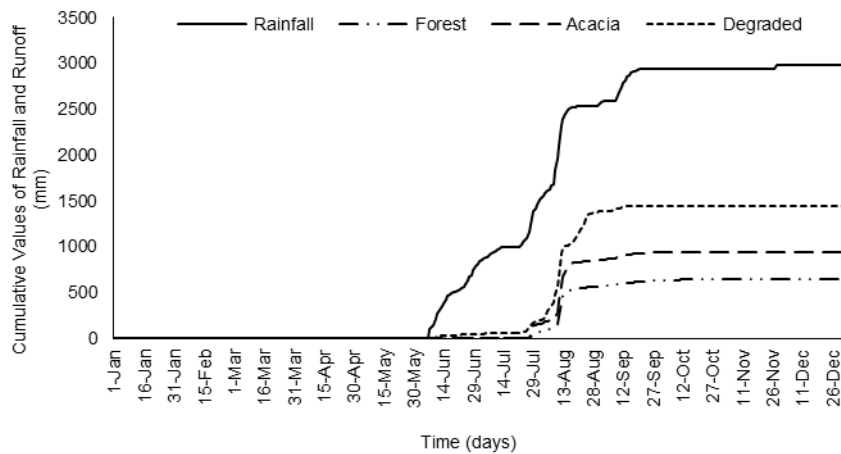
Further, the results showed that the study area received high intensity rain (>25mm/hr) only on few occasions and their contributions were also lower (1 %,8 % and 4 % respectively in all three categories of rainfall). Low intensity rainfalls contributed more than 70 % for normal rainfall category and below normal rainfall category lasting for 94 % of the time and above 50 % for above normal rainfall category lasted for 80 % duration. Contributions from rainfall of moderate intensity between 10 to 25 mm/hr were 24 %, 42 % and 26 % approximately for all the three category of rainfall which lasted for 6, 15, and 7% of the times. Results showed evidences of rainfall at Kodigibail being contributed mostly by the spells of low intensity rainfall rather than higher intensity rains though there were large year to year variations in the intensities.

### **5.3 RUNOFF ANALYSIS**

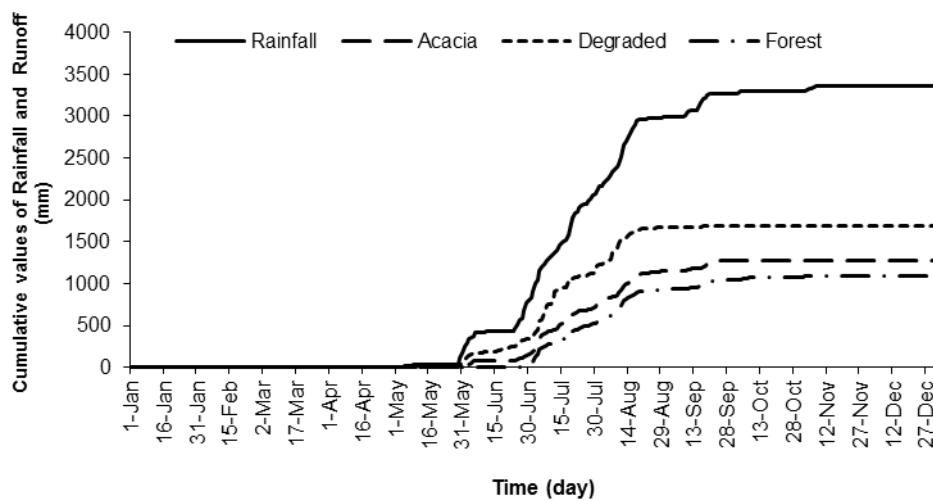
In the present analysis, an attempt is made to characterize differences in the runoff responses of the three watersheds possessing distinctly different land covers. The daily stream flows from the experimental watersheds were measured during the study period using calibrated broad crested notches. These observed mean daily discharge values were converted to equivalent runoff depth units (mm) so as to facilitate the comparison with the rainfall. Also the observed flows were used to derive the following parameters:

1. Specific discharge: discharge per unit area of watershed.
2. Specific peak discharge: peak discharge per unit area of watershed.

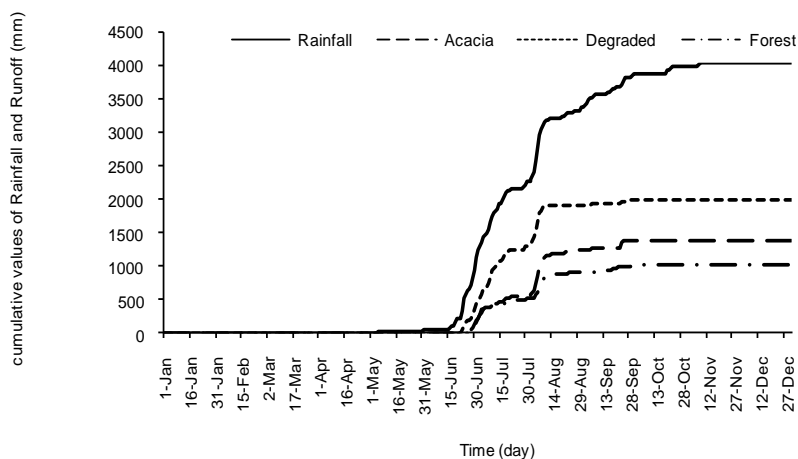
As a first step, daily rainfall values recorded at- site and the associated daily runoff measured at the outlets of the three watersheds were used to obtain plots of cumulative rainfall versus cumulative runoff for all three categorized types of rainfall.



**Fig 5.3 Cumulative plot of rainfall and runoff for different land covers for Below Normal Rainfall**



**Fig 5.3 Cumulative plot of rainfall and runoff for different land covers for Normal Rainfall**

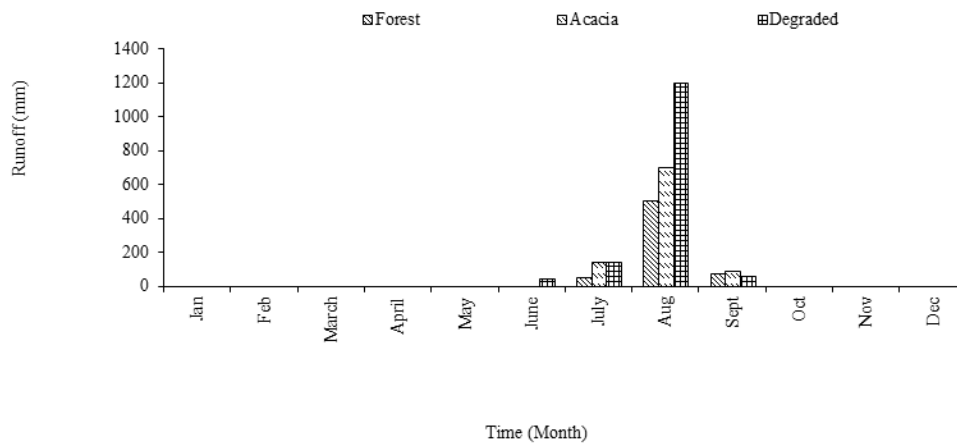


**Fig 5.4 Cumulative plot of rainfall and runoff for different land covers for Above Normal Rainfall**

From these plots, it can be seen that during all the categorized rainfall types, the total cumulative runoff were highest in degraded watershed, followed by acacia. The total runoff from the forest watershed was least during all the three years. This is an interesting feature, given the fact that not only was the total annual rainfalls during the three years quite differ, but the intra -annual distribution of rainfall amounts and rainfall intensities were also different ( Tables 5.1 –5.3 and Tables 5.4 –5.6. The higher yields from the degraded land cover supports the notion of an overland flow pathway occurring. In addition, total evaporation is likely to be lower over this degraded forest basins when compared to the forest which thus favours a greater proportion of rainfall available for runoff. Conversely, the lowest runoff are from the forest basin may be on account of

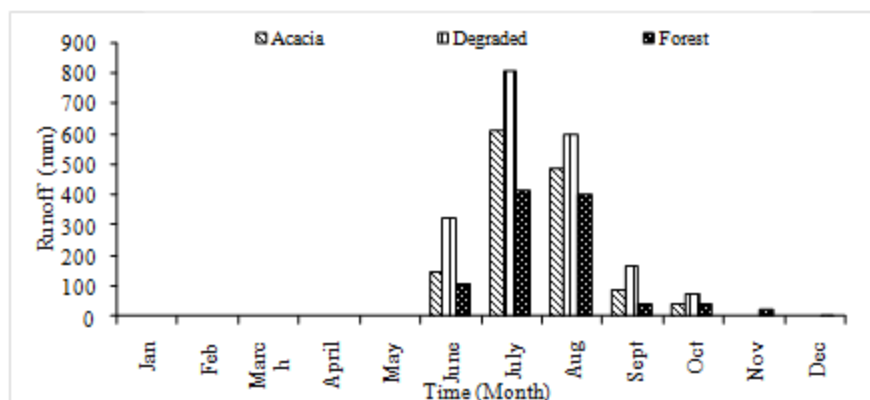
greater potential for groundwater recharge and higher evapotranspiration losses. The intermediate rank order in runoff yields from the Acacia basin suggests some recovery towards the levels of runoff response associated with the forest due to amelioration of soil properties and possibly evaporation approaching that of the forest.

The mean daily discharges of categorized rainfall data were aggregated to monthly totals for all three categorized rainfall and are plotted in fig 5.6, fig 5.7 and fig 5.8. These figures provide an overview of stream flow responses from the selected watersheds. The differences observed in the amount of runoff may largely be attributed to the influence of land cover of the watershed.



**Fig 5.6 Monthly distribution of measured runoff under different land covers for Below Normal Rainfall**

**Fig 5.7 Monthly distribution of measured runoff under different land covers for Normal Rainfall**



**Fig 5.8 Monthly distribution of measured runoff under different land cover above Normal Rainfall**

It can be noted from figure, that the degraded watershed yielded more runoff in comparison to that of the other two land covers. Runoff from the watershed covered with acacia plantation was smaller in comparison to degraded watershed. The least discharge was observed under the forested watershed. However, the flow was reported up to November in forested watersheds which could be largely attributed to the higher moisture holding capacity of the forest soils resulting in more sustained runoff in comparison to the degraded watershed. Also the flow in acacia watershed continues till the month of October which indicated that the water holding capacity of the soil conditions similar to that of forests.

The salient features of the observed flows from these three land covers types are shown in table 5.7, table 5.8 and table 5.9. In order to understand the influence of land cover on runoff generation, parameters such as specific discharge and specific peak discharge were also computed for selected watersheds. Results show that the observed runoff coefficient as lowest in forested watershed followed by acacia and degraded watershed. Table 5.7, Table 5.8 and Table 5.9 show that in spite of variation in the rainfall emerging as the runoff between the land covers remain consistent.

**Table 5.7 Runoff characteristic under different land covers of the study area for Below Normal Rainfall**

| Sl.No | Land use type | % Discharge | Specific Discharge (cumec/ha) | Difference in specific discharge | Specific peak discharge (cumec/ha) |
|-------|---------------|-------------|-------------------------------|----------------------------------|------------------------------------|
|       |               |             |                               |                                  |                                    |

|   |                    |      |       |                     |       |
|---|--------------------|------|-------|---------------------|-------|
|   |                    |      |       | wrt forest<br>( % ) |       |
| 1 | Natural<br>Forest  | 21.5 | 0.074 |                     | 0.018 |
| 2 | Degraded<br>forest | 48.4 | 0.167 | 70.42               | 0.029 |
| 3 | Acacia             | 31.7 | 0.109 | 41.93               | 0.020 |

**Table 5.8 Runoff characteristic under different land covers of the study area for Normal Rainfall**

| Sl.No | Land- use<br>type  | %<br>Discharge | Specific<br>Discharge<br>(cumec/ha) | Difference<br>in<br>specific<br>discharge<br>wrt forest<br>( % ) | Specific<br>peak<br>discharge<br>(cumec/ha) |
|-------|--------------------|----------------|-------------------------------------|--|---|
| 1     | Natural<br>Forest  | 29.5           | 0.1108                              |  | 0.0063                                      |
| 2     | Degraded<br>forest | 49.1           | 0.1597                              | 44.05  | 0.0106                                      |
| 3     | Acacia             | 37.77          | 0.1164                              | 5.01   | 0.0107                                      |

**Table 5.9 Runoff characteristic under different land covers of the study area for Above Normal Rainfall**

| Sl.No | Land use<br>type | % Discharge | Specific<br>Discharge<br>(cumec/ha) | Difference<br>in<br>specific<br>discharge | Specific<br>peak<br>discharge<br>(cumec/ha) |
|-------|------------------|-------------|-------------------------------------|---|---|
|-------|------------------|-------------|-------------------------------------|---|---|

|   |                    |       |        | wrt forest<br>( % ) |        |
|---|--------------------|-------|--------|---------------------|--------|
| 1 | Natural<br>Forest  | 24.4  | 0.1386 |                     | 0.0100 |
| 2 | Degraded<br>forest | 48.9  | 0.1901 | 37.16               | 0.0132 |
| 3 | Acacia             | 31.14 | 0.1375 | 1.25                | 0.0097 |

It can be noticed that the degraded watershed registered the highest specific discharge and the specific peak discharge while minimum was from forested watershed. The observed values of specific peak discharge from acacia watershed were lower than the degraded watershed but closer to the values observed in forested watershed. Results also indicated an increase in specific discharge by 5 and 44 % for normal rainfall mm and 37 % for above normal rainfall for acacia and degraded forest respectively in comparison to natural forest. This marginal increase in specific discharge for above normal rainfall could be due to the rainfall increase of 22 % as compared to that of rainfall < 3000 mm.

## 5.4 PEAK FLOW

The peak discharges observed and the associated rainfall events are presented in table 5.10, table 5.11 and table 5.12 for all the three categorized rainfall. Higher intensity rainfalls with shorter durations give higher peak flows. For the rainfall event of 132 mm (normal rainfall), a moderate peak flow of 0.123 m<sup>3</sup>/sec was observed for the degraded forest whereas it was .024m<sup>3</sup>/sec for the forested watershed. However for above normal rainfall, higher peak flow was observed in degraded watershed. Between normal rainfall and above normal rainfall, the peak flow increase from 173 % to 241 % in degraded watershed in comparison to the forested watershed. During the same period, there was an increase of 31 % to 69 % in peak flow in acacia watershed.

**Table 5.10 Peak flow for selected rainfall events for Below Normal Rainfall**

| Dates   | Rainfall (mm) | Peak Discharge (cumecs) |          |        |
|---|---------------|-------------------------|----------|--------|
|   |               | Natural Forest          | Degraded | Acacia |
| 12-aug  | 225           | 0.108                   | 0.263    | 0.1430 |
| 9-aug   | 153.6         | 0.013                   | 0.080    | 0.0486 |
| 28-july   | 146           | 0.011                   | 0.091    | 0.0347 |
| 11-aug  | 135.6         | 0.051                   | 0.122    | 0.0820 |
| 10-aug  | 120           | 0.023                   | 0.085    | 0.0418 |
| 13-aug  | 70.6          | 0.036                   | 0.092    | 0.0612 |
| Average   | 141.8         | 0.040                   | 0.122    | 0.0686 |
| Percentage Increase of Runoff over forested watershed |               |                         | 201.75   | 68.41  |

**Table 5.10 Peak flow for selected rainfall events for Normal Rainfall**

| Dates   | Rainfall (mm) | Peak Discharge (cumecs) |          |        |
|---------|---------------|-------------------------|----------|--------|
|         |               | Natural forest          | Degraded | Acacia |
| 19-july | 140           | 0.026                   | 0.011    | 0.139  |
| 12-aug  | 132           | 0.024                   | 0.123    | 0.075  |
| 5-july  | 106.6         | 0.013                   | 0.093    | 0.185  |
| 11-aug  | 98.9          | 0.038                   | 0.042    | 0.030  |

|   |        |       |        |       |
|---|--------|-------|--------|-------|
| 29-jun  | 97.4   | 0.012 | 0.052  | 0.023 |
| 3-july  | 90.2   | 0.023 | 0.049  | 0.021 |
| 28-june   | 84.2   | 0.011 | 0.034  | 0.013 |
| Average   | 107.02 | 0.021 | 0.058  | 0.028 |
| Percentage increase<br>of Runoff over<br>forested watershed |        |       | 173.21 | 31.40 |

**Table 5.11 Peak flow for selected rainfall events for Above Normal Rainfall**

| Dates  | Rainfall (mm) | Peak Discharge (cumecs) |          |        |
|--|---------------|-------------------------|----------|--------|
|  |               | Natural forest          | Degraded | Acacia |
| 7-aug  | 198.22        | 0.060                   | 0.052    | 0.067  |
| 6-aug  | 198           | 0.030                   | 0.109    | 0.054  |
| 1-jul  | 186           | 0.007                   | 0.072    | 0.034  |
| 24-jun   | 177           | 0.013                   | 0.025    | 0.009  |
| 5-aug  | 144           | 0.021                   | 0.080    | 0.062  |
| 29-jun   | 120           | 0.015                   | 0.055    | 0.020  |
| 23-july  | 116           | 0.026                   | 0.033    | 0.007  |
| 2-july   | 113           | 0.011                   | 0.054    | 0.031  |
| 9-july   | 94.2          | 0.012                   | 0.037    | 0.009  |
| 10-jul   | 92.4          | 0.009                   | 0.052    | 0.021  |
| 30-jun   | 108.6         | 0.017                   | 0.093    | 0.062  |
| Average  | 140.6         | 0.020                   | 0.070    | 0.034  |
| Percentage increase of<br>Runoff over<br>forested<br>watershed |               |                         | 241.51   | 69.7   |

A combined plot of rainfall and the peak discharges for all land covers show that the peak flow observed in the forested watershed was very close to that of degraded watershed. A closer scrutiny of the observed peak flow under question is preceded by a large rainfall event, which might have saturated the soils under forested watershed.

