Estimation of Groundwater Recharge under various land covers in parts of Western ghat, Karnataka, India.

Ocena napajanja podzemne vode na območjih z različno pokrovnostjo tal v delih zahodnega Gathsa, Karnataka, Indija

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Abstract: Land use practices are assumed to have important impacts on availability of water resources. These impacts can be both positive and negative. Therefore, it is essential to understand the impact of land cover changes on hydrological regime. In this connection, the present study has been carried out to estimate the groundwater recharge under various land covers, viz, natural forest, degraded and afforested regions. Extensive field investigations were carried out to determine the soil hydraulic properties and retention characteristics of soils, which are basic input parameters for modeling. SWIM model was applied to estimate the ground recharge. It is observed that, the groundwater recharge is higher in forested catchments and afforested regions. The minimum recharge was noticed in degraded forests. The present study throws a light on forest management strategies to be adopted for maximizing the water resources.

Izvleček: Infiltracija je eden najpomembnejših parametrov pri modeliranju hidroloških procesov in ključni dejavnik pri hidroloških spremembah, ki so posledica človekove dejavnosti. Kljub temu je vpliv tovrstnih sprememb na hidrološki krog slabo razumljen. Ena pomembnejših nalog hidrologov je ocena vplivov sprememb rabe tal na podzemni del hidrološkega kroga. Da bi bolje razumeli vpliv, posebej na napajanje podzemne vode, je bila študija izvedena na območjih pokrajine Uttara Kannada v indijski zvezni državi Karnataka, kjer

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poteka obsežno pogozdovanje z eksotičnimi vrstami dreves (npr. Accacia auriculiformis). Lokalno prebivalstvo na tem območju je zaskrbljeno zaradi vpliva pogozdovanja na zaloge in razpoložljivost podzemne vode. Zato je osnovni cilj študije ocena napajanja podzemne vode v odvisnosti od različnih pokrovnosti tal. Obsežne terenske raziskave so bile izvedene za določitev hidravličnih lastnosti tal, ki so osnovni vhodni parametri za modeliranje. Za oceno napajanja je bil uporabljen model SWIM. Ugotovljeno je bilo, da je napajanje podzemne vode največje na napajalnih zaledjih, pokritih z gozdom, in na pogozdenih območjih, najmanjše pa na degradiranih območjih. Gledano v celoti, študija osvetljuje določene aspekte strategije upravljanja z gozdovi na degradiranih območjih, ki lahko prispevajo k ohranjanju vodnih virov.

Key words: Groundwater, Recharge, infiltration, Hydraulic conductivity, Soil Water Infiltration Movement Model (SWIM**),** Western Ghats
Ključne besede: podzemna voda, napajanje, infiltracija, prepustnost, SWIM-model, zahodni Ghats

Introduction

Tropical forests in India have undergone dramatic land use changes in the last few decades. The myriad of changes that have, and still are, taking place are the effect of an equally large number of local causes and factors, highlighting a complexity that tends to defy easy generalizations. One of the important factor which lead to such dramatic change is the population explosion combined with more and more industrialization. The ultimate result of such a growth was deforestation in order to meet the local people needs. Of late, the degraded and the open land in the forests have been brought under the forest cover by extensive plantation. In many developing countries, extensive areas are undergoing land use changes. The largest changes in terms of land area, and arguably also in terms of hydrological impacts, often arise from afforestation and deforestation. Increasing areas are undergoing afforestation with fast growing monocultures of often exotic tree species.

There are world wide concern that increased establishment of plantation of exotic forest species for wood, fiber production, either as result of conversion of native forests and scrublands or afforestation of pasture and native grassland may have a detrimental effect on the environment. One of the most interesting questions put forward is that, what happens to water yield when the headwater catchments are planted with monoculture species. There are only limited studies carried out to evaluate the hydrological impacts of plantation. In India, during the last few years, considerable effort has been made to understand the impact of forest degradation on the soil hydrological regime. However, studies are quite limited as far as the impact of forest degradation on groundwater regime in western ghat region.

