Studies on Ground water Recharge in Spring Discharge zone of Ghataprabha Sub-Basin Western Ghats, India

BY

B. K. PURANDARA
SUDHIR KUMAR
RAJAN VATSA

NATIONAL INSTITUTE OF HYDROLOGY
HARD ROCK REGIONAL CENTER
BELAGAVI

2016-2017

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ABSTRACT

Land and water management issues are the two important aspects which needs immediate attention from both scientific community and administration. In order to address the problems facing in water sector, it is necessary to understand the impacts of proposed land management, vegetative changes, groundwater withdrawals, and reservoir management on water supply and water quality. As acquisition of field data is costly and time consuming, models have been created to test various land use practices and their concomitant effects on the hydrologic budget of watersheds. To simulate such management scenarios realistically, a model should be able to simulate the individual components of the hydrologic budget. In the present study, the hydrological simulation is carried out by using Soil and Water Assessment Tool (SWAT) model, which is integrated with Arc Gis software, to estimate some of the most important parameters of hydrology, such runoff, groundwater recharge and evapotranspiration. The model was applied to Ghataprabha sub-basin, which is a right bank tributary of river Krishna. The analysis was carried out in three phases to understand the hydrological response to catchment characteristics, particularly with reference to catchment area. The calibration and validation of the model was done by using the data of adjoining basin, Malaprabha as there is a lack of rainfall data for the regions in headwaters of Ghataprabha catchment. The model was calibrated and validated by using data for a period 1991 to 1998. Long term mean hydro-meteorological data and physical characteristics of the catchment such as land use/land cover, soil type, topography, groundwater level and slope are used as an input to the model. The mean annual groundwater recharge, evapotranspiration and runoff were found to be 18%, 30% and 46% for headwater catchments with a considerable decline with an increase in catchment area. Comparison of measured and predicted values demonstrated that each component of the model is quite acceptable and realistic in nature. However, it is necessary to go data intensive modeling to get an accurate view of the hydrological processes.

CHAPTER -1

1.0 Introduction

The term `spring' in hydrology refers to a water sprout which originates from the earth's subsurface and flows through the head water streams. Flow in the streams or nala continues during the dry seasons though there will be a decrease in the discharge at the end of the season **(Purandara, 2016).** Springs are very important sources of water in the present scenario of climate change and therefore captured the imagination of scientists during the last few decades. Till recently, the most widely held views in the Western world were that, the springs can contribute large quantity of water that condensed below the surface. Following watershed mass balance measurements and calculations done in the late 1600s, it became apparent that precipitation can supply more than enough water for rivers and springs. In the history of Water resources of development and management of head water catchments, the springs have played a geographic role in human settlement, especially in arid environments. Spring waters, in particular those from mineral and hot springs, have long been purported to have medicinal or therapeutic value (Crook 1899, Waring 1915). Spring water is also very important as it contains number of elements of the natural environment.

According to a report of USAID (2009) more than one billion people do not have access to safe drinking water and over 2.5 billion people have inadequate sanitation. In India also the situation is not much different from the other developing countries. Water is life and especially potable water is essential for life and health. So, access to drinking water, improves overall socio-economic and environmental existence (Gebrehiwot, 2006).In developing countries national and regional governments, local and international NGOs and other concerned organizations invest large sums every year for the implementation of rural water supply projects (Gebrehiwot, 2006). However, construction of water projects does not help if they fail after a short time. In order to make the investment in water supplies more effective, failure rates of these systems should be reduced. According to Gebrehiwot (2006), this can be accomplished by better integration of people who receive the water and water project suppliers indecisions concerning planning construction and management of water supply systems.