On an average, the volume of precipitation from individual rainstorms that generated the peak flows was similar across the considered land covers. The land covers thereby supporting to the hypothesis that the degraded lands do generate higher peak flow. The degraded watershed generated the highest peak flow in comparison with the peak flow observed under forested watershed. However, no significant differences in peak flow were observed between the acacia and forest watershed. These observations imply that forest and acacia watersheds presumably have similar flow generating mechanism during the lower rainfall. But at higher rainfall, they have entirely different runoff mechanism. Also these observations may support the assumption that acacia plants can induce an improvement in the soil hydraulic characteristics and thereby increasing the water holding capacity of soils.

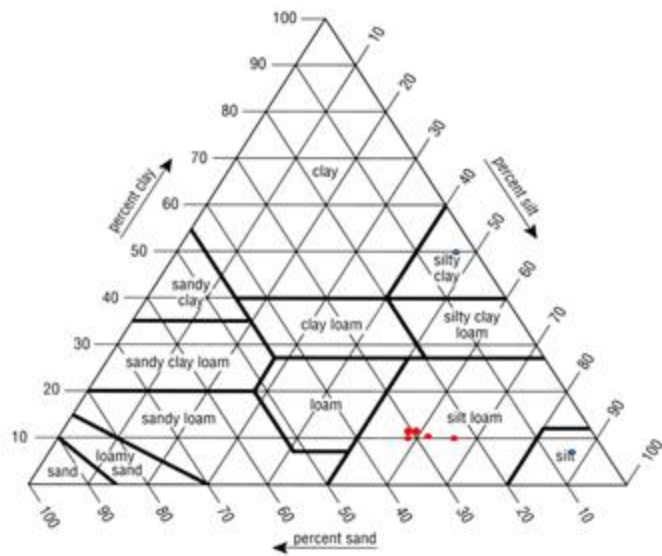
## **5.5 SOIL MOISTURE**

### **5.5.1 GEOLOGY AND SOILS**

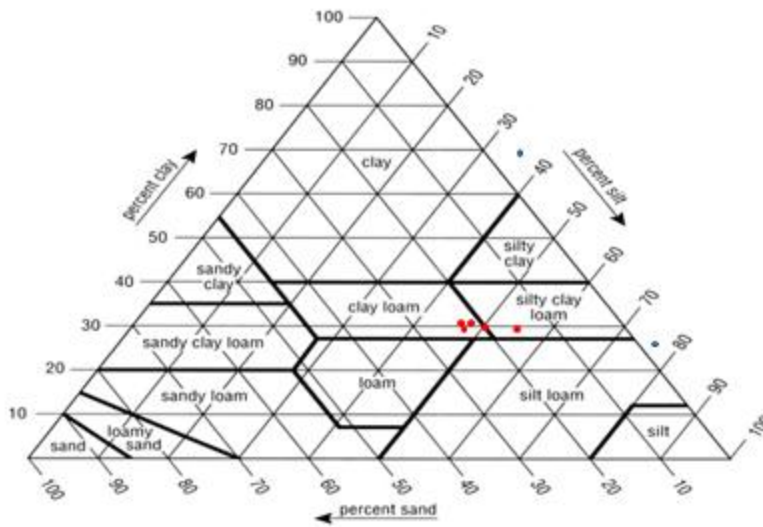
The soils in the catchments are generally deep, often going below 2 m. The soil texture at different depth in the selected catchments is shown in Fig 5.9. Note that there is limited variation in soil texture across depth, but that there is significant variation across the sample watersheds, in particular that the degraded site has high clay content in its surface layer. This feature is relevant in explaining some of the differences in soil moisture depletion discussed later.

| Depth Below Surface (cm) | Acacia                                | Degraded                               | Forest                                 |
|--------------------------|---------------------------------------|--|--|
| 0-20                     | Sand 27.9%<br>Silt 62.1%<br>Clay 10%  | Sand 1.6%<br>Silt 11.2%<br>Clay 87.2%  | Sand 27.7%<br>Silt 61.9%<br>Clay 10.4% |
| 20-40                    | Sand 41.1%<br>Silt 48.9%<br>Clay 10%  | Sand 26.6%<br>Silt 63.4%<br>Clay 10.0% | Sand 31.2%<br>Silt 58.5%<br>Clay 10.0% |
| 40-60                    | Sand 41.2%<br>Silt 49.2%<br>Clay 9.6% | Sand 25.9%<br>Silt 63.7%<br>Clay 10.4% | Sand 29.3%<br>Silt 59.5%<br>Clay 11.2% |
| 60-80                    | Sand 19.9%<br>Silt 9.6%<br>Clay 70.5% | Sand 13.6%<br>Silt 75.6%<br>Clay 10.8% | Sand 23.4%<br>Silt 66.6%<br>Clay 10.0% |
| 80-100                   | Sand 22.3%<br>Silt 68.1%<br>Clay 9.6% | Sand 16.2%<br>Silt 73.0%<br>Clay 10.8% | Sand 30.7%<br>Silt 58.1%<br>Clay 11.2% |

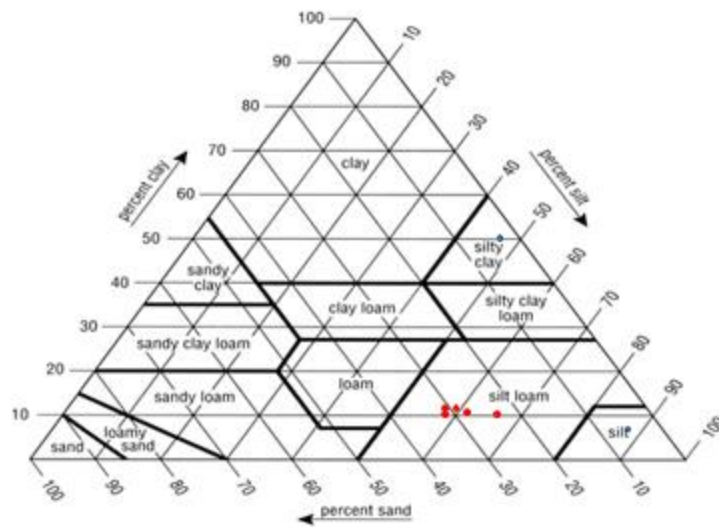
**Figure 5.9 Average soil textures at different depths in Kodgibail sample watersheds**



**Fig 5.10 USDA Soil Classification for Forest**



**Fig 5.11 USDA Soil Classification for Degraded**



**Fig 5.12 USDA Soil Classification for Acacia**

**5.5.2 SOIL PHYSICAL PROPERTIES FOR SELECTED WATERSHEDS AT DIFFERENT DEPTHS**

Results of laboratory experiments to determine physical properties of the soil at various depths under each land cover are summarized in Table . From these results it can be seen that the clay content is more or less same at all depths under all land cover s. However, some variations in the silt and sand fractions are evident both with depth and also across land covers. The degraded watershed appears to have higher silt content in comparison to the other two land covers. Classification of the soils in each layer as per the USDA classification is shown in the Table 5.13. It can be seen that the predominant category is silty loam (USDA, NRCS, 2008).

**Table 5.13 Soil Physical Properties For Selected Watersheds At Different Depths**

| Depth(m) | Land Cover | Sand(%) | Silt(%) | Clay(%) | USDA Soil Type | DryBulk Density (g/cm <sup>3</sup> ) |
|----------|------------|---------|---------|---------|----------------|--------------------------------------|
| 0.50     | Forest     | 27.7    | 61.9    | 10.4    | Sity loam      | 1.45                                 |
|          | Degraded   | 1.6     | 87.2    | 11.2    | Sity loam      | 1.35                                 |
|          | Acacia     | 27.9    | 62.1    | 10.0    | Sity loam      | 1.40                                 |
| 1.00     | Forest     | 29.3    | 59.5    | 11.2    | Sity loam      | 1.45                                 |
|          | Degraded   | 25.9    | 63.7    | 10.4    | Sity loam      | 1.20                                 |
|          | Acacia     | 41.2    | 49.2    | 9.6     | Sity loam      | 1.50                                 |
| 1.50     | Forest     | 23.4    | 66.6    | 10.0    | Sity loam      | 1.42                                 |
|          | Degraded   | 13.6    | 75.6    | 10.8    | Sity loam      | 1.44                                 |
|          | Acacia     | 19.9    | 70.5    | 9.6     | Sity loam      | 1.38                                 |

### 5.5.3 DEVELOPMENT OF SOIL WATER RETENTION CURVES

The soil water retention curve (WRC) and unsaturated hydraulic conductivity function are two of the most important hydraulic properties of the unsaturated soil zone. Knowledge of these properties is crucial for modelling water and solute movement in this

zone. Among these, the WRC is of the fundamental importance since the hydraulic conductivity function can be derived from it. A WRC represents the relationship between volumetric soil moisture content ( $\theta$ ) and soil water pressure ( $h$ ) and provides useful information on field capacity and permanent wilting point of the soil which can be used to estimate available water and water holding capacity. The WRC for a soil layer may be established by fitting an analytical model (van Genuchten 1980) to a concurrent set of water retention measurements ( $\theta$ ,  $h$ ) made in the laboratory or in-situ. The shape of the WRC is determined largely by physio-chemical properties such as texture, structure and organic matter content. Since the physio-chemical properties are assumed to be time invariant, the WRC for a given soil is assumed to be a static property.

In the present study, WRCs for the soil profiles in the selected watershed were experimentally determined for the following purposes.

- To characterise the soil water retention behaviour of the soils.
- To convert observed soil matric potentials to equivalent volumetric soil moisture contents to enable easy interpretability of the soil dynamics of vadose zone processes.

Also, the presence of actively growing deep-rooted vegetation may significantly modify soil structure and organic matter content of the soil and lead to temporal changes in retention behaviour of the soil profile over the period growth. Also, land use/land cover changes such as deforestation are known to alter water yield (e.g. Bruijnzeel 1990; Bonell and Balek 1993) on account of modifications in soil infiltration and retention properties. Few studies seem to have been undertaken to monitor temporal changes in the shape of the WRC, a notable exception being the study by Spaans et al. (1989) who analysed the effects of land use changes on soil physical properties in the tropics.

However, very little quantitative information exists on the physical and hydraulic properties of soils, as well as on the impact of different land covers on the soil hydraulic properties in the Sahayadri mountains. Characterization of soil properties and their variations with respect to land cover. Therefore, the following section describes the development of WRC for soils under different land covers and characterizing the temporal variabilities in the WRCs.

### **5.5.3.1 Soil Water Retention Curves**

Retention data obtained in this manner for each soil sample was used to fit the soil water retention model proposed by Genuchten (1980) (eq. 5.1).

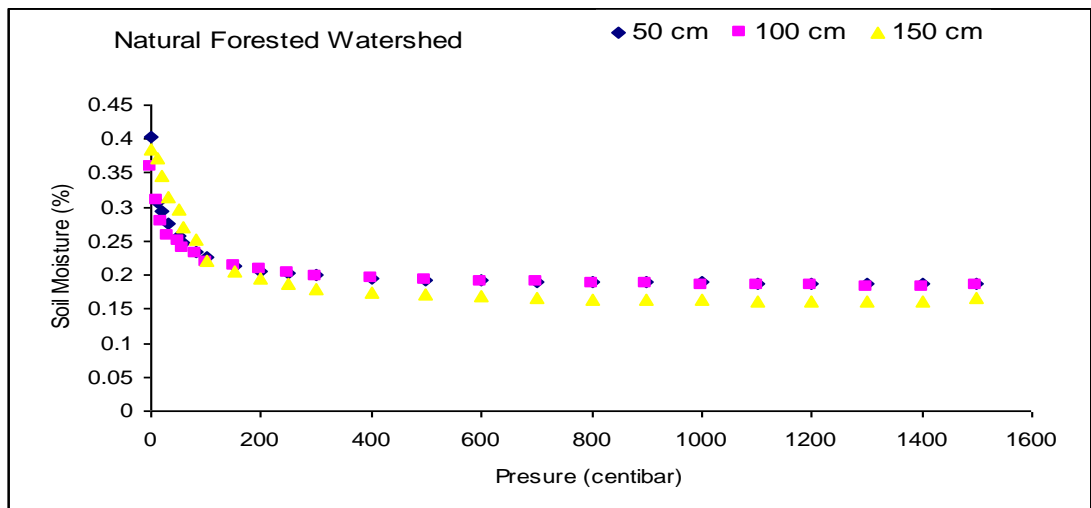
$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1 + (\alpha h)^n)^m} \dots\dots\dots(5.1)$$

Where  $\theta$  (h) is soil water content ( $\text{cm}^3 \text{ cm}^{-3}$ ) corresponding to soil water pressure h (centibar),  $\theta_r$  is the residual soil water content ( $\text{cm}^3 \text{ cm}^{-3}$ ),  $\theta_s$  is the saturation soil water content ( $\text{cm}^3 \text{ cm}^{-3}$ ),  $\theta$ , n and m are the empirical parameters. Van Genuchten proposed use of  $m=1-1/n$ . Optimal model parameters  $\theta$  and n were determined using SOLVER Adding in Micro Soft Excel®. Saturation soil water content ( $\theta_s$ ) and residual soil water content ( $\theta_r$ ) were also treated as unknown parameters and their optimal values were determined. A similar procedure was adopted to determine model parameters by pooling the retention data for all soil samples at each depth within each watershed.

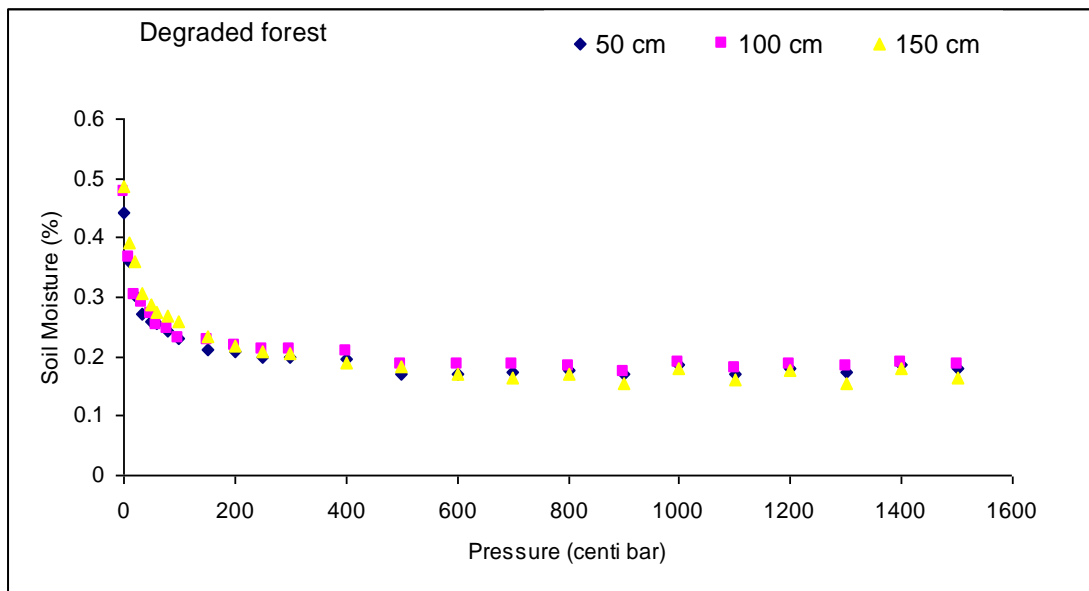
The fitted retention curves were used to convert the observed soil matric head values to equivalent values of volumetric soil moisture content ( $\text{cm}^3/\text{cm}^3$ ). Uncertainties introduced into inferred soil moisture content values on account of pressure plate measurements and also due to fitting the Van Genuchten model.