The Western Ghat region is the origin and primary catchment of many rivers (west and east flowing) in peninsular India. The lives of the majority of the rural population in the four southern states (Kerala, Tamil Nadu, Andhra Pradesh and Karnataka) plus parts of Maharashtra are thus critically dependent upon the watershed services provided by the Western Ghats forests. The portion of the Western Ghats that lies in Karnataka state, contains the major portion of the forests. It is reported that, there has been an increased anthropogenic activities in the western ghat mountain region, a rapid change in variety of land-use and land cover are taking place, which could have very significant impact on the water regime of the region, which includes the baseflow and groundwater recharge.

In the present study is an attempt to understand the impact of the land-uses on the groundwater recharge under different rainfall regimes with change in land-use conditions. In order to facilitate the analysis, SWIM (Soil Water and Infiltration Movement) model is chosen. It is selected in view of its simplicity and use of input parameters (soil moisture characteristics) that can be directly measured in the field/laboratory.

Materials and methds

Study Area

Uttara Kannada is a district with an area of 10,291 km^2, with its administrative headquarters at Karwar (Figure 1). The main geographic feature of the district is the Western Ghats (WG), which runs from north to south through the district. Between the WG and the sea is narrow coastal strip, which varies from 8 km to 24 km in width. Behind the coastal plain are flat topped hills from 60 m to 100 m in height, and behind these hills are the ridges and peaks of the WG. East of the WG is the upland, part of the vast Deccan plateau.

In the WG region, majority of the rain falls during June- September., i.e., south-west monsoon. More than 90 % of the annual rainfall occurs during the four monsoon months, with an average number 120–140 rainy days per year. During the monsoon, a major portion of the rainfall is contributed by four to five spells each lasting 8–10 days.