Enhancing the capacity of the community in planning, implementation, development and maintenance of rural water supply systems are the first step towards the sustainability development of rural water supply schemes. To examine the impact of the water supply system socio economically, the full impact should be taken under consideration (UNICEF, 1999).Involvement of the communities is crucial for the sustainability of rural water supply systems. Females are responsible for fetching water by carrying a clay pot water container or jar long distances. The rural part of Ethiopian topography has rugged terrain and the water points are far especially during the dry phase of the monsoon from the individual households as a result females move up and down by carrying water (Admassu et.al, 2002). About three hours are being lost per day per household fetching water by rural households who have no access to safe drinking water sources around their houses (UNICEF, 1999). Sometimes women prefer fetching water from unprotected spring, river and other sources of it is closely in order to decrease the time spent to fetch water and from these sources they get water free from payment without worrying about the quality of water and its consequences (Admassu et.al, 2002). Therefore, it is quite essential to look for an alternative source of water particularly in the head water catchments which can be utilized effectively for agriculture and drinking purposes locally. Head water catchments can play a major role in water conservation and ground water replenishment in the catchment areas and also it can enhance the water availability for the downstream users.

In mountainous catchments, all recharge to groundwater discharges naturally and can be used by a wide variety of organisms, including (but not limited to) mankind, in the special ecosystem that they sustain. Springs are natural outlets through which groundwater emerges at the ground surface as concentrated discharge from an aquifer and are one of the most conspicuous forms of natural return of groundwater to the surface. As spring waters flow down a slope, a portion of the flow may seep into the ground, adding to the recharge of the lower aquifers. In the long history of mankind, these great resources have often been destroyed by diversion or ‘development’ in short-sighted attempts to improve water supplies for human communities. This frequently has had adverse effects on the environs of the original springs and seeps. Springs in the high hills of the Western Ghats (hills), in the western margin of the Indian Peninsula, are no exception. They sustain the life of thousands of human beings, plants, animals, birds and other organisms. In the name of development, these springs are under constant exploitation for local water supply.

Natural settings and sources are often modified, thus diminishing their life and often causing their complete disappearance. Therefore, it is important to enhance the capacity of the community in planning, implementation, development and maintenance of these spring water for the socioeconomic development of the forest dwellers. Further, involvement of the communities is crucial for the sustainability of rural water supply systems. Females are responsible for fetching water by carrying a clay pot water container or jar long distances. The rural part of Ethiopian topography has rugged terrain and the water points are far especially during the dry phase of the monsoon from the individual households as a result females move up and down by carrying water (Admassu et.al, 2002). About three hours are being lost per day per household fetching water by rural households who have no access to safe drinking water sources around their houses (UNICEF, 1999). Sometimes women prefer fetching water from unprotected spring, river and other sources of it is closely in order to decrease the time spent to fetch water and from these sources they get water free from payment without worrying about the quality of water and its consequences (Admassu et.al, 2002). Therefore, it is quite essential to look for an alternative source of water particularly in the head water catchments which can be utilized effectively for agriculture and drinking purposes locally. Head water catchments can play a major role in water conservation and ground water replenishment in the catchment areas and also it can enhance the water availability for the downstream users.

1.1 Objectives of the Study:

1. Estimation of recharge rates in the selected watersheds using spring flow, rainfall and Temperature data
2. To evaluate the sustainability of the springs in the changing scenario of land use/land covers and its (spring water) role in rural water supply schemes
3. Assessment of water quality of spring water, groundwater and surface water

CHAPTER- 2

literature Review

There are five million springs across India, based on current estimates. From the Himalayas in the north to Nilgiris in the Western Ghats to the Eastern Ghats. Springs are a safe source of drinking water for rural and urban communities. For many people, springs are the sole source of water. However, Water scarcity followed by drying of springs in the upper catchment underscore the need to increase the understanding of spring hydrology, especially in the Himalayan and parts of Western Ghats region of India. Though adequate literature on springs in the Himalayas are available, still the studies in the western ghat areas are quite limited. In a review of microscale and meso-scale studies, Negi (2002) highlighted the need for systematic monitoring to aid the management of Himalayan springs. According to Bruijnzeel and Bremmer (1989) and Alford (1992), the current understanding of the occurrence and distribution of springs in the Himalayas is insufficient and management plans stemming from inadequate understanding would not solve water scarcity challenges. Therefore, it necessitates the understanding of the functioning of springs so that appropriate measures can be taken to rejuvenate the existing springs which will play a significant role in the socioeconomic development of the mountainous region.

One of the major issues in the mountainous