**5.5.3.2 Soil Water Retention Relationships**

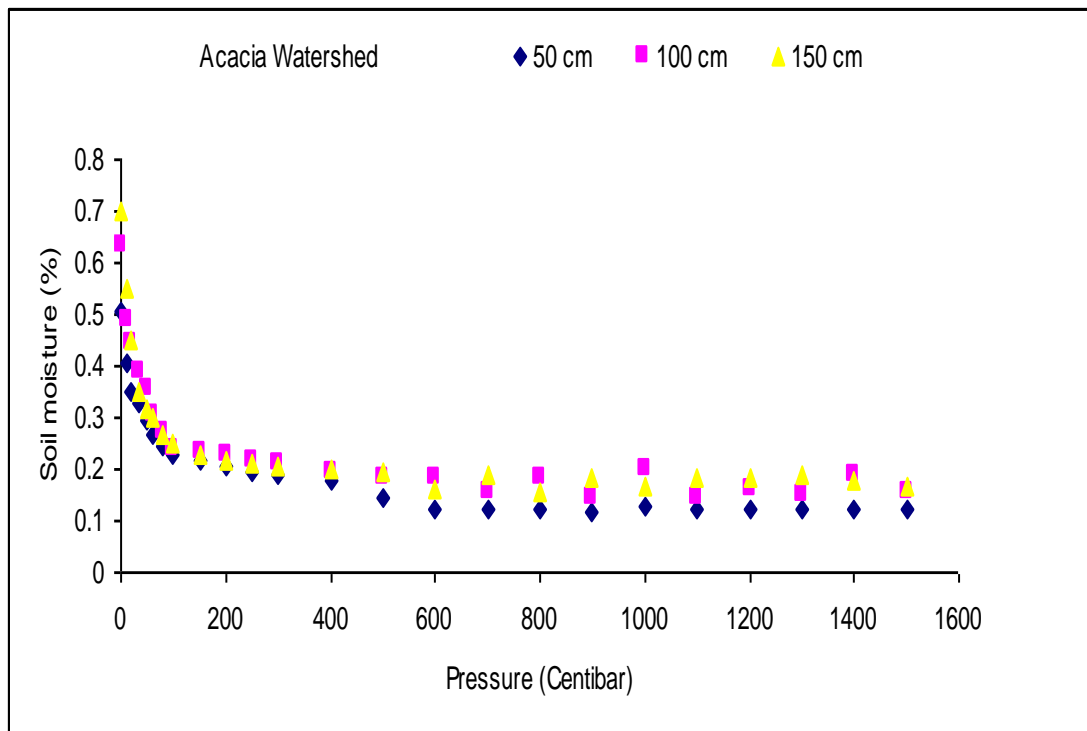
The soil samples were collected at 3 depths, 0.5m, 1.0m and 1.5 m from selected watersheds under forest, acacia and degraded land cover. These samples were subjected to pressure from 0.1 bar to 15 bar using pressure plate apparatus. A plot of soil moisture vs pressure was drawn to develop the soil water retention relationships. As an example, the WRCs for natural forest, degraded and acacia watershed are shown in the Fig 5.14, Fig 5.15 and Fig 5.16 for the three depths.



**Fig 5.13 Fitted Soil Water Retention Curves for Natural forested watersheds**



**Fig 5.14 Fitted Soil Water Retention Curves for degraded watersheds**



**Fig 5.15 Fitted Soil Water Retention Curves for acacia watersheds**

#### **5.5.4 FOREST COVER AND COMPOSITION**

The natural forest vegetation in the Kodgibail area is semi-evergreen, but with human use over centuries, the vegetation today is a mosaic of dense semi-evergreen patches, moist deciduous tree savannas, and scrub thicket sand grasslands, interspersed with *Acacia auriculiformis* plantations. The first-order catchments were chosen to have relatively homogeneous vegetation, but this was not always possible. We carried out a detailed field sampling of the forest vegetation, laying 100mx20m transects in each first-order catchment and enumerating tree species, tree girth, tree height and disturbance level. We then used the results of this sampling to visually interpret Google Earth imagery and generate forest cover maps for the first order catchments and for the entire Bilgihole catchment. A brief summary of the estimated tree densities, basal area and observed dominant species is given in Table 5.14.

**Table 5.14 Summary of vegetation parameters for 1st order catchment**

| Catchment   | Estimated average tree density | Estimated average basal area for entire catchment | Dominant species  |
|-------------|--------------------------------|---|---|
| Hulimane NF | 615                            | 2632  | Gymnonthraconarica, Sagereaea listari, Ixora  |
| Vajgar NF   | 485                            | 3536  | Lophopetalum wightianum, Alseodaphne semicarpifolia, Gymnonthraconarica, Sagereaea          |
| Vajgar SB   | 615                            | 1896  | Alseodaphnesemicarpifolia, Lophopetalum wightianum, Ixora barcheata, <del>Alseodaphne</del> |
| Mavinahalli | 352                            | 2099  | Hopea wightiana, Terminalia panniculata, Aporosa  |
| Acacia 1    | 132                            | 1068  | Acacia auriculiformis, Anacardium occidentale,  |
| Acacia 2    | 345                            | 2053  | Acacia auriculiformis, Buchanania lanzan, Holigarna aronottiana, Alseodaphne                |

### **The vegetation sampling and mapping exercise indicated that**

1. While Acacia plantations were least diverse, some natural tree species are mixed within the plantation.
2. Both so-called 'degraded' catchments contained significant areas of dense tree vegetation. There was also significant difference in the species composition and tree density of the Mavinahalli degraded catchment vis-à-vis the Vajgar degraded catchment, with the latter being denser and containing more semi-evergreen species compared to the former.
3. There were also significant differences in the species composition between the two natural forest catchments. However, both clearly had high tree densities and basal area compared to all other categories.

### **5.5.5 COMPARISON OF SOIL HYDRAULIC CONDUVTIVITY**

In order to predict the hydrological effects of land cover change, it is important to understand what the treatment involves: whether it is a change in land cover or are the associated changes to soil properties as well. Saturated and unsaturated hydraulic conductivity are both related to the degree of resistance from soil particles when water flows in pores. These resistances are affected markedly by the form sizes, branching's, jointing's and tortuosity's of pores as well as by the viscosity of the water.

The present investigations were carried out by using disc and Guelph permeameters in the Malnaad block region of Uttara Kannada district in Karnataka. Table 5.15 Illustrates the variation of hydraulic conductivity values measured under varied land cover changes. It is noticed that the field saturated hydraulic conductivity ( $K_s^*$ ) varies between 3.59 mm/day and 0.35 mm/day in a natural forest followed by plantation of acacia auriculiformis (1.38 mm/day to 0.13 mm/day) and in degraded land it was minimum varying from 0.94 mm/day to 0.05 mm/day.

**Table 5.15 Saturated Hydraulic Conductivity values under different land-use types**

| Site Number | Soil Type / Land use | Layer  | No of Samples | K*mmh <sup>-1</sup> |          |                 | Antilog Si |
|-------------|----------------------|--------|---------------|---------------------|----------|-----------------|------------|
|             |                      |        |               | Arith. Mean         | Log Mean | Range           |            |
|             |                      | 0.00 m | 18            | 61.80               | 57.32    | 31.59 to 109.88 | 0.406      |
|             |                      | 0.10 m | 18            | 38.23               | 35.64    | 19.93 to 74.11  | 0.371      |
|             |                      | 0.45 m | 13            | 19.93               | 16.16    | 8.55 to 68.4    | 0.613      |
|             |                      | 0.60 m | 13            | 16.88               | 15.88    | 9.12 to 36.00   | 0.352      |
|             |                      | 0.90 m | 13            | 21.22               | 19.17    | 10.6 to 43.20   | 0.455      |
|             |                      | 1.20 m | 13            | 13.47               | 12.18    | 7.03 to 31.80   | 0.442      |
|             |                      | 1.50 m | 13            | 7.06                | 5.35     | 2.18 to 19.45   | 0.639      |
|             |                      | 0.00 m | 18            | 42.30               | 39.31    | 14.41 to 75.95  | 0.409      |
|             |                      | 0.10 m | 18            | 40.19               | 29.47    | 2.26 to 106.52  | 0.910      |
|             |                      | 0.45 m | 13            | 25.83               | 25.40    | 17.56 to 36.00  | 0.190      |
|             |                      | 0.60 m | 13            | 8.16                | 5.63     | 1.8 to 21.6     | 0.909      |
|             |                      | 0.90 m | 13            | 3.84                | 2.85     | 0.72 to 21.6    | 0.846      |
|             |                      | 1.20 m | 13            | 2.51                | 2.15     | 0.91 to 6.7     | 0.564      |
|             |                      | 1.50 m | 13            | 2.73                | 2.19     | 1.05 to 6.9     | 0.683      |
|             |                      | 0.00 m | 18            | 180.62              | 149.66   | 51.15 to 384.18 | 0.647      |
|             |                      | 0.10 m | 18            | 76.98               | 57.45    | 11.89 to 171.56 | 0.870      |
|             |                      | 0.45 m | 13            | 17.35               | 16.07    | 11.44 to 36.00  | 0.384      |
|             |                      | 0.60 m | 13            | 16.44               | 15.23    | 11.8 to 42      | 0.359      |
|             |                      | 0.90 m | 13            | 16.20               | 15.19    | 10.08 to 36     | 0.346      |
|             |                      | 1.20 m | 13            | 16.20               | 14.50    | 4.35 to 37.11   | 0.518      |
|             |                      | 1.50 m | 13            | 18.39               | 17.36    | 9.61 to 37.55   | 0.347      |

In all the three cases, the  $K_s^*$  is maximum in surface layers and showed a sudden decrease with depth. Logarithmic mean is 149.66 mm/hr and 57.45 mm/hr at the surface and 0.1 m depth respectively. Beyond this depth there is a gradual decline up to a depth of 1.2m and then showed an increase at a depth of 1.5 m.

The observation made in the acacia auriculiformis, showed a similar trend in surface and at 0.1 m depth. However, it is noticed that the maximum  $K_s^*$  is 109.88 mm/hr with a logarithmic mean of 57.32 mm/hr whereas at a depth of 0.1 m it reduced to 74.11 mm/hr with a log mean of 35.64 mm/hr.

Investigations carried out on degraded land showed that the field saturated hydraulic conductivity vary between 14.41 mm/hr and 75.95 mm/hr in the surface layer whereas at a depth of 0.1m, more wider range (2.26 mm/hr to 106.52 mm/hr) is observed. This clearly indicates that such variation could be the result of soil compaction due to trampling cattle and anthropogenic disturbances. It is interesting to note that the  $K_s^*$  decreases significantly with depth in comparison to acacia plantation. In spite of having similar soil and geologic condition there is a considerable decrease in field saturated

hydraulic conductivity. The higher hydraulic conductivity observed in acacia plantation could be attributed to the improved soil conditions resulting from plant growth and root development. However, in natural forest the entire hydrological process varies significantly due to the biomass and density of root, interception, stem flow and canopy cover (Fleming and Smiles, 1975). In general, vegetation cover reduces the impact energy of droplets, so reducing surface slaking and crusting. Removal of water by transpiration results in a more uniform reduction of soil moisture with depth, enhancing infiltration and hydraulic conductivity, whilst the accumulation of organic matter provides a suitable substrate for soil micro-organisms as well as conferring a degree of structural stability to the soil mantle and impeding overland flow.

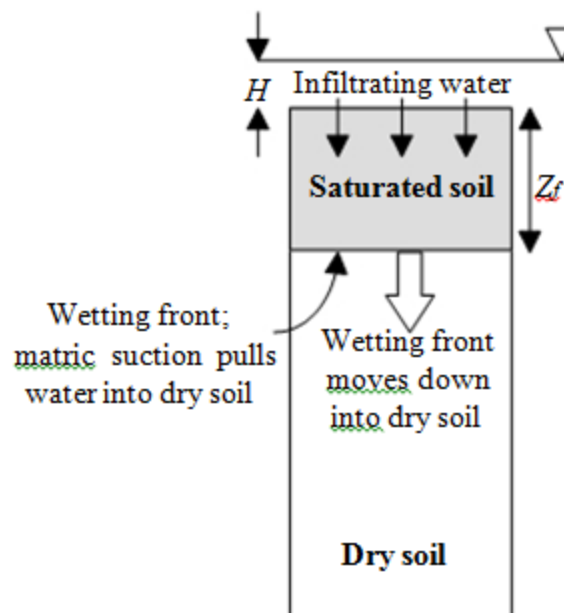
Our analysis of rainfall intensity in Kodgibail (not shown here) indicated that the maximum intensity of 54 mm/hr occurred only once in 3 years, and an intensity of 50 mm/hr occurred twice in 3 years and the 44 mm/hr repeated 12 times in 3 years (intensities were summed with reference to 15 minute rainfall). A comparison of these intensities with saturated hydraulic conductivity at different depths in different catchments is given in the Appendix. It shows that that all the higher intensity rainfall are much lesser than the field saturated hydraulic conductivity at the surface and 0.1 m depth, particularly in forest and acacia plantation. However, due to the sharp decrease in hydraulic conductivity at depth, all the concentrated water will flow as delayed flow or interflow. The case is similar in acacia in the surface layer but at a depth of 0.1 m, there is a sharp decrease in hydraulic conductivity leading to saturation excess overland flow.

#### **5.5.6 SOIL MOISTURE BY GREEN-AMPT METHOD**

Soil moisture is an important variable for understanding and predicting a range of hydrological processes including flooding, erosion, solute transport and land-atmosphere interactions. Soil moisture exhibits a high degree of spatial and temporal variability. Both surface soil moisture and subsoil moisture have profound effects on the above processes. While, many researchers have studied the horizontal variation and temporal changes of soil moisture, but little attention has been paid to the profile features of the soil moisture. There have been a number of recent papers indicating that land use (Fu et al., 2000), slope gradient (Moore et al., 1988), aspect and curvature (Western et al., 1999), slope position and relative elevation (Cra`ve and Gascuel-odux, 1997), precipitation (Famiglietti et al., 1998) and mean soil moisture (Bell et al., 1980) have influence of the distribution of soil moisture. However, in the present study, in order to gain a better understanding of soil moisture variations in relations to land use is analysed.

### 5.5.6.1 Green And Ampt Infiltration Model

The Horton equation captures the basic behavior of infiltration but the physical interpretation of the exponential constant is uncertain. Green and Ampt (1911) presented an approach that is based on fundamental physics and also gives results that match empirical observations. They use the following simplification of infiltration reality:



**Fig 5.16 Green and Ampt Infiltration**

In reality, there is often not a sharp wetting front and/or the soil above the wetting front may not saturate. The equation to use if you need to consider the most realistic situation is the Richard's equation; Richard's equation is beyond the scope of this class but you should be aware of it. The problem with all mechanistic infiltration equations is uncertainty about how to generalize to the field or landscape scale, especially with respect to the suction forces at the wetting front. None-the-less, many researchers are embracing these approaches and making good progress so you should have some rudimentary knowledge of, at least, the Green and Ampt concept.

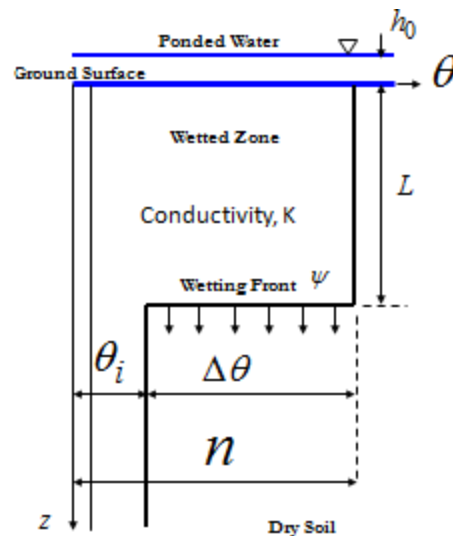
This method derives an equation for total depth of infiltration :

$$F = \frac{K_s S_w (\theta_s - \theta_i)}{i - K_s}$$

where  $\theta_s$  and  $\theta_i$  are the saturated and initial volumetric water contents, respectively,  $S_w$  is the soil water suction (negative pressure) at the wetting front,  $i$  is rainfall intensity, and  $K_s$  is the saturated hydraulic conductivity.

### 5.5.6.2 GREEN-AMPT ASSUMPTIONS

1. wetting front advances at constant rate (and is well-defined)
2. volumetric water contents remain constant above and below the wetting front as it moves
3. soil water suction below the wetting front remains constant
4.  $\Delta\theta$  = increase in moisture content as wetting front passes



**Fig 5.17 Green Ampt Model**

Where,

$\Psi$  = Suction head at “sharp” wetting front

$L$  = Wetted depth

$K$  = Conductivity in wetted zone

$h_0$  = Depth of water ponding on surface (small)

Even in uniform soil with negligible evaporation and transpiration, redistribution is a complex process which involves hysteresis between the capillary potential  $\Psi$  and moisture  $\theta$  of a soil. This arises because, even in the infiltration phase, the soil at different depths wets to different maximum moisture contents. Subsequently, as water moves downwards, there is a unique  $\Psi(\theta)$  relationship for each depth of the soil throughout the zone where moisture contents are decreasing.

Factors affecting the water balance component, and thus the redistribution of soil moisture and solutes, are closely related to the scale under discussion (Jacques et al., 2001). On a catchment or even large scale, topography driven lateral redistributions of water and energy and topography related heterogeneities are key factors in the water cycle ( Ambroise, 1995). On a field plot within a large plain, the effects of these factors in the redistribution of soil moisture and solute in the unsaturated zone can be neglected, since the topographic gradient is very small.