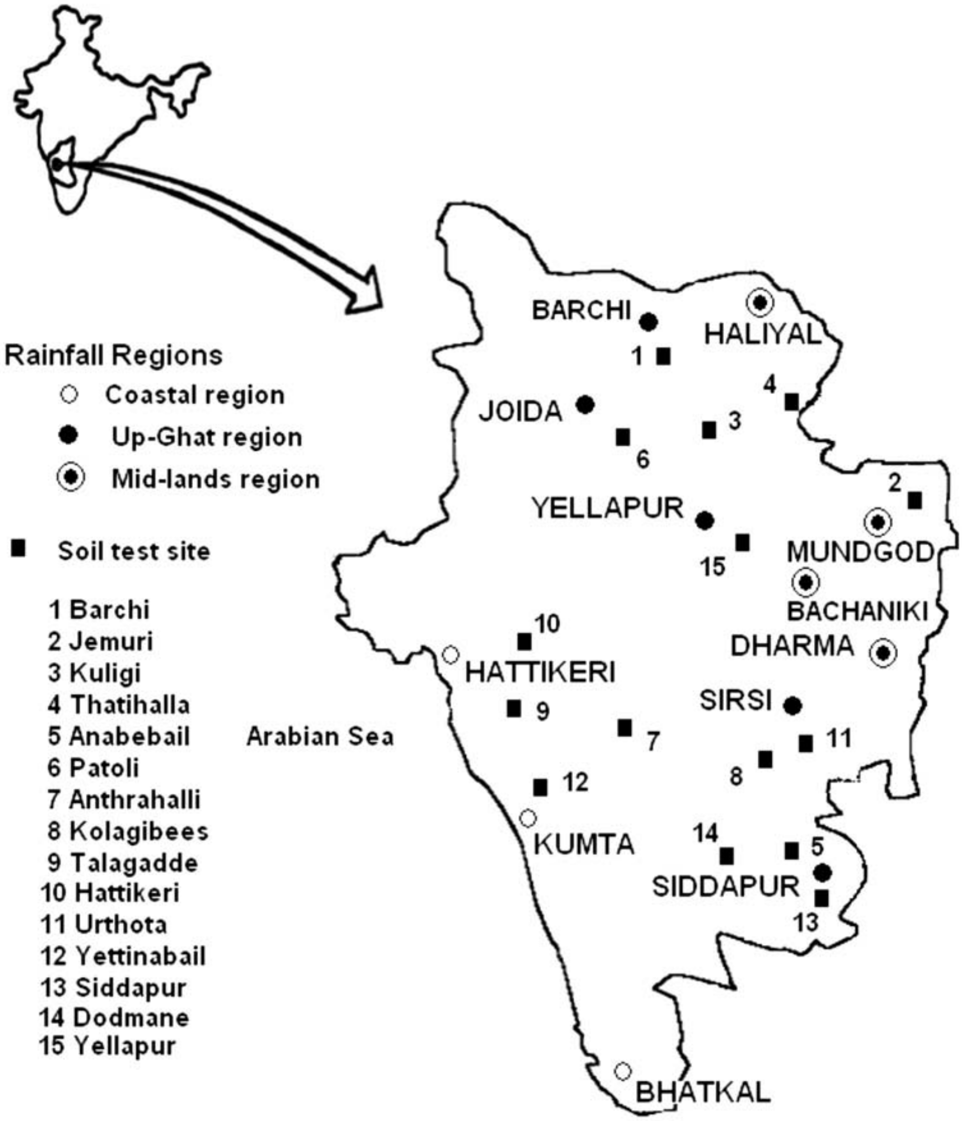

Figure 1. Index map of Study area with location of raingauges and experimental sites.

During such spells, daily values are very high. However, intensities are relatively moderate and rainfall occurs during most part of the day (PUTTY, 1994). PUTTY et al. (2000) reported that 15-minute intensities seldom exceed 80 mm/h and contribute about 2 % of the annual rainfall, while hourly intensities of 60 mm/h contribute less than 1 % of the annual rainfall.

Geology and Soils

Geologically, the study area consists of Pre-Cambrian formations with gneiss and intrusive granites (mostly along the coastal tracts and adjoining areas towards east). In the northern part of the study area basaltic rocks of Upper Cretaceous age are seen. Soil is deep particularly in coastal areas (few feet to few meters). Laterites are commonly found in coastal areas and plateau region is covered by black soils, where as the up-ghat region is characterized by both red and mixed soils. By contrast, large areas along the coastal tracts of North Kanara district, the parts of Western Ghat are severely degraded with laterite (Geologically Recent in age) induced by natural climatic variability. In the plateau areas of the Western Ghats, deep forest soils rich in humus. Black soil is found locally, i.e. in areas having elevation above 500–600 m. Generally, regions with heavy rainfall and dissected topography (slope varying between 12–15 %) are devoid of black soil indicating that, climate, topography and lack of drainage are more important than nature of underlying rocks in the formation of black soil.

The Karnataka Forest Department (KFD) has taken up various reforestation strategies depending upon the state of land degradation. The major species used for the afforestation activities are Teak and acacia ariculiformis.

Methodology

Rainfall Analysis

The entire Uttara Kannada district has been divided into three distinct regions based on the elevation. The three regions are Coastal, Up-ghats and Plateau. The automatic raingauge stations covered under coastal region are, Kumta, Aversa and Bhatkal. Sirsi, Yellapur, Joida and Siddapur are included under the Up-ghat region. Raingauge stations available in the plateau region are Mundgod, Dharma, Barchi, Bachaniki and Haliyal. The rainfall intensity and duration data for these rainfall stations were extracted from the hourly rainfall charts (The Water Resources Development Organisation, Govt. of Karnataka, maintains these stations). The records from the raingauge stations in each region were taken together to give regional record totals in station years. This amalgamation of annual maximum values assumes that they are independent of the stations and they are representative of their regions defined from the criteria. These compounded records were then subjected to an analysis using the Gumbel's frequency distribution with the probability weighted moment method.