The plant and/or crop is related closely to land use and influences the redistribution of moisture and solute through transpiration, root water extraction, and growing characteristics, such as leaf area index (LAI), no matter whether they are in dry or wet environment (de Faria and Madramootoo, 1996; Thornes et al., 1996; De Roo et al., 2001), and the different species and class have diverse effects on the soil water storage (Hodnett et al., 1995). Irrigation and rainfall can be considered jointly as an important factor affecting infiltration, redistribution and drainage (Li and Kawano, 1996; Gaze et al., 1997). Soil characteristics are of course, the internal factors controlling the soil moisture and solute transported.

### **5.5.6.3 Soil moisture redistribution**

The soil moisture in each layer responds differently to a rainfall event and it may show little or no change due to antecedent storage conditions. There is a large increase in response to a continuous event. Infiltration and redistribution are generally regarded as one-dimensional unless the water supply is not spatially uniform. The estimated soil moisture redistribution using Green-Ampt method is given below (Table 5.16).

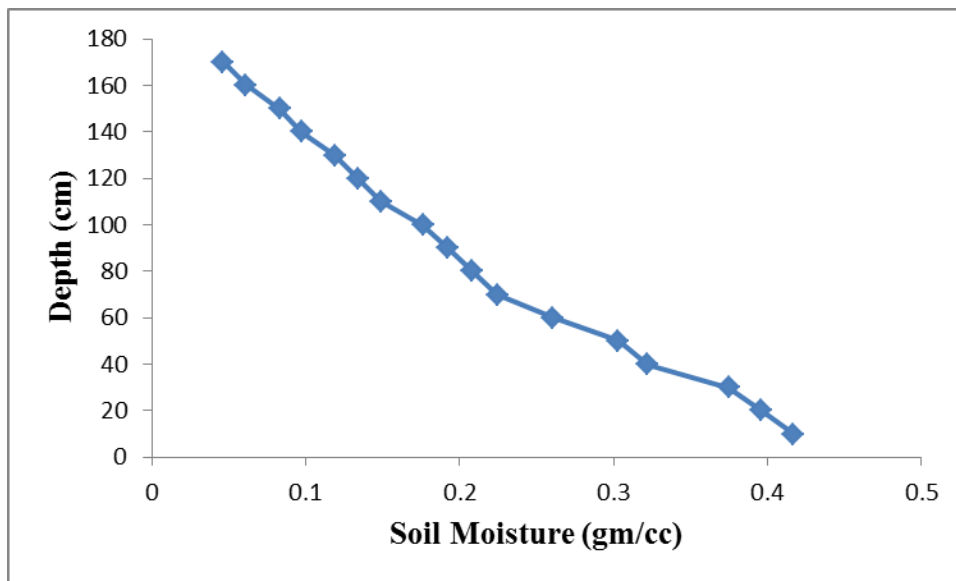
The results indicate that the moisture varies between 0.416 – 0.046 (gm/cc), 0.62 – 0.05 (gm/cc) and 0.25 – 0.03 (gm/cc) in forest, degraded and acacia land covers respectively. The estimated values were compared with the observed values in three watersheds and found that the model predicted values are much higher than the observed

values, particularly in the top layers. This variation in the observed and predicted values could be due to the change in rainfall pattern, type of soil and grain-size distribution.

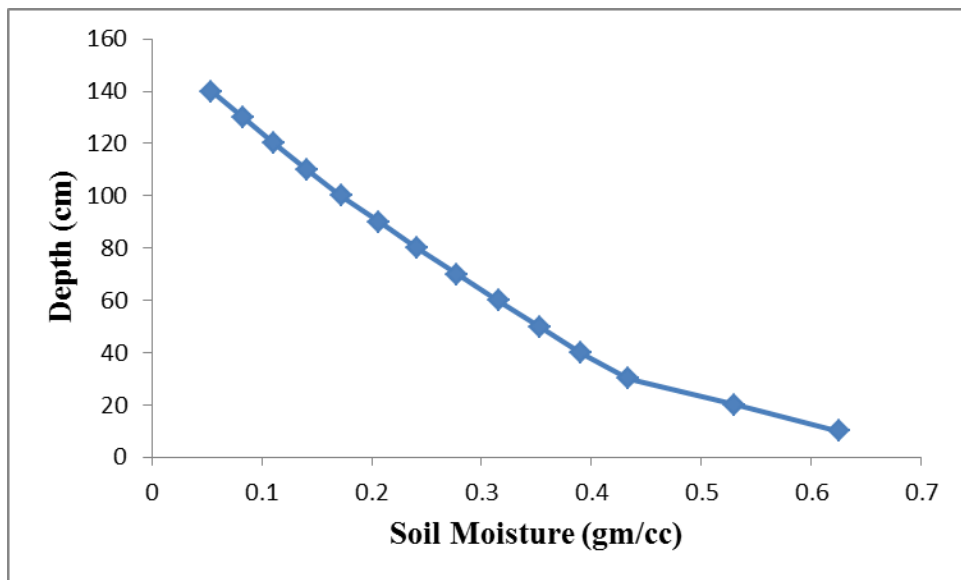
**Table 5.16 Soil moisture values using Green-Ampt Method**

| Sl.No | Depth (cm) | $(\theta_s - \theta_i)$ values for Land use / Land Covers (gm/cc) |          |        |
|-------|------------|---|----------|--------|
|       |            | Forest  | Degraded | Acacia |
| 1     | 10         | 0.416   | 0.625    | 0.25   |
| 2     | 20         | 0.395   | 0.530    | 0.229  |
| 3     | 30         | 0.375   | 0.433    | 0.208  |
| 4     | 40         | 0.321   | 0.390    | 0.174  |
| 5     | 50         | 0.303   | 0.352    | 0.151  |
| 6     | 60         | 0.260   | 0.315    | 0.131  |

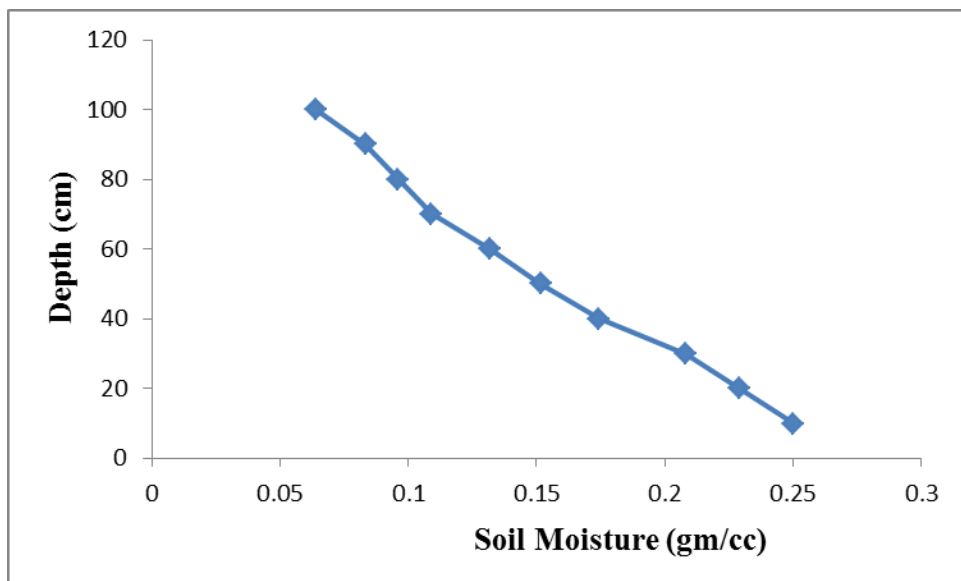
|    |     |       |        |        |
|----|-----|-------|--------|--------|
| 7  | 70  | 0.224 | 0.277  | 0.108  |
| 8  | 80  | 0.208 | 0.241  | 0.096  |
| 9  | 90  | 0.192 | 0.206  | 0.083  |
| 10 | 100 | 0.176 | 0.172  | 0.064  |
| 11 | 110 | 0.148 | 0.140  | 0.056  |
| 12 | 120 | 0.133 | 0.111  | 0.0529 |
| 13 | 130 | 0.119 | 0.0827 | 0.049  |
| 14 | 140 | 0.097 | 0.054  | 0.044  |
| 15 | 150 | 0.083 | -      | 0.042  |
| 16 | 160 | 0.061 | -      | 0.036  |
| 17 | 170 | 0.046 | -      | 0.032  |



**Fig 5.18 Redistribution of Soil – moisture under Forest Cover**



**Fig 5.19 Redistribution of Soil – moisture under Degraded Cover**



**Fig 5.20 Redistribution of Soil – moisture under Acacia Cover**

Soil moisture redistribution depends on various parameters such as initial moisture content, saturated hydraulic conductivity, porosity and rainfall intensity. Figure 5.18, fig 5.19 and 5.20 shows the soil moisture profiles simulated by using Green and Ampt Model under three different land covers. The results indicate that there is a gradual decrease in moisture with depth in all land covers (viz. natural forest, degraded and acacia).

The horizontal and profile variation of soil moisture, shows that there is an effect of topography. Famiglietti et al., 1998 and Western et al., 1998 also noticed variation in soil moisture content with topography. Previous studies carried out by Fu et al., 2001; Fu and Chen, 2000; have identified parameters such as slope, relative elevation and aspect that are the main factors controlling the soil moisture.



**Fig 5.21 Soil Profile in a Forested Watershed at Kodgibail with high root density**

The effect of undulation can be seen in the distribution of the soil moisture across the point within each of the watersheds. The lower point has more soil moisture than that of the top point. This indicates that the lower points are situated more or less on a flat terrain than that of the other two points. Some of these variations in soil moisture can be due to the variation of the topography itself. However, quantification of these effects is not in the framework of the present analysis.

At the outset, based on the results obtained from Green-Ampt equation, the forest can generate higher amount of runoff as that of the other land-use types.

## **5.6 PLANT GROWTH AND RICHNESS**

Forest is an integral part of the ecosystem. It helps for environmental conservation and control extremities of climate. The forests of the wet region of Karnataka represent an enormous potential of natural resources. Large populations have lived, and live, entirely of what these forests generate in terms of food, water, fuel and housing materials. The degradation of large portion of these invaluable resources due to increased population pressure and human intervention necessitate for the regeneration of this degraded forest. However, the importance of the forest-ecosystem for the well-being of local communities is now being recognised and programs have started over the last 15 years dealing with the reforestation and rehabilitation of the degraded areas. To enhance the selection of appropriate reforestation strategies, there is a need for short-term evaluation for (re-) generation of basic resources for local communities.

Ecological indices for some of the meteorological stations of the study area are given in Table1. Karnataka Forest Department (1991) classified vegetation of the State into various forest types based on forest types, species, climate and ecology. The ecological index serves in two ways. It indicates potential of the region and also gives an idea of what vegetation type the region can support. Region of lowest values of ecological index can support only hardy, xerophytic species. In all such areas while selecting species for plantation, only hardy species, which can stand long dry spells and have capacity to throw a deep tap root system in shortest possible time, should be planted. Similarly, the object of land management practices in such areas should be more for community welfare, moderating climate and maintaining environmental balance, and to act as an umbrella to the vast agricultural land. Land management in such areas may be savanna type with trees scattered in more favourable locality. Grass and fodder should be the main crop with a few hardy trees yielding small timber and fuel. Agave can also find a place in such areas. As the ecological index of the countryside improves, planting more and more trees can suitably modify the land management.

### **5.6.1 EFFECT OF THE SOIL pH ON PLANT GROWTH AND RICHNESS**

Soil pH is an important factor for plant growth. It affects nutrient availability, nutrient toxicity, and microbial activity, as well as extending a direct effect on protoplasm of plant root cells (Larcher, 1980; Marschner, 1986). Grime (1973) and Gould and Walker (1999) found a unimodal relationship between plant richness and pH. In this model species richness declined towards both acidic and alkaline soils, which may relate to the availability and toxicity of soil nutrients.

Different plant species may not have the same range of adaptability and may require narrow range of pH to survive (Larcher, 1980; Grubb, 1985; Leskiw, 1998). It has been reported that forest soils should be slightly acidic for nutrient supply to be balanced (Leskiw, 1998). The pH of top soil ranges between 5.7 – 6.4 and that of the bottom soil ranges between 5.8 – 6.6. In acidic soils ( $\text{pH} < 6$ ) the essential nutrients such as calcium, magnesium, potassium, phosphorus and molybdenum are depleted or unavailable in a form useable to plants, which leads to nutrient deficiency (Larcher, 1980). Total nitrogen is also very low and the available nitrogen is limited to  $\text{NH}_4^+$  form, because nitrification is inhibited (Marschner, 1986). In strongly acidic soils  $\text{Al}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Mn}^{2+}$  ions rise to toxic levels for the majority of plant species (Wolf, 2000). Sodic soils ( $\text{pH} > 8$ ) tend to be deficient in Zn, Fe, Cu, K and Mn (Marschner, 1986).

### **5.6.2 EFFECT OF THE SOIL SALINITY ON PLANT GROWTH AND RICHNESS**

Salinity affects yield (Ayers and Westcot, 1985) and germination rate of plants (Hayward and Bernstein, 1958) through an osmotic effect, specific ion effects, and changes in soil physical properties (Keren, 2000). The osmotic effect relates to the fact that plants extract water from the soil by exerting an absorptive force greater than that which holds the water to the soil (Ayers and Westcot, 1985). The more salt in water, the greater the osmotic potential and the more energy required by the plant to extract water. As a result, in soils with high salt concentration, plants extract less water than in soils with low salt concentration. Therefore, high salinity may reduce moisture availability to plants and result in plant dehydration (Ayers and Westcot, 1985). In addition, reduced moisture availability diminishes nutrient uptake, which may further restrict plant growth (Allen et al., 1994). Due to the effect of salinity on moisture availability, climatic conditions (such as moisture, temperature, light) can greatly affect salt tolerance (Shannon, 1979). It has been reported that most crops can tolerate greater salt stress under cool humid than hot dry conditions (Keren, 2000). In general, the increase in soil salinity results in decrease of infiltration and moisture content. However, in the study area, it is observed that the soil salinity is much below the desirable limit and does not affect the plant growth. This clearly, indicates that the soil is capable of holding higher moisture content which may lead to better plant growth.

### **5.6.3 EFFECT OF SOIL MOISTURE ON PLANT GROWTH AND RICHNESS**

Water availability is reported to be one of the most important environmental parameters controlling plant richness (Lavers and Field, 2006). Its effect is even more profound in arid environments, where soil moisture is the major limiting primary

resource. Vegetation structure in southern African savannas and grasslands is determined by moisture availability (Scholes et al., 1997), and precipitation is considered to be one of the most important factors affecting plant diversity (Cody, 1989). These observations can be explained by the fact that in semi-arid Africa, plant productivity is limited by moisture availability (Belsky, 1995). Higher moisture availability enhances plant growth and productivity, which in turn is likely to affect plant diversity. Present observations shows that soil moisture estimation done by using Green-Ampt equation shows that the moisture content is higher in the forested and afforested watershed as compared to degraded.

#### **5.6.4 SOIL INFILTRABILITY AND CRUST FORMATION**

Soil infiltrability is defined as the infiltration rate resulting when water at atmospheric pressure is freely available at the soil surface, such as when the rainfall rate exceeds the ability of the soil to absorb water. It is largely determined by surface crusting. Number of researchers reported that crusts form in two stages: physical dispersion of soil aggregates caused by the impact action of the raindrops, and a chemical dispersion. The dispersion can be initiated by swelling, which reduces soil pore sizes, and can result in blocking or partial blocking of the conducting pores also explain a decrease in hydraulic conductivity (HC) by swelling.

Dispersion operates when the charged clay platelets, which are moving apart in the process of swelling or as a result of raindrop impact, have separated enough so that attractive forces are no longer strong enough to oppose repulsive forces and the platelets can move by an external force. Dispersed particles move down into the soil profile, where they lodge and clog the conducting pores thereby reducing infiltration. The importance of dispersion in affecting soil permeability has been recognized by numerous researchers.

The result of the above processes is the formation of a surface seal, which is a very thin layer (0.1-5 mm) at, or just below, the soil surface that forms due to the breakdown of soil aggregates and chemical dispersion of clay particles under raindrop impact. Once the seal dries out, it develops high soil strength due to the increased density of the layer and is called a crust. Surface crusts are characterized by greater bulk density, greater strength, narrower pores, and conductivity than the underlying soil.

The surface crust found in some parts of the watersheds, showed a significant decrease in infiltration, i.e. more than 10 times, particularly, on the top layer. Crusting also reduces seedling emergence, and increases runoff and soil erodibility.

A number of physical and chemical properties affect crust formation. The physical properties include texture and the chemical properties include soil sodicity and the

electrolyte concentration in the soil solution. Interactions between these factors can modify their individual influence. The infiltration and sorptivity values for forest, degraded and acacia watersheds are given in the Table 5.18.