As the first step of the analysis, the values of maximum intensities for 1 h, 2 h, 3 h and 5 h duration from all 12 stations were considered. The frequencies of all these maximum intensity values were computed using the Weibull plotting position procedure. A multiple regression model is used to develop a relationship of intensity versus duration and frequency of the form of, $I = 112{,}47\ D^{-0.341}\ T^{\,0.21}$, The multiple correlation coefficient obtained was 0.80

Field Investigations

Field experiments were carried out for the determination of saturated hydraulic conductivity in three typical zones by using Disc permeameter (PERROUX & WHITE, 1988) and Guelph permeameter. In each location a plot of 10 m/10 m was selected and carried out 6–8 experiments in order to get a proper representation. Data has been subjected to statistical analysis to get log mean values. LSD and F tests were also carried out for the analysis.

Laboratory Investigations

Laboratory investigations included determination of saturated moisture content, and soil moisture retention characteristics using the pressure plate apparatus.

MODELING

Daily rainfall and evaporation data of 1986 to 2000 were used for the study. Water balance components like runoff, evapotranspiration and drainage (recharge to groundwater from rainfall) were determined through SWIM.

SWIM is an acronym that stands for Soil Water Infiltration and Movement Model. It is a software package developed within the CSIRO Division of soils for simulating infiltration, evapotranspiration, and redistribution. The model is based on a numerical solution of the Richards' equation and the advection-dispersion equation. It can be used to simulate runoff, infiltration, redistribution, solute transport and redistribution of solutes, plant uptake and transpiration, soil evaporation, deep drainage and leaching. Soil water and solute transport properties, initial conditions, and time dependent boundary conditions (e.g., precipitation, evaporative demand, solute input) need to be supplied by the user in order to run the model. The governing partial differential equation (Richards' equation) applicable for one-dimensional flow in the unsaturated zone can be written as:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x} K\left[\frac{\partial \psi}{\partial x} + \frac{dz}{dx}\right] + S$$

where,

θ = volumetric water content [cm³/cm³]; water/soil

t = time [h]

x = distance into the soil [cm]

K = hydraulic conductivity

[cm^2 /(cm/h); water/soil]
ψ = matric potential [cm]; water
z = gravitational potential[cm] and
S = sink strength[$cm^3/(cm^3/h)$]; water/soil

The model deals with a one-dimensional soil profile. For a vertical soil profile, this means that it may be vertically inhomogeneous, but must be horizontally uniform. This assumption has two consequences of importance in many common simulations. There is only one hydraulic conductivity function for each layer, so that any macropore, or bypass flow can only accounted for in a limited way. Secondly, the calculated solute concentrations apply to the whole soil layer, which means that there is no concentration gradient from the bulk soil to near the root surface. The presence of such a concentration gradient may in reality affect the soil osmotic potential and hence water and solute uptake (Verburg et al, 1996).

Model Conceptualization

In order to simulate the water balance components of the study area, a soil profile in each zone, viz., coastal, up ghat and plateau areas were considered with a thicknes of about 150 cm. Vapour conductivity is not taken into consideration nor is the effect of osmotic potential. There are two hydraulic property sets (for upper and lower soil horizons) that applied to 16 nodes of the 150 cm deep profile. Hysterises is not taken into account. Initially, there is no water ponded on the surface. Runoff is governed by a simple power law function and a surface conductance function. No by pass flow was included. A matric potential gradient of 0, i.e., `unit gradient' has been applied as bottom boundary condition through out the simulation. Cumulative rainfall and evaporation records (daily) for the period 1986–2000 were given as the input for determination of water balance components (runoff, evapotranspiration and drainage). The model parameters (soil hydraulic properties and moisture characteristics) were actually measured in the field and laboratory. Therefore, the model does not require any calibration as such.

Input Data for SWIM Model

1. Rainfall: Based upon the available information, two distinct soil layers were identified. The following input data was used for simulation of soil moisture movement through SWIM. Daily rainfall data of Honnavar, Barchi and Siddapur were used.
2. Evaporation: Daily evaporation data of Honnavar (coastal), Barchi (plateau) and Siddapur (Up ghat) were considered for the analysis.
3. Saturated Hydraulic Conductivity:

Saturated hydraulic conductivity was measured at 9 locations in the study area by using disc permeameter (locations are shown in Figure 1).The average saturated hydraulic conductivity values for the surface was measured by using disc permeameter and lower layer by using Guelph permeameter.

4. 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 two soil layers were obtained by non-linear regression analysis (Table 1).
5. Vegetation: Forested watershed, minimum xylem potential = –15000 cm, exponential root growth with depth and sigmoid with time were assumed for the study.

Table 1. Measured saturated hydraulic conductivity and van Genuchten Parameters for the Two Soil Layers

Zones	Land use type	Soil Layers Depth (cm)	Sample size	Log-mean Ksat (mm/h)	Van-Genuchten Parameter	
					α	n
Coastal	Natural Forest	Surface	10	93.92	0.0192	1.6161
		120–150	10	44.74	0.0105	1.6270
	Degraded Forest	Surface	12	6.73	0.0201	1.7008
		120–150	12	0.20	0.0298	1.5353
	Afforested	Surface	10	88.20	0.0792	1.2586
		120–150	10	88.20	0.8118	1.2446
Plateau	Natural forest	Surface	15	11.88	0.0044	1.9400
		120 – 150	15	0.21	0.0110	1.8151
	Degraded Forest	Surface	12	6.21	0.0119	1.6320
		120–150	12	0.40	0.0123	1.6296
	Afforested	Surface	15	6.01	0.0050	1.8698
		120–150	15	0.60	0.0051	1.7644
Up-Ghat	Natural Forest	Surface	20	179.64	0.0253	1.4570
		120–150	20	1.66	0.0104	1.4514
	Degraded Forest	Surface	20	2.78	0.0214	1.3563
		120–150	20	2.78	0.0201	1.5861
	Afforested	Surface	20	90.00	0.0125	1.6925
		120 –150	20	43.2	0.003	1.7701

Results and Discussion

Regional Analysis of Rainfall

Data of all the station that are grouped under three regions were pooled together to fit Gumbel distribution. The results obtained from fitting Gumbel distribution for individual stations and region wise were compared with the observed values. The estimates obtained from fitted distribution matches the observed values with an error of (10–15).

Table 2, reveals that the rainfall intensity is higher in coastal region for the return periods 2 and 5 years. The return period 10, 25 and 50 years show higher intensity in region III, compared to Region I. However, it is interesting to note that in Region II, the intensity is comparatively lower for all the return periods than the other two regions. This is true for only for intensity duration of 1 h. In the case of 2 h, 3 h and 5 h duration, the intensity is higher in up ghat region than in plateau region. The coastal region is distinct with the higher intensity than the other two regions.

Statistical and Numerical Analyses

Statistical methods provide a satisfactory tool for hydrological analyses. Tukey (1977) indicated that the K data frequency distributions are closely approximated by the log-normal function. These observations are in close agreement with other field investigations (Bonell et al., 1983; Talsma, et. al., 1980) Consequently the use of log-means for interlayer comparison of K is more appropriate measure than the arithmetic means (Talsma, 1965; Nielsen et. al., 1973). The use of further statistical and numerical analysis on the K data is confined to the sur-

Table 2. Rainfall intensity –duration estimates for different regions for selected return period