**Table 5.17 Infiltration and Sorptivity values for Forest, Degraded and Acacia**

| Natural Forest          |                                       | Degraded                |                                       | Acacia                  |                                       |
|-------------------------|---------------------------------------|-------------------------|---------------------------------------|-------------------------|---------------------------------------|
| Infiltration<br>(mm/hr) | Sorptivity<br>(mm/hr <sup>1/2</sup> ) | Infiltration<br>(mm/hr) | Sorptivity<br>(mm/hr <sup>1/2</sup> ) | Infiltration<br>(mm/hr) | Sorptivity<br>(mm/hr <sup>1/2</sup> ) |
| 82.51                   | 50.54                                 | 268.15                  | 104.17                                | 144.38                  | 74.6                                  |
| 103.13                  | 65.32                                 | 82.51                   | 57.76                                 | 103.13                  | 39                                    |
| 103.14                  | 51.57                                 | 41.25                   | 34.72                                 | 123.76                  | 71.85                                 |
| 226.9                   | 110.01                                | 268.15                  | 122.23                                | 226.89                  | 97.64                                 |
| 165.02                  | 71.16                                 | 391.91                  | 147.83                                | 123.76                  | 71.51                                 |
| 103.14                  | 63.60                                 | 206.27                  | 79.41                                 | 144.39                  | 147.33                                |
| 61.88                   | 49.16                                 | 41.25                   | 49.16                                 | 82.51                   | 56.72                                 |
| 165.02                  | 77.01                                 | 247.53                  | 91.45                                 | 268.15                  | 96.26                                 |
| 268.15                  | 122.04                                | 825.08                  | 257.84                                | 123.76                  | 71.51                                 |
| 144.39                  | 73.23                                 | 773.52                  | 229.19                                | 206.27                  | 84.91                                 |
| 103.14                  | 58.44                                 | 474.42                  | 166.39                                | 103.14                  | 74.73                                 |
| 41.25                   | 47.78                                 | 884.01                  | 245.46                                | 226.90                  | 94.2                                  |
| 61.88                   | 57.76                                 |                         |                                       | 103.14                  | 56.04                                 |
| 103.14                  | 68.75                                 |                         |                                       | 123.76                  | 74.94                                 |
| 123.76                  | 71.85                                 |                         |                                       | 247.53                  | 121.01                                |
| 103.020                 | 68.76                                 |                         |                                       | 103.14                  | 60.16                                 |
| 144.38                  | 66.35                                 |                         |                                       |                         |                                       |
| 309.41                  | 137.51                                |                         |                                       |                         |                                       |
| 123.76                  | 64.97                                 |                         |                                       |                         |                                       |
| 123.76                  | 72.19                                 |                         |                                       |                         |                                       |
| 41.25                   | 38.16                                 |                         |                                       |                         |                                       |
| 61.88                   | 47.79                                 |                         |                                       |                         |                                       |

### 5.6.6 SOIL TEXTURE EFFECT ON INFILTRABILITY

Soil texture is viewed as one of the most important soil properties controlling infiltrability. This is related to the fact that saturated water movement through a soil

profile is controlled by soil porosity, by layering of textural classes and by dispersion of soil particles that result in surface crusting.

Infiltrability depends on pores sizes and on the tendency of particles to clog pores. Water in soil is held as films on particles surfaces and in small pores. Coarse-textured, or sandy soils, have large particles sizes and more pores compared to fine-textured soils. Large pores allow water to drain by gravitational flow. Therefore in coarse-textured soils infiltrability will be faster than in fine-textured soils. In the fine-textured soils silt and clay particles can fill voids between sand grains and in this way restrict water movement through the soil, while small pores retain water by capillary forces, which further restrict water movement down the profile.

Layering of different particle size fractions of soils also affects infiltrability. Buried clay or dry sand layers near the surface can reduce infiltration rates. An unstructured buried clay layer usually has a lower hydraulic conductivity than an overlying coarse-textured layer and reduces infiltrability once the wetting front enters the clay layer. A buried dry sand layer under a fine-textured layer also reduces infiltrability, but through a different mechanism. The water at the leading edge of the wetting front may be under high tension and cannot enter the smallest pores in the sand layer (which are much larger than the largest pores in the layer above) until the potential at the wetting front increases beyond the water potential for the sand. Once the sand is saturated it no longer impedes flow, because hydraulic conductivity is high in the sand compared to the fine-textured layer above.

Dispersion of soil particles and crust formation is another mechanism through which soil particles control infiltration. During a rainfall event, soil aggregates break down and disperse. As a result of this a thin seal layer forms, which impedes infiltration. In the next section the role of dispersion will be discussed in greater detail.

#### **5.6.6.1 Role of Soil particle size fractions in crust formation**

Dispersion and crust formation processes have been widely investigated, although there is to date no clear conclusion as to which particle size fraction plays the most significant role in crust formation. It has been reported that silt plays a very important role in crust composition. Some researchers have published photographs showing silty surface layers (Duley, 1939; Evans and Buol, 1968; Norton, 1987). In a sequence of experiments (Moss, 1991a & b) showed that during runoff, silt particles of 10-50  $\mu\text{m}$  were deposited as tightly packed bed-load sediments and formed a seal layer over a compacted layer.

Very fine sand particles of 50-100  $\mu\text{m}$  were transitional in behaviour, and 100-1000  $\mu\text{m}$  particles were highly mobile in the air splash environment.

Moss (1991a) showed that susceptibility to crusting depended not only on the proportion of silt present, but also on its abundance relative to the fine sand (63-125  $\mu\text{m}$ ) fraction. In his studies the infiltration was greater in soils with the higher ratio of fine sand to silt fractions. Moss (1991a) also found a discontinuous layer, which comprised small patches of loosely packed coarse particles, mainly sand to be an apparent component of the rain-impact soil crust. He explained his findings by saying that larger than 1000  $\mu\text{m}$  are moved only with difficulty by large raindrops, while particles of 3000  $\mu\text{m}$  diameter cannot be lifted at all. This finding was in accordance with (1984), who reported that overland flow removes relatively large quantities of material and leaves behind the heavy particles.

Some researchers have emphasized the importance of clay particles in crust formation. Ben-Hur et al. (1985) reported that in soils with low clay content (< 10 %) the amount of clay available to disperse and clog soil pores is limited and poorly developed seals formed. Tackett and Pearson (1965) and Evans and Buol (1968) stated that clay orientation played an important role in the crusting. Morin et al. (1981) explained how this orientation of clay particles into a continuous dense skin comes about during crusting, as a result of suction forces below the crust or seal. This suction mechanism results in a continuous build up of the crust out of the suspended clay particles. McIntyre (1958a & b) reported washing of fine particles beneath the so called 'skin seal' of 0.1 mm, and the formation of a 'washed in' layer comprised of tightly packed clay particles. This layer was responsible for the restriction of infiltration in his experiment, which was done on a horizontal soil surface. Moss (1991b) reported that the formation of a 'skin seal' or a compacted clay layer was not a feature of sloping soil surfaces, where particles of < 10  $\mu\text{m}$  were removed by air splash and runoff flow.

#### **5.6.6.2 Particle Size Analysis**

Particle size analysis was carried out to know the particle size distribution of the soil sample. A known amount of soil sample was weighed using weighing balance and was put into different sieves ranging from 4.75 mm to 75  $\mu\text{m}$ . The sieves contained soil sample was kept in a sieve shaker for about 15 minutes. The weight of soil retained from each sieve for forest, degraded and acacia watersheds is presented in the Table 5.18, Table 5.19 and table 20.

**Table 5.18 Particle size analysis for Forest**

| Sieve         | Retained Weight |             |
|---------------|-----------------|-------------|
|               | ( in gm)        | % by weight |
| 4.75mm        | 145.99          | 12.9        |
| 2mm           | 179.68          | 15.9        |
| 1.4mm         | 86.94           | 7.7         |
| 1mm           | 105.74          | 9.4         |
| 600µm         | 70.98           | 6.3         |
| 425µm         | 85.94           | 7.6         |
| 300µm         | 40.7            | 3.6         |
| 212µm         | 68.18           | 6           |
| 150µm         | 139.78          | 12.4        |
| 75µm          | 117.4           | 10.4        |
| below<br>75µm | 86.06           | 7.6         |

**Table 5.19 Particle size analysis for Degraded**

| Sieve | Retained weight |             |
|-------|-----------------|-------------|
|       | (in gm)         | % by weight |

|                |        |      |
|----------------|--------|------|
| 4.75mm         | 117.98 | 14.7 |
| 2mm            | 162.57 | 20.2 |
| 1.4mm          | 71     | 8.8  |
| 1mm            | 69.98  | 8.7  |
| 600µm          | 53.22  | 6.6  |
| 425µm          | 61.17  | 7.6  |
| 300µm          | 23.3   | 2.9  |
| 212µm          | 44.7   | 5.6  |
| 150µm          | 85     | 10.6 |
| 75µm           | 69.28  | 8.6  |
| below 75<br>µm | 45.9   | 5.7  |

**Table 5.20 Particle size analysis for Acacia**

| Sieve         | Retained weight |             |
|---------------|-----------------|-------------|
|               | (in gm)         | % by weight |
| 4.75mm        | 324.21          | 34.8        |
| 2mm           | 191.62          | 20.6        |
| 1.4mm         | 88.94           | 9.5         |
| 1mm           | 73.94           | 7.9         |
| 600µm         | 49.04           | 5.3         |
| 425µm         | 51.4            | 5.5         |
| 300µm         | 21.25           | 2.3         |
| 212µm         | 20.45           | 2.2         |
| 150µm         | 22.2            | 2.4         |
| 75µm          | 36.38           | 3.9         |
| below<br>75µm | 52.24           | 5.6         |



**Fig 5.22 Sieve Analysis**

Based on the field and laboratory investigations and corresponding results and discussion different afforestation strategies and planting practices to be followed are suggested.

### **5.6.7 PLANTING PRACTICES/ AFFORESTATION METHOD**

#### **5.6.7.1 Planting Schedule**

Climatic data collected at various places do not help in predicting soil moisture build up. Information of soil moisture build up is very useful in raising plantation. When seedlings are planted in the field, they are exposed to a set of new conditions. These conditions have to be congenial as possible. They should help seeding to combat initial shock to establish in new surroundings. Seeds when sown, the soil moisture should be enough to stimulate germination and the young seedlings to throw a vigorous root system. To project the monthly progress of soil moisture build up, the method given by Thornthwaite can be used, which gives the interaction between climate and soil for some meteorological stations of the study area.

#### **5.7.7.2 Planting Zones**

Average monthly soil moisture data of the study is shown in Table 5.22, Table 5.23 and Table 5.24 under three different land use/covers results shows that, the progress of soil moisture build up does not have a common pattern. It differs from region to region and also on land use/land cover changes.

At the time of planting the soil moisture in the top 30 cm is important. Soil moisture should be adequate to receive seedlings. Waheed Khan (1970) opined that minimum of 50mm of soil moisture is necessary. A soil moisture build up half way between wilting point and field capacity which is 127.5 mm in clay soil, 40mm in loamy soil and 27.5 mm in sandy soil is considered fairly safe.

### **5.6.7.3 Planting Method**

The correct planting method gives a plantation a good start. In many cases the planting method decides success of plantations. Method that is used are direct sowing of seeds or planting of nursery raised seedlings. Seedlings may be directly from the nursery beds, planted without ball of earth or may be raised in containers and planted with ball of earth. When seeds are directly sown care should be taken, to see that they are not exposed to insects and rodents. Soil should have enough moisture to stimulate germination. Germination period of seeds varies from species to species. It can be hastened by pre-treating before sowing. Areas where favourable soil moisture period is short. Part of it is spent in germination of seeds. Young seedlings then will be exposed to very dry conditions ultimately resulting in failure. In planting seedlings, germination period is spent in the nursery under controlled conditions. When these are planted and strike roots, they are hardy to withstand to harsh field conditions. Hence in places where favourable soil moisture period is very short, it may be obligatory to plant seedlings only.

In present afforestation practices planting methods are arbitrarily selected. Many times it has no relation to prevailing moisture conditions of the locality. Soil moisture data also does not help in selecting a planting method. As rainwater is the source of soil moisture, precipitation data of the locality sometimes helps to decide a planting method. Seth (1958) while suggesting annual rainfall classes also suggested how rainfall data can be used to select a planting method. According to him the product of precipitation and number of rainy days can express effectiveness of rainfall. As planting is always confined to monsoon period, the rainfall data of June to September and October to December. The product of June to September as Summer Effective Precipitation Index, S. E. P. I. And of October to December as Winter Effective Precipitation Index, W. E. P. I. Seth (1958)

suggested that when S. E. P. I. is less than 11430 and W. E. P. I. is 5715 or less planting of seedlings should be advocated. When values of these indices are more, sowing can be under taken. These indices for various zones are given in Table 3.4.

### **5.6.8 SOIL WORKING TECHNIQUE**

Soil working is an important operation in all afforestation works. It should be such that; it ensures soil depth, good tilth, aeration, granulation and crump structure for optimum plant growth. Water trapped in the form of pool or free water cannot be stored for long periods. It evaporates rapidly. On the other hand water stored as soil moisture at field capacity is retained for long time. As such, soil working must be used as a tool to hold maximum rainwater in the root zone and reduce soil moisture losses. It should also eliminate root competition to prevent transpiration losses. Soil working method therefore, should help infiltration; maintain granulation and porosity to hold maximum soil moisture. It should prevent formation of crust on the top layer by impact of rain and due to flowing water. Top layer should also act as effective mulch to prevent soil moisture losses.

Correct soil working technique under prevailing climatic condition decides the period of favourable soil moisture. Normally two soil working techniques are adopted in afforestation practices. These are deep mechanised ploughing and contour trenching. Soil working technique, which ensures longer period of favourable soil moisture, should be selected. In afforestation work of dry zone only degraded and eroded sites are made available. In all such sites soil is compact and infiltration of rainwater is very poor. Soil working technique should be taken up much in advance, so that; dug out earth is exposed for good weathering in the form of clods. This promotes internal granulation and crump formulation.

#### **5.6.8.1 Mulching**

Mulching is of a profound importance in afforestations of dry zone and may be considered as the corner post of successful plantation. Mulching has number of beneficial effects, such as, ( i ) suppression of weeds, (ii) conservation of soil moisture by check run off water decreasing evapotranspiration and increasing infiltration, (iii) conservation of soil by preventing soil erosion (iv) and improvement of soil structure and soil fauna. In soils rich in soluble salts mulches prevent upward movement of salts.

In the dry zone most common mulches that can be used are soil mulch, stone mulch and organic mulch.

### 5.6.8.2 Weeding

Main purpose of weeding is to eliminate root competition to reduce transpiration and conserve soil moisture needed for healthy growth of seedlings. This operation also involves cultivation of topsoil or mulching. Frequency of weeding is decided by the rate of growth of weeds and grass. Areas having long favourable soil moisture period may need more frequent weeding.

### 5.6.9 APPLICATION OF FERTILISER AND MANURE

Use of fertiliser is very expensive operation, so far rarely adopted in dry zone afforestation. It is well established that fertiliser applied a little at a time before and after planting in poor soils can boost the growth.

### 5.6.10 SELECTION OF SPECIES

Selection of species is perhaps the most important aspect of afforestation. Species selected should be maximum benefit to the community. Following point should be taken into consideration at the time of selection of species.

1. Overall ecological condition of planting site .
2. Planting of a mixture of species should not be more than four for the management point of view.
3. Silvicultural characters and habits of species should also be considered in deciding mixture.

| Zones    | Total rainfall<br>in a year<br>(mm) [P] | No. Of<br>Rainy days<br>in a year [D] | Potential<br>Evapo –<br>transpiration<br>in a year<br>(mm) [PET] | Temperature<br>Range [T.R] | Ecological<br>Index |
|----------|---|---------------------------------------|--|----------------------------|---------------------|
| Siddapur | 3129.7                                  | 103.7                                 | 1465.6   | 4.0                        | 55.36               |

|       |        |       |        |     |       |
|-------|--------|-------|--------|-----|-------|
| Sirsi | 3483.3 | 103.8 | 1486.0 | 3.3 | 73.73 |
|-------|--------|-------|--------|-----|-------|

**Table 5.21 Ecological Index for the different zones of the study area**

Climatic data collected at various places do not help in predicting soil moisture build up. Information of soil moisture build up is very useful in raising plantation. To project the monthly progress of soil moisture build up, the method given by Thornthwaite can be used, which gives the interaction between climate and soil as shown in the table 3 for some meteorological stations of the study area.

#### **5.6.11 Monthly Progress Of Soil Moisture Build Up For Some Of The Selected Meterological Stations.**

**Table 5.22 Station- Forest (Loamy Soil) Field capacity- 65.0 mm, Wilting point- 20.0mm**

| Mm    | May  | June  | July  | Aug   | Sept | Oct  | Nov  | Dec  | Jan  | Feb | Mar  | April |
|-------|------|-------|-------|-------|------|------|------|------|------|-----|------|-------|
| Av.Rf | 5.23 | 32.01 | 34.07 | 30.10 | 3.85 | 0.2  | 0.71 | 0.32 | 0    | 0   | 0    | 0     |
| PET   | 4.19 | 3.66  | 3.40  | 3.52  | 3.35 | 3.51 | 3.38 | 3.54 | 3.86 | 4.2 | 4.16 | 4.37  |
| AWC   | 19.0 | 33.0  | 33.0  | 33.0  | 33.0 | 33.0 | 33.2 | 15   | 13   | 12  | 13   | 11    |

Note: Av. Rf –Average Rainfall, PET. – Evapo-transpiration, AWC - Available Water Content.

In forest it is found (Table 5.22) that though the available water content is higher than the wilting point during the rainy season. There is a sharp decline after November, which falls below the wilting point. This clearly indicates that there is soil moisture deficiency during non-monsoon season and any mixing of species and growing under storied plants will result in degradation of existing forest covers, instead water harvesting structures to maintain moisture within watershed.

**Table 5.23 Station- Acacia (Loamy Soil) Field capacity- 50.0 mm, Wilting point- 20.0mm**

| Mm           | May  | June  | July  | Aug   | Sept | Oct  | Nov  | Dec  | Jan  | Feb | Mar  | April |
|--------------|------|-------|-------|-------|------|------|------|------|------|-----|------|-------|
| Av.<br>D. Rf | 5.23 | 32.01 | 34.07 | 30.10 | 3.85 | 0.2  | 0.71 | 0.32 | 0    | 0   | 0    | 0     |
| PET          | 3.81 | 3.31  | 3.0   | 3.08  | 3.05 | 3.3  | 3.14 | 2.90 | 3.07 | 3.3 | 3.51 | 3.87  |
| AWC<br>mm    | 19.0 | 33.0  | 33.0  | 33.0  | 33.0 | 33.0 | 33.2 | 15   | 13   | 12  | 13   | 11    |

The analysis of Acacia plantation (Table 5.23) shows that there is high moisture content during rainy season and it continues to maintain moisture even during non-monsoon season (wilting point). So this indicates that the plantation of Acacia is good management strategy than going for alternate species.

**Table 5.24 Station–Degraded (Loamy Soil) Field capacity- 60.0 mm, Wilting point- 15.0mm**

| Mm    | May  | June  | July  | Aug   | Sept | Oct  | Nov  | Dec  | Jan  | Feb | Mar | April |
|-------|------|-------|-------|-------|------|------|------|------|------|-----|-----|-------|
| Av.Rf | 5.23 | 32.01 | 34.07 | 30.10 | 3.85 | 0.2  | 0.71 | 0.32 | 0    | 0   | 0   | 0     |
| PET   | 5.09 | 4.52  | 3.95  | 4.06  | 3.93 | 3.96 | 3.59 | 3.32 | 3.67 | 4.1 | 4.4 | 5.06  |
| AWC   | 17   | 18    | 18    | 18    | 18   | 16   | 16   | 16   | 16   | 16  | 16  | 16    |

In Degraded forest (Table 5.24) there is a higher moisture content than wilting point even during the non-monsoon season which could support plants and enrich the specified areas by using selective species.

Study conducted in parts of Western Ghats and low land areas show that rehabilitation of degraded forests is very essential, as large areas of forest are lying unproductive. The task of rehabilitation is also not difficult provided the areas are relieved of the biotic pressures. The cost involved is also low as compared to that in raising plantation on new sites. Mere closure of the area with cattle proof trench, some cheap type of fencing material which may be locally available cutting back of malformed growth, coupled with gap planting would suffice to restore the productivity of the forests at full level. For assuredly quicker results, Arial seeding over such areas can also be resorted to. The villagers living close to the area should be given employment in forestry operations. Some forest based cottage industries should also be encouraged which may provide employment to people because in an area where people are so poor that they have to live by selling of fuel wood and by allowing their cattle to graze in forests, there is no chance of proper forest growth unless the basic socio-economic problem is solved.

Selection of species is perhaps the most important aspect of afforestation. Species selected should be maximum benefit to the community. Following point should be taken into consideration at the time of selection of species.

1. Overall ecological condition of planting site.
2. Planting of a mixture of species should not be more than two in management point of view.

3. Silvicultural characters and habits of species should also be considered in deciding combination of species.

List of species that are suitable for planting in different zone of the area is given in Table 5.25.

**Table 5.25 List of species suitable for different zone of the area**

| S.N | Humid and Coastal zone     |
|-----|----------------------------|
| 1   | <i>Azadirachta indica</i>  |
| 2   | <i>Albizia amara</i>       |
| 3   | <i>Albizia lebbek</i>      |
| 4   | <i>Acacia nilotica</i>     |
| 5   | <i>Acacia leucophloea</i>  |
| 7   | <i>Adanisonia digitata</i> |
| 8   | <i>Phyllanthus emblica</i> |
| 10  | <i>Prosopis Juliflora</i>  |
| 11  | <i>Salvadora Persica</i>   |
| 12  | <i>Salvadora Olecides</i>  |
| 13  | <i>Prosopis Spicigera</i>  |
| 14  | <i>Agave spp.</i>          |

## **CHAPTER 6**

### **HYDRUS - 1D**

#### **6.1 GENERAL**

HYDRUS – 1D is a public domain computer software package that simulates the one dimensional movement of water, heat and multiple solutes in variably saturated media. It numerically solves the Richards equation for variably-saturated water flow and advection-dispersion type equations for heat and solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. The flow equation

may also consider dual-porosity type flow in which one fraction of the water content is mobile and another fraction immobile, or dual-permeability type flow involving two mobile regions, one representing the matrix and one the macropores. The heat transport equation considers transport due to conduction and convection with flowing water. Coupled water, vapor, and energy transport can be considered as well. The solute transport equations consider advective-dispersive transport in the liquid phase, as well as diffusion in the gaseous phase. The transport equations also include provisions for nonlinear nonequilibrium reactions between the solid and liquid phases, linear equilibrium reactions between the liquid and gaseous phases, zero-order production, and two first-order degradation reactions: one which is independent of other solutes, and one which provides the coupling between solutes involved in sequential first-order decay reactions. Physical nonequilibrium solute transport can be accounted for by assuming a two-region, dual-porosity type formulation which partitions the liquid phase into separate mobile and immobile regions. Additionally, the transport equations may include provisions for kinetic attachment/detachment of solutes to the solid phase, thus permitting simulations of the transport of viruses, colloids, or bacteria.

The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media. The flow region may be composed of nonuniform soils. Flow and transport can occur in the vertical, horizontal, or a generally inclined direction. The water flow part of the model can deal with prescribed head and flux boundaries, boundaries controlled by atmospheric conditions, as well as free drainage boundary conditions. The governing flow and transport equations are solved numerically using Galerkin - type linear finite element schemes. HYDRUS-1D also includes a Marquardt-Levenberg type parameter optimization algorithm for inverse estimation of soil hydraulic and/or solute transport and reaction parameters from measured transient or steady-state flow and/or transport data.

HYDRUS-1D further incorporates modules simulating carbon dioxide production and major ion solute movement. The CO<sub>2</sub> transport processes include diffusion in both the liquid and gas phases and advection in the liquid phase. The CO<sub>2</sub> production model is described in detail.

The major variables of the chemical system are Ca, Mg, Na, K, SO<sub>4</sub>, Cl, NO<sub>3</sub>, H<sub>4</sub>SiO<sub>4</sub>, alkalinity, and CO<sub>2</sub>. The model accounts for equilibrium chemical reactions between these components such as complexation, cation exchange and precipitation-

dissolution. For the precipitation-dissolution of calcite and dissolution of dolomite, either equilibrium or multicomponent kinetic expressions are used which include both forward and back reactions. Other dissolution-precipitation reactions considered include gypsum, hydromagnesite, nesquehonite, and sepiolite. Since the ionic strength of soil solutions can vary considerably with time and space and often reach high values, both modified Debye-Hückel and Pitzer expressions were incorporated into the model as options to calculate single ion activities.

## 6.2 GOVERNING WATER FLOW EQUATIONS

### 6.2.1. UNIFORM WATER FLOW

One-dimensional uniform (equilibrium) water movement in a partially saturated rigid porous medium is described by a modified form of the Richards equation using the assumptions that the air phase plays an insignificant role in the liquid flow process and that water flow due to thermal gradients can be neglected.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} \left[ K \left( \frac{\partial h}{\partial x} + \cos \alpha \right) \right] - S$$

Eqn 6.1

where  $h$  is the water pressure head [L],  $\theta$  is the volumetric water content [ $L^3L^{-3}$ ],  $t$  is time [T],  $x$  is the spatial coordinate [L] (positive upward),  $S$  is the sink term [ $L^3L^{-3}$ ],  $\alpha$  is the angle between the flow direction and the vertical axis (i.e.,  $\alpha = 00$  for vertical flow,  $900$  for horizontal flow, and  $00 < \alpha < 900$  for inclined flow), and  $K$  is the unsaturated hydraulic conductivity function [ $LT^{-1}$ ].

### 6.2.2 UNIFORM WATER FLOW AND VAPOR TRANSPORT

The Richards equation considers only water flow in the liquid phase and ignores the effects of the vapor phase on the overall water mass balance. While this assumption is justified for the majority of applications, a number of problems exist in which the effect of vapor flow cannot be neglected. Vapor movement is often an important part of the total water flux when the soil is relatively dry.

## 6.3 ROOT WATER UPTAKE

### 6.3.1 ROOT WATER UPTAKE WITHOUT COMPENSATION

The sink term,  $S$ , is defined as the volume of water removed from a unit volume of soil per unit time due to plant water uptake. Feddes et al. [1978] defined  $S$  as

$$S(h) = \alpha(h) S_p \quad \text{Eqn 6.3}$$

where the root-water uptake water stress response function  $\alpha(h)$  is a prescribed dimensionless function of the soil water pressure head ( $0 \leq \alpha \leq 1$ ), and  $S_p$  the potential water uptake rate [ $T^{-1}$ ].

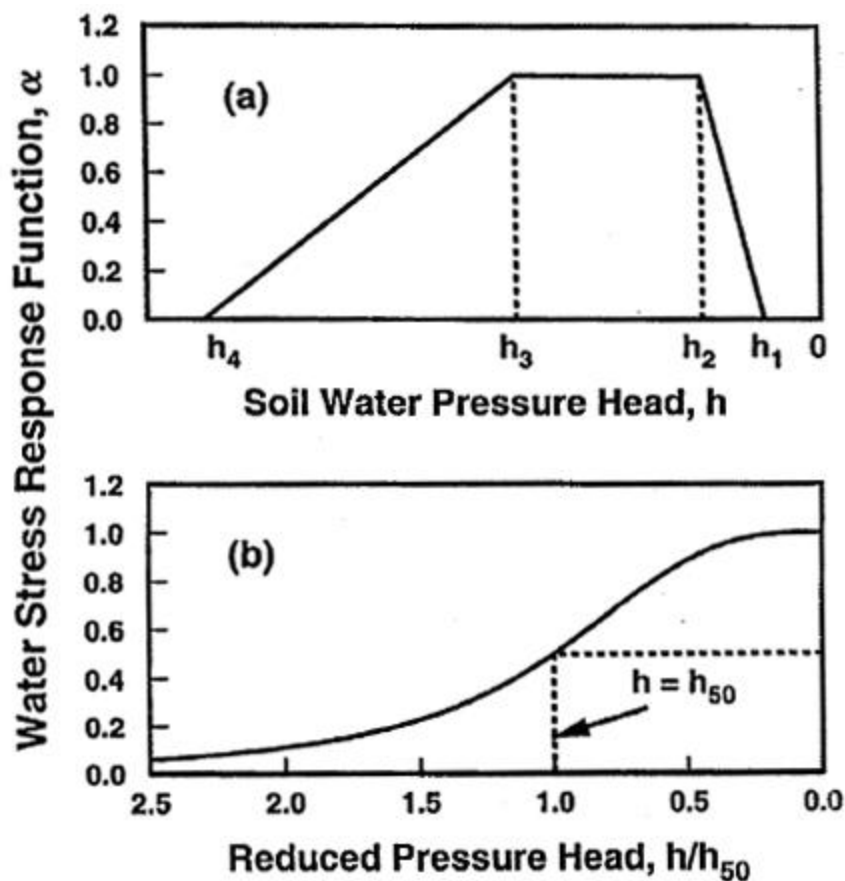


Fig 6.1 Schematic of the plant water stress response function,  $\alpha(h)$ , as used by a) Feddes et al. [1978] and b) van Genuchten [1987].

## 6.4 THE UNSATURATED SOIL HYDRAULIC PROPERTIES

### 6.4.1. UNIFORM WATER FLOW SYSTEM

The unsaturated soil hydraulic properties,  $\theta(h)$  and  $K(h)$ , are in general highly nonlinear functions of the pressure head. HYDRUS permits the use of five different analytical models for the hydraulic properties [Brooks and Corey, 1964; van Genuchten, 1980; Vogel and Císlerová, 1988; Kosugi, 1996; and Durner, 1994].

The soil water retention,  $\theta(h)$ , and hydraulic conductivity,  $K(h)$ , functions according to Brooks and Corey [1964] are given by

$$S_e = \begin{cases} |\alpha h|^{-n} & h < -1/\alpha \\ 1 & h \geq -1/\alpha \end{cases}$$

$$K = K_s S_e^{2/n+1+2}$$

Eqn 6.3

respectively, where  $S_e$  is effective saturation:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

Eqn 6.4

in which  $\theta_r$  and  $\theta_s$  denote the residual and saturated water contents, respectively;  $K_s$  is the saturated hydraulic conductivity,  $\alpha$  is the inverse of the air-entry value (or bubbling pressure),  $n$  is a pore-size distribution index, and  $l$  is a pore-connectivity parameter assumed to be 2.0 in the original study of Brooks and Corey [1964]. The parameters  $\alpha$ ,  $n$  and  $l$  in HYDRUS are considered to be empirical coefficients affecting the shape of the hydraulic functions.

HYDRUS also implements the soil-hydraulic functions of van Genuchten [1980] who used the statistical pore-size distribution model of Mualem [1976] to obtain a predictive equation for the unsaturated hydraulic conductivity function in terms of soil water retention parameters. The expressions of van Genuchten [1980] are given by

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases}$$

Eqn (6.5)

Where  $\theta_s$  and  $\theta_r$  are the saturated and residual moisture and  $\alpha$  and  $n$  are the van-Genuchten parameters, and

$$m = 1 - 1/n$$

## 6.5 INPUT DATA

Based upon the available information, two distinct soil layers were identified. The following input data was used for simulation of soil moisture movement through Hydrus.

**Rainfall** : Daily rainfall data for the period of 2011 – 2013, were collected from the statistical department (Karnataka State) for raingauges located within the catchment of Kodgibail basin.

### Soil Hydraulic Parameters

The unsaturated soil hydraulic properties in the HYDRUS code are described with a set of closed-form equations resembling those of van Genuchten [1980] who used the statistical pore-size distribution model of Mualem [1976] to obtain a predictive equation for the unsaturated hydraulic conductivity function.

**Table 6.1 Soil Hydraulic Parameters for Forest**

| $\theta_r$ | $\theta_s$ | $\alpha$ | $n$  | $K_s$  |
|------------|------------|----------|------|--------|
| 0.09       | 0.35       | 0.0058   | 1.82 | 191.04 |
| 0.09       | 0.25       | 0.0058   | 1.77 | 41.6   |

**Table 6.2 Soil Hydraulic Parameters for Degraded**

| $\theta_r$ | $\theta_s$ | $\alpha$ | n    | $K_s$ |
|------------|------------|----------|------|-------|
| 0.021      | 0.29       | 0.00043  | 2.12 | 38.56 |
| 0.04       | 0.1        | 0.00043  | 2    | 41.66 |

**Table 6.3 Soil Hydraulic Parameters for Acacia**

| $\theta_r$ | $\theta_s$ | $\alpha$ | n      | $K_s$  |
|------------|------------|----------|--------|--------|
| 0.109      | 0.23       | 0.0233   | 1.6782 | 148.32 |
| 0.16       | 0.51       | 0.0016   | 1.739  | 91.752 |

Where  $\theta_s$  and  $\theta_r$  are the saturated and residual moisture and  $\alpha$  and n are the van-Genuchten parameters, and

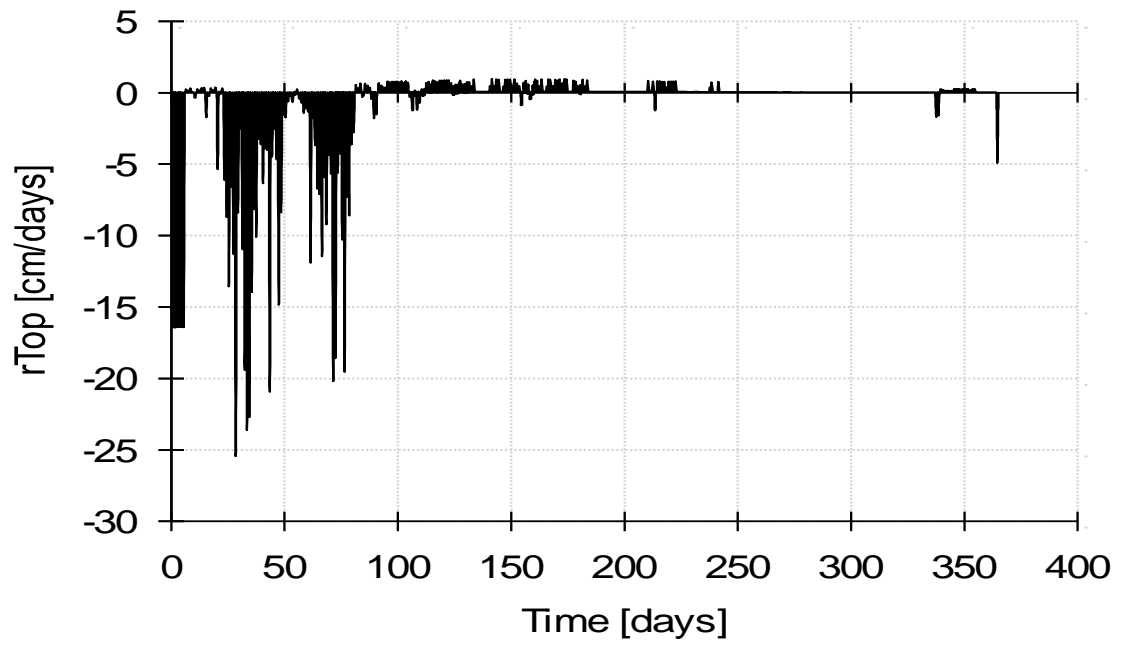
$$m = 1 - 1/n$$

**Van Genuchten Parameters** : The collected soil samples from the study area were analysed in the laboratory by pressure plate apparatus for soil moisture retention characteristics. The averaged van-Genuchten parameters for the soil layer were obtained by non-linear regression analysis.