RP*	Region I				Region II				Region III			
	1 h	2 h	3 h	5 h	1 h	2 h	3 h	5 h	1 h	2 h	3 h	5 h
2	34.06	28.41	29.19	20.27	26.06	21.34	14.27	11.98	29.23	17.17	12.04	9.64
5	42.40	41.14	39.14	31.3	38.01	29.09	22.00	18.14	41.75	25.73	18.25	14.82
10	47.57	49.57	45.73	38.60	45.57	34.23	27.11	22.22	50.04	31.4	22.37	18.26
25	54.10	60.22	54.05	47.82	55.12	40.72	33.57	27.38	60.51	38.56	27.56	22.60
50	58.94	68.12	60.23	54.66	62.2	45.53	38.37	31.21	68.28	43.87	31.41	25.82

Return Period, Region I – Coastal, Region II – Up Ghat, Region III – Plateau
Values are in mm/hr

face and layer between 120–150 cm, as these controls the runoff process. A significance level of 0.01 was used to test differences between specific pairs of sites. However, results indicated that, both F-test ($F < 0.001$) and Least Significant Difference was significant at this level.

The measured saturated hydraulic conductivities are plotted as box plots to view the variation within the measured values. The length of the box reflects the inter-quartile range, and the fence or tails of the box plots are marked by the extremes if there are no outliers, or else by the largest and smallest observation that does not qualify for an outlier. The outliers are defined as data points more than 1.5 times the inter-quartile range away from the upper or lower quartile. The middle horizontal bar on the box plot represents the median of the data.

The saturated hydraulic conductivity observed for soils in the undisturbed forests and also in afforested regions is comparatively higher in the lateritic soils, followed by red soil and least is observed in black cotton soils (Figure 2). Another set of data observed across an array of land use types, showed that the saturated hydraulic conductivity is maximum in forest and plantations (afforested land). Minimum saturated hydraulic conductivity was observed in degraded forests. However, saturated hydraulic conductivity in afforested region depends upon both soil type and also the type of plantation, such as teak, causarina or Acacia. A diagrammatic representation of the variation in saturated hydraulic conductivity with land use type is shown in Figure 3. Similar observation was made by VENKATESH et al. (2004) for Barchi watershed in a plateau region. It is reported that in regions afforested with teak plantation has the lowest K_s value as compared to the forest and degraded lands.

The computed rainfall intensities for different frequencies are superimposed on these box plots to identify the possible runoff generation mechanism. From the Figure 2 it is evident that, the red and lateritic soils are more permeable than the black soils. However, in black soils, the mean Ks are exceeded by the rainfall intensities even at 1 in 1 year and above, indicating the domination of infiltration excess overland flow (Hortonian overland flow) occurrences.

The box-plot.3, depicts that, the natural forest and acacia plantation are comparatively has higher permeability than the other land-uses considered for the analysis. From the box-plot, it is observed that, the K_s values in natural forest are much higher than the rainfall intensities at 1 in 50 years, indicating that in such regions the probability of having Hortonian overland flow is rare. However, PUTTY et al. (2000) reported the pipe flow phenomenon in such conditions.