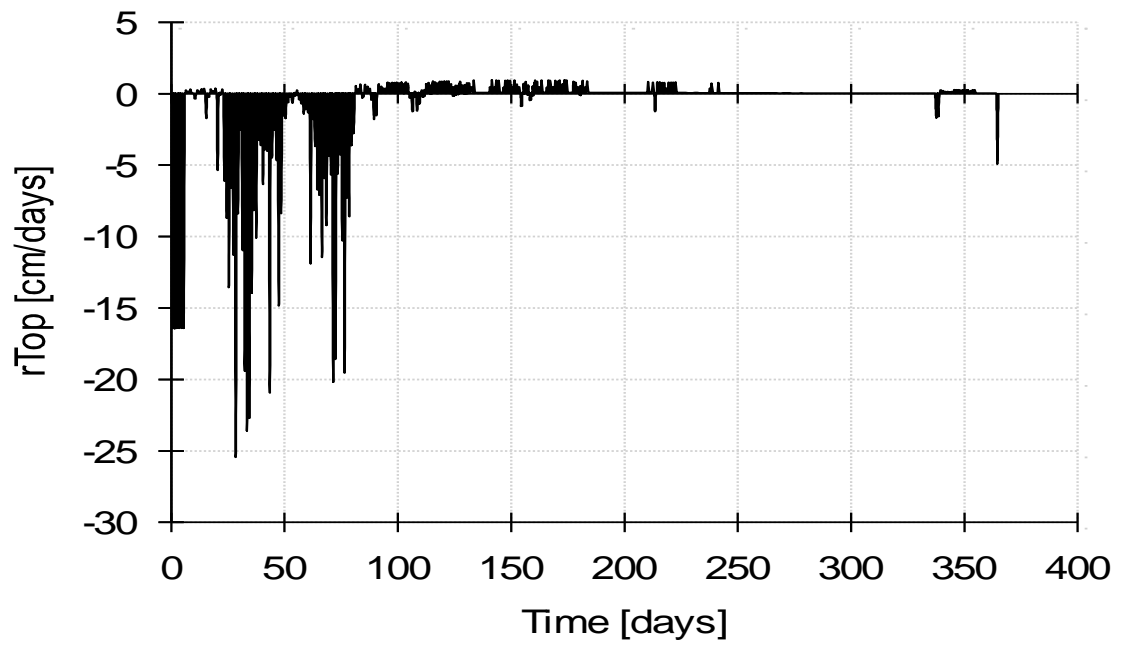
## 6.6 OUTPUT OF HYDRUS – 1D

### 6.6.1 POTENTIAL SURFACE FLUX

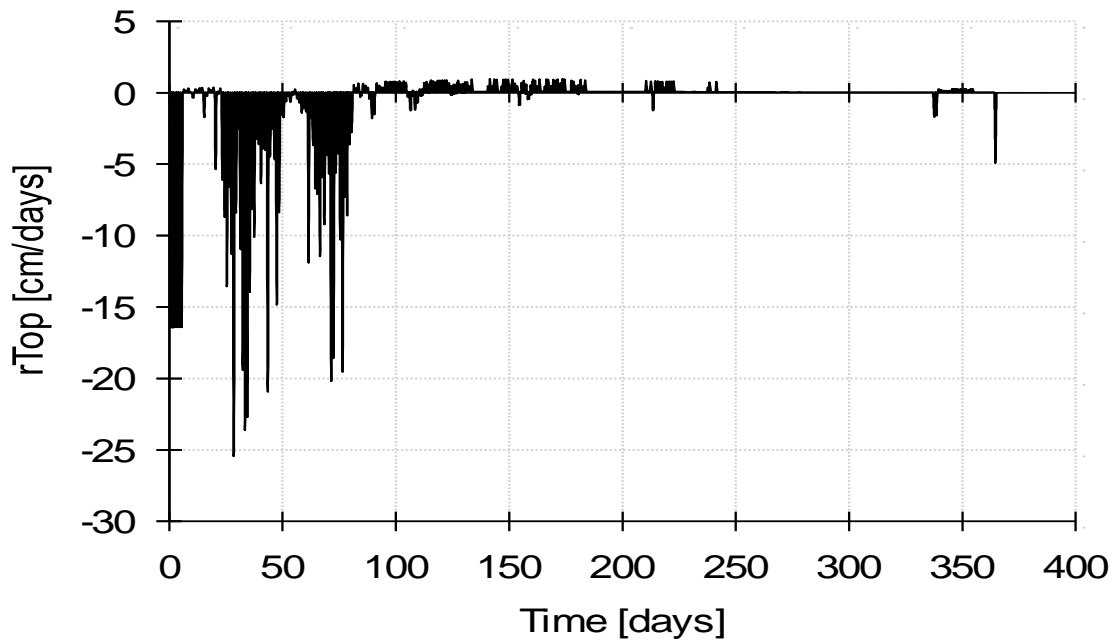
The potential flux in three land covers viz. forest, degraded land and acacia auriculiformis showed considerable variations during the study period. In the forested watersheds, it varies between 0 and 25 cm/days. The gaining and recession limbs showed a rapid movement indicating the variation of soil moisture variation at the top of the soil layer due to climatic conditions. In the case of bottom flux, gain and recession limbs show a lag time which could be attributed to the changes in the hydraulic properties. It is also important to note that this gradual increase and decrease depends on the root length and root density, apart from soil physical and chemical characteristics. The variation of potential flux predicted by model are shown in fig 6.2,6.3 and 6.4.



**Fig 6.2 Potential surface flux for Forest watersheds**



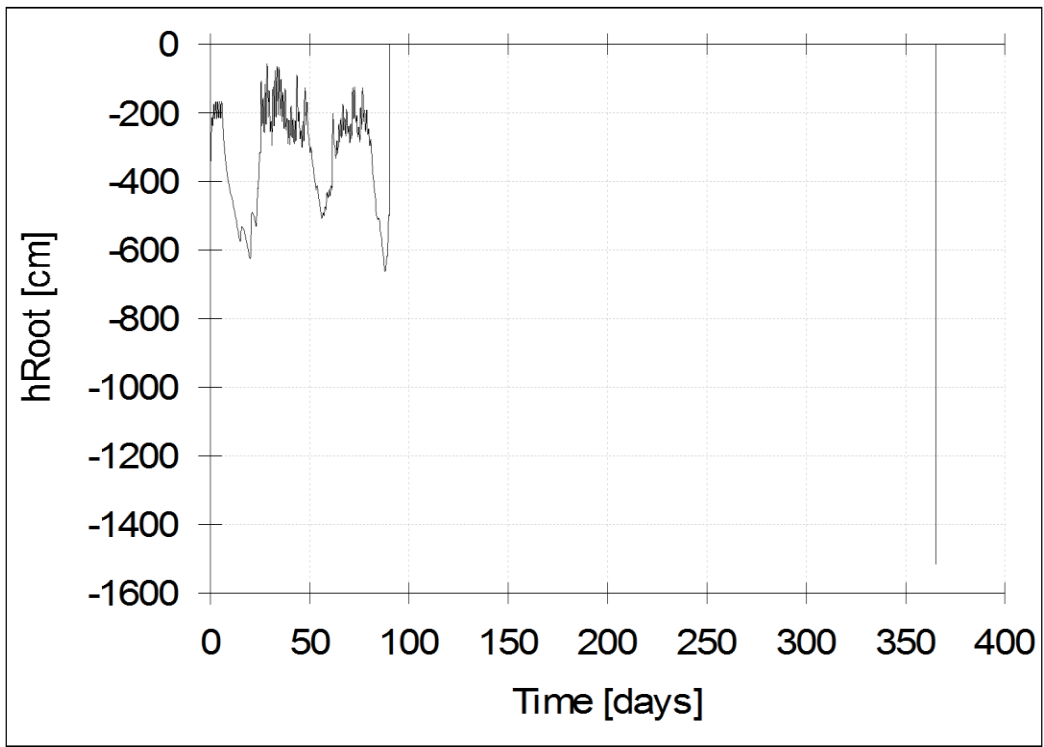
**Fig 6.3 Potential surface flux for Degeaded watersheds**



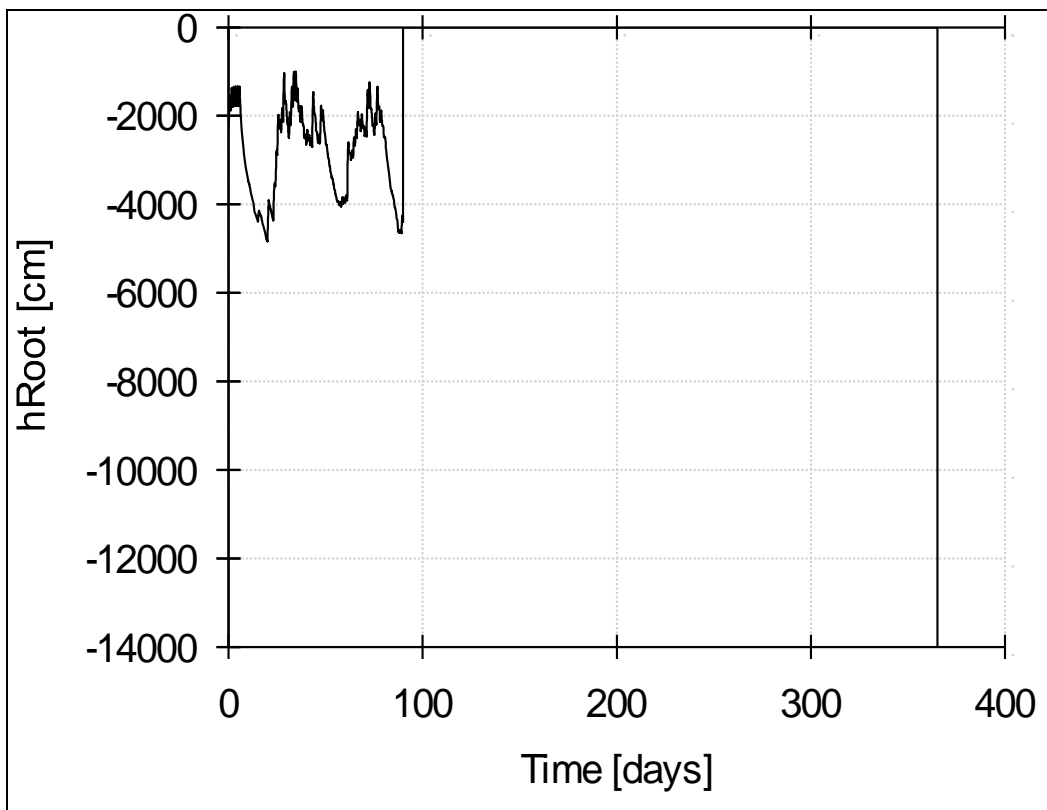
**Fig 6.4 Potential surface flux for Acacia watersheds**

### **6.6.2 ROOT ZONE PRESSURE HEAD**

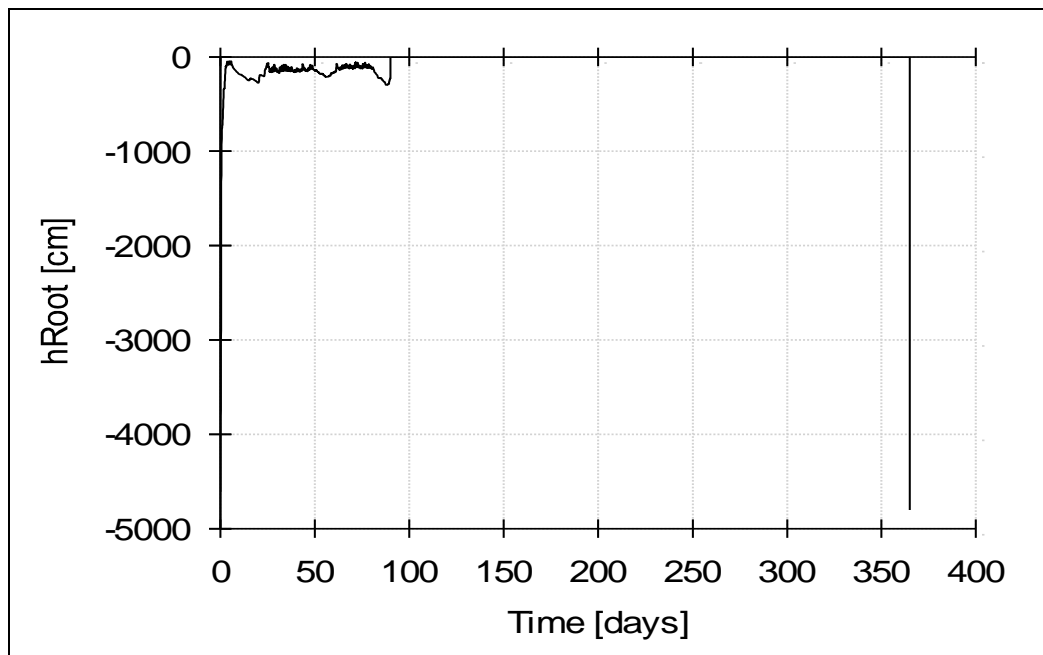
Root zone pressure head obtained from the HYDRUS model shows that, it is maximum in the degraded lands as compared to forests and acacia auriculiformis. The pressure head observed is -4000 cm. In the degraded lands the root zone pressure goes up to -600cm and in the acacia auriculiformis it is -200cm. The higher root zone pressure head in the forested watersheds could be due to excessive evapotranspiration through forest plants and hydro-climatic conditions existing in the forested watersheds. The variation of root zone pressure head predicted by model are shown in fig 6.5, 6.6 and 6.7.