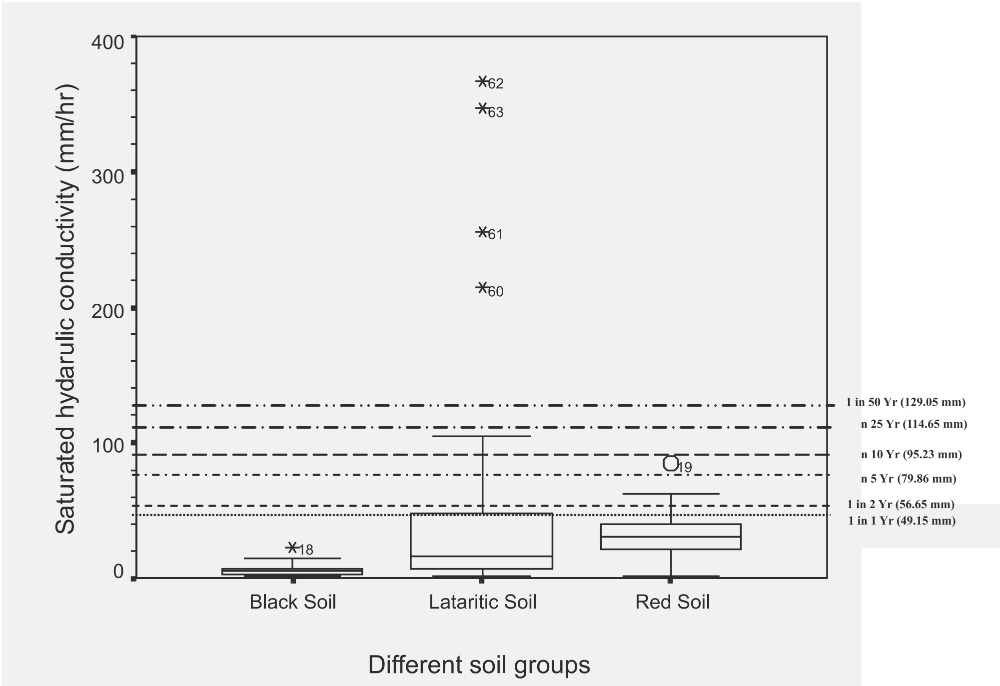

Figure 2. Saturated hydraulic conductivity, K_s as a function of soil

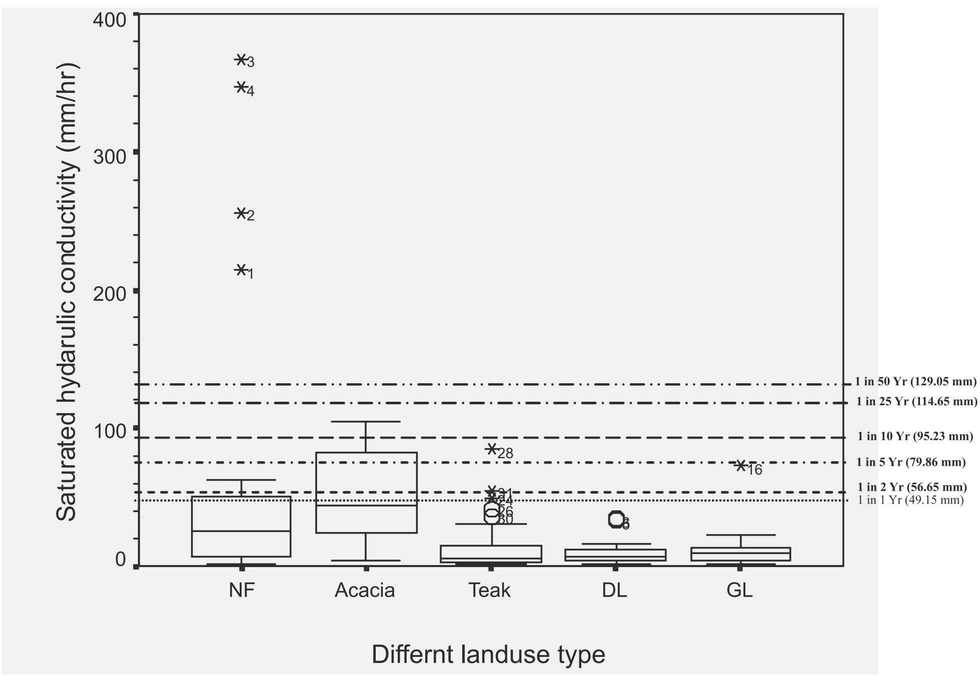

Figure 3. Saturated hydraulic conductivity, K_s as a function of land-use

Table 3. Estimates of Groundwater Recharge using SWIM Model

Sl No	Zones	Rainfall records Considered	Land use type	Average rainfall (mm)	Recharge percentage
1	Coastal	1986–2000	Forest	3090–4192	52–55
2			Degraded land		28–30
3			Afforested land		60–65
4	Plateau	1986–1999	Forest	941–1521	30–35
5			Degraded land		18–22
6			Afforested land		22–25
7	Up Ghat	1989–2000	Forest	2489–2734	50–55
8			Degraded land		28–32
9			Affores ted land		48–52