**Fig 6.5 Root zone pressure head for forested watersheds**



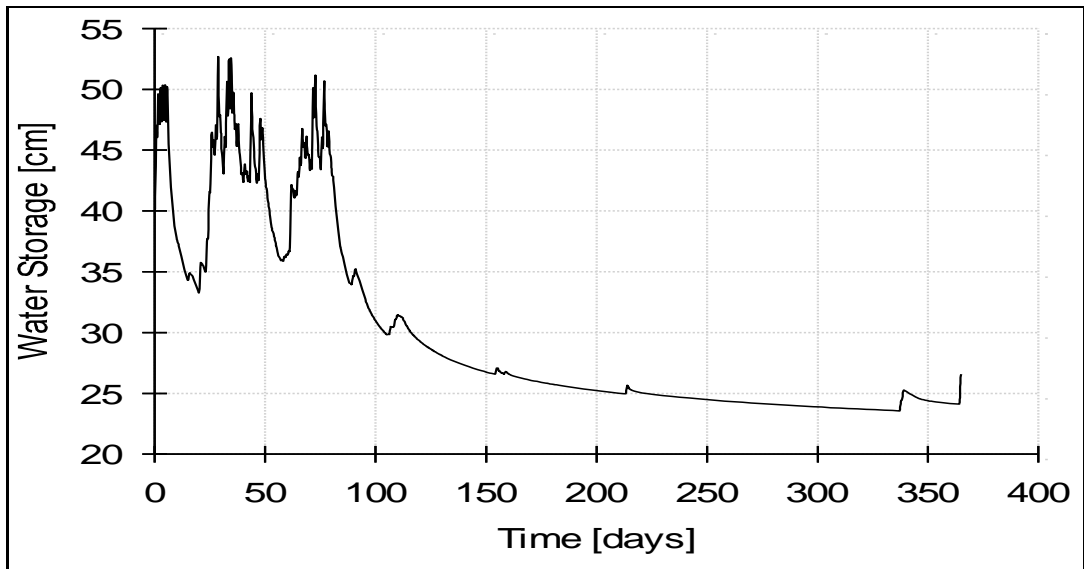
**Fig 6.6 Root zone pressure head for degraded watersheds**



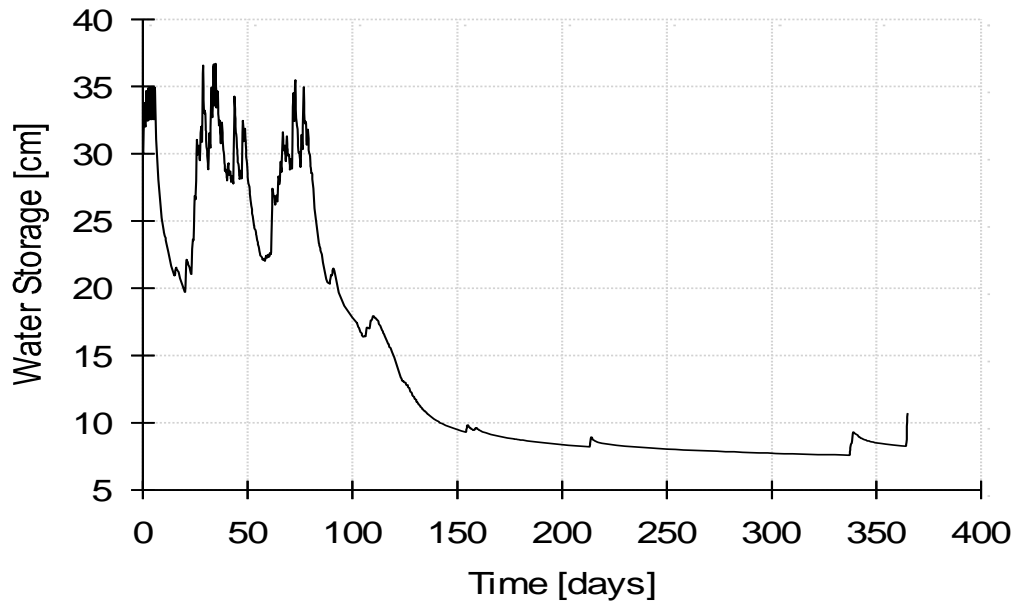
**Fig 6.7 Root zone pressure head for acacia watersheds**

### **6.6.3 SOIL WATER STORAGE**

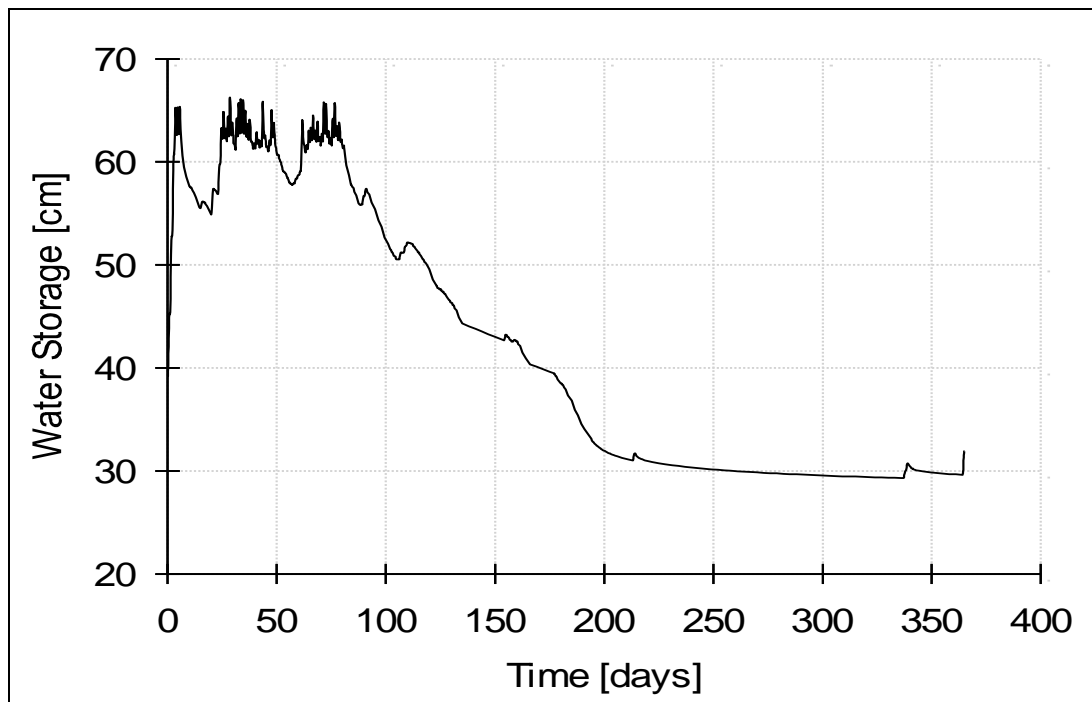
The soil water storage is one of the major components which contribute to the groundwater recharge. In the present investigation it is noticed that *Acacia auriculiformis* transmits more water to the groundwater storage. The variations of soil water storage predicted by model are shown in fig 6.8, 6.9 and 6.10. The HYDRUS model results indicate that the maximum recharge in the forested water is 16.5% which declines to 7.8 % during non-monsoon seasons. In Acacia, the recharge is slightly higher than the forests and the maximum recharge estimated is 19.5 % with an annual recharge of 9.5 %. As expected, in the degraded lands, it is found that 9.5 % is the maximum recharge and 3.2 % is the minimum recharge.



**Fig 6.8 Soil water storage for forested watersheds**



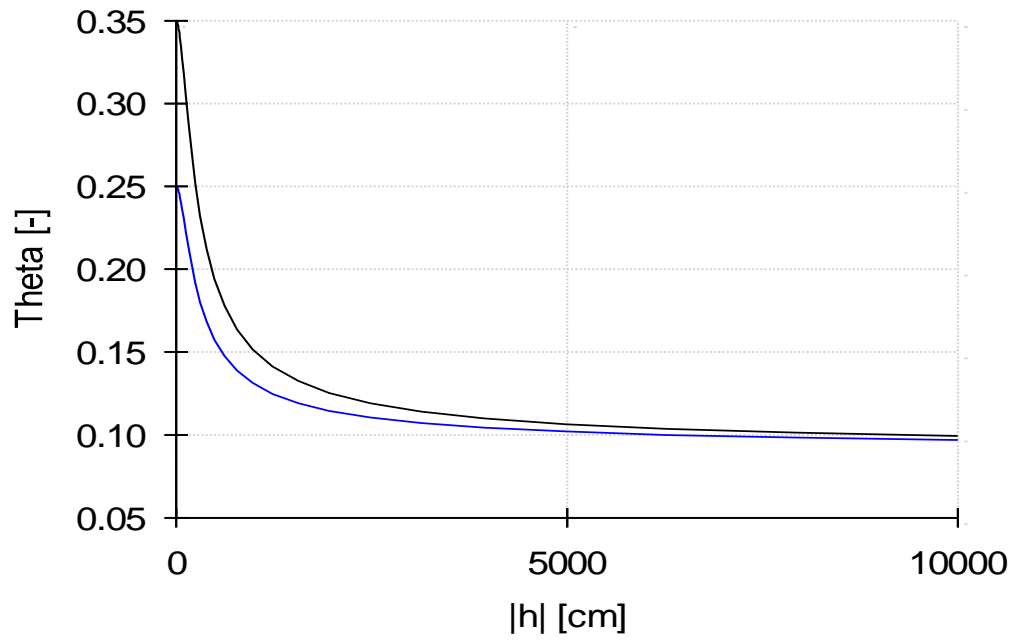
**Fig 6.9 Soil water storage for degraded watersheds**



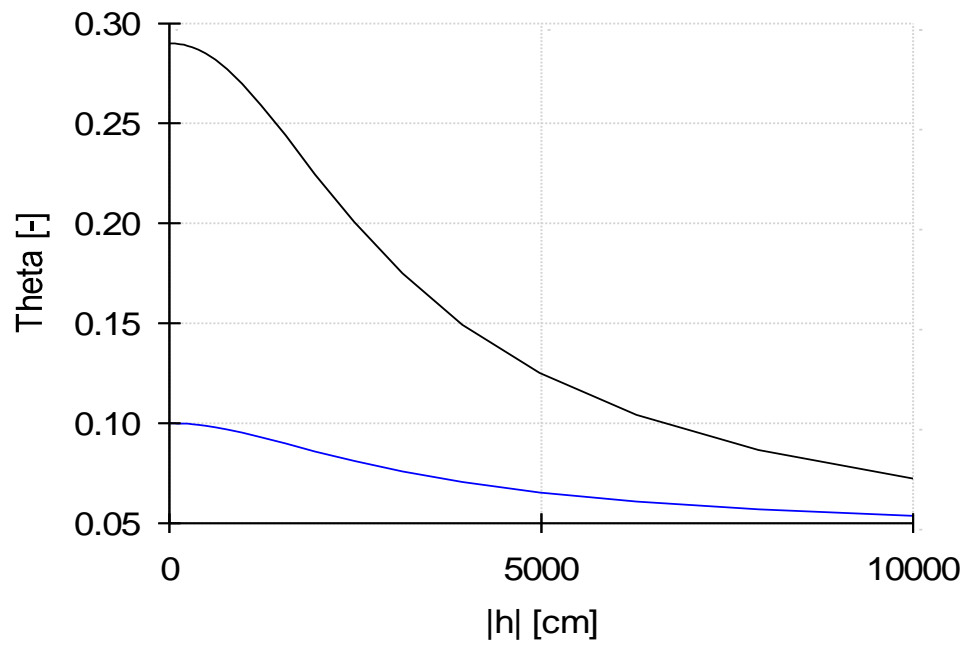
**Fig 6.10 Soil water storage for acacia watersheds**

#### **6.6.4 SOIL HYDRAULICS PROPERTIES**

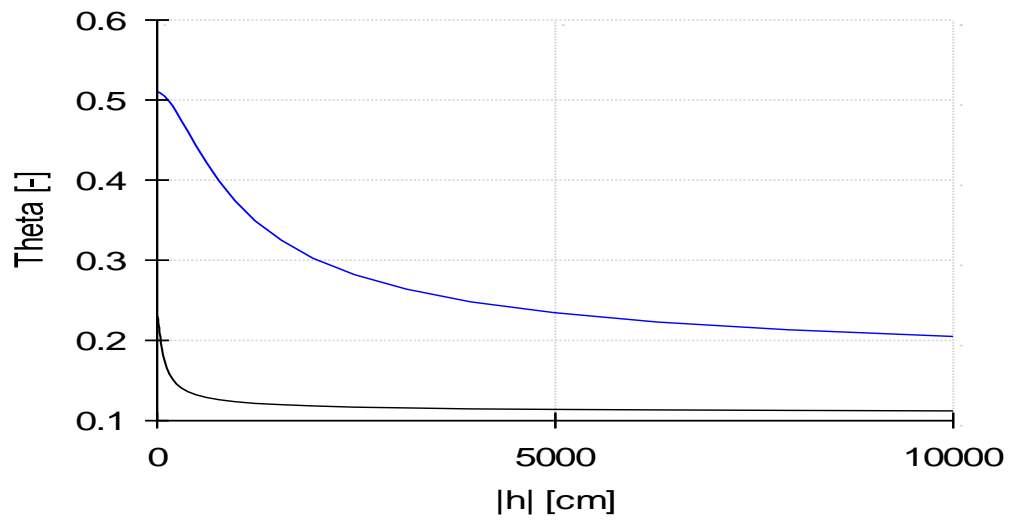
$\theta - h$  relationship observed under three land covers, the forest soils exhibit a sharp decline in the water content with pressure head initially and it smoothens and move parallel to the x-axis as the theta value approaches 0.1. The same trend is seen in the case of bottom soils also. In the case of degraded lands, the movement of soil moisture is gradual and becomes parallel when h is 5000 cm. The variation in the  $\theta - h$  relationship is very low in the case of bottom soil. In Acacia one of the interesting result is that unlike forests and degraded lands, there is a larger variation in theta- h relationship of top and bottom soils. The variation of soil hydraulic properties predicted by model are shown in fig 6.11, 6.12 and 6.13.



**Fig 6.11 Soil hydraulic properties for forested watersheds**



**Fig 6.12 Soil hydraulic properties for degraded watersheds**



**Fig 6.13 Soil hydraulic properties for acacia watersheds**

# CONCLUSIONS

## 7.1 CONCLUSIONS

In the humid tropics, large scale deforestation is responsible for an increase in the frequency of floods and conversely a reduction in dry season discharge within organised drainage networks. However, it is reported from studies conducted in controlled experimental catchments in east Africa, northern Australia and Malaysia provide contrary evidence. Such experiments involve the hydrological calibration of paired experimental catchments of similar area, topography and geology. Subsequently, the forest on one of the catchments is converted to another land use, and the differences in total water flow, stormflow and dry weather flow from these catchment experiments, show that total water yield increase is mostly connected with 'dry-weather flow', and not stormflow, in agreement with findings from humid temperate forests. The replacement of deep rooted trees by more shallow rooted crops, such as a herbaceous cover, reduces the transpiration demand and the ensuing 'savings of water use' are credited to dry weather flow.

Nonetheless there has been a recent scientific appraisal of the above controversy, and the recognition that the existing catalogue of experimental catchment studies may not be sufficiently representative of the more widespread, human -impacted landscapes which have been in various states of 'degradation' for several decades into centuries. In other words, the controlled experiments only monitored the initial few years following forest conversion to a replacement crop, and this period was insufficient for the soils (and their associated hydrological properties) to adjust to the new land-use type. Furthermore, socio-economic pressure on such disturbed areas in these experimental catchments was considered minimal and unrepresentative compared with the wider human impacted landscapes found elsewhere in the humid tropics. Consequently, the alternative hypothesis is that in severely degraded landscapes the surface soil infiltration rates are drastically reduced which lead to a reduction in groundwater recharge via vertical percolation through the soil/rock profile. Conversely from the reduced infiltration, an increase in overland flow downslope occurs during progressively become more important as the rate of global deforestation extends to less accessible area.

Therefore, an integrated management of forest vegetation on forested or upland watersheds require attention from the various sectors of the society which will alter the

water budget of a catchment. The present study is an attempt to understand the impact of land use/land cover changes on hydrological parameters such as infiltration, hydraulic conductivity and soil retention characteristics using HYDRUS -1D model. From the study following conclusions are drawn.

Some of the important observations made from the study are the following.

1. The specific discharge is highest in degraded watershed (24% higher than forest) and lowest in forested watershed
2. The influence of land-use on the soil moisture variation and its dynamics is observed and statistical analysis indicates the root density is concentrated within 30 to 90 cm and down to 200 cm in Acacia plants and in natural forest respectively
3. The soil moisture deficit index is appeared to be having an influence on the runoff generation in the watersheds.
4. The Ksat values in Acacia are more or less comparable with that of the forest, hence the possibility of more water movement down the soil strata.
5. Comparatively higher groundwater recharge is observed in the acacia plantation.
6. It is observed that the hydraulic properties such as infiltration and hydraulic conductivity showed an improvement in comparison to degraded lands. In the degraded forests, Hortonian overland flow is very common phenomenon.
7. The current study clearly indicated that selective reforestation and afforestation with acacia species ameliorates the surface hydraulic properties and encourages greater percolation and conversely, inhibits infiltration excess overland flow occurrence.
8. It is also noticed that there is a declining trend in the field saturated hydraulic conductivity ( $K^*$ ) with the depth across all the land covers. It is further observed that there is an improvement of hydraulic properties below 0.5m. Similar observation was made by Venkatesh (2011). It is also found that subsurface flow and surface overland flow are dominating preferential flow path existing in study area.
9. Spatial and temporal variation of soil moisture indicated that in the degraded forests the moisture content varies considerably in comparison to acacia and forested watershed. The temporal variation of soil moisture was influenced by rainfall and peak soil

moisture was generally preceded by peak rainfall. The response of soil moisture to rainfall in the degraded forests was relatively faster compared to other two watersheds.

10. Groundwater recharge estimated for different land use/land covers indicated that the maximum recharge is in the acacia plantation (19.5%) and minimum in the degraded forests (9.5%). Recharge in the forested watershed was also greater than degraded forests in spite of higher ET (16.5%).

## **7.2 RECOMMENDATIONS**

1. Selective afforestation of species based on soil and geology will improve the hydrological condition in region. Therefore it is necessary to identify right species based on scientific investigations.
2. In degraded lands, land management will improve soil moisture status which will ultimately lead to groundwater recharge. Therefore it is suggested to take up afforestation in all degraded lands.
3. In order to improve plant growth and richness, it is necessary to go for soil characteristics and ecological conditions.

## **7.3 SCOPE FOR FUTURE RESEARCH**

1. There is a need to evaluate the role played by groundwater on the hydrologic regime of watersheds/catchments in the western ghats. This will require geophysical mapping and also continuous monitoring of groundwater fluctuations in such experimental studies. In a similar manner, studies need to be taken up to understand the impacts of land cover changes on regional groundwater flow and availability.
2. It is generally believed that, the quality of runoff from watersheds will be effected by the nature of land cover. Also, sediment yield and soil nutrient dynamics are affected by land cover. Experimental studies to characterise these issues need to be taken up.

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