Simulations using SWIM Model

The water balance estimated for the coastal region (using SWIM model) in three plots, namely, natural forest, degraded forest, afforested land, it is found that with an average rainfall of 3663 mm rainfall, the rainfall got apportioned into 1648 mm as runoff, 1200 mm as evapotranspiration, and 811 mm as deep drainage. The estimation of evapo–transpiration by the SWIM model is based on the potential evaporation. The PE values were available for only one station in each region. Therefore, no variation was observed in the estimated ET amount under different land use. The variation observed in the recharge percentage during the study period (for the data of 1986 to 2000) was 51–55 % in natural forest, 28–30 % in degraded forest and 60–65 % in areas where the afforestation was done about 10 years back. The runoff coefficient observed for the catchments in coastal area varied between 0.17 and 0.85. The minimum was noted in the forested plots and maximum is on degraded forests. This shows that there is a wide variation in runoff characteristics due to continuous change in land use and climatic conditions. Other important observation made was that high recharge and deep drainages are the characteristic features in coastal region due to high permeable lateritic rocks. Similar observations reported for the basins originating from WG of Karnataka (SHETTY, 1999).

In the plateau area, especially, in black cotton soils (vertisol), the estimated recharge in natural forest was 30–35 %, degraded forests, 18–22 % and 22–25 % in afforested lands. SWIM model analysis carried out for the Barchi nala catchment showed that with an average rainfall of 1303 mm, 524 mm is evapo–transpiration and 350 mm was estimated runoff. The deep drainage component was only 410 mm.

Hydrologically, the up lands of the WG are characterized by steep slopes and high rainfall. The major part of the WG is covered by lateritic soil underlain by crystalline rocks. The runoff percentage estimated is 43 %. The average rainfall in the area is 2361 mm. SWIM model results showed that 878 mm as evapotranspiration and 1015 mm runoff. The drainage component estimated was 461 mm. This is quite lower than that estimated for the coastal region but higher than that of plateau region.

Baseflow indices were estimated for two regions (Venkatesh et al., 2002), one dominated by red soils and the other is black cotton soils. In the black cotton soil area it is found that, the baseflow index showed high value (0.51) as compared to the red soil region (0.36). This variation is attributed to the fact that, in red soil region major part of the rainfall infiltrated into deeper zones and increased the ground water recharge, where as in the black cotton soil area, the deep drainage component is quite lower due to low infiltration rates as observed in this part of the study area.

Conclusions

The application of SWIM has been demonstrated for different land use in parts of WG of North Kanara district of Karnataka, India. The advantage of the model is that it can be used both for laboratory and field studies to simulate the soil water and solute transport and can also be used for understanding the impact of different land use management hydrologic regime of the area. In this study, simulations using the SWIM has been substantiated by the field experiments to understand the runoff generation dynamics under different land–use conditions.

Following are some of the important conclusions drawn from the study

1. The impact of afforestation showed a considerable increase in infiltration and hydraulic conductivity and also generates infiltration excess overland flow at higher rainfall intensities.
2. The results obtained through SWIM model indicated that there is marked differences in recharge percentages as the land cover changes (i.e., converting the land from degraded has been brought under Acacia plantation in the present case). This higher groundwater recharge may contribute to the

dry season flows in the streams.

3. The current study clearly indicated that selective reforestation/afforestation with specific species may lead to improve the surface hydraulic properties and encourage greater percolation and conversely, inhibits the occurrence infiltration excess overland flow.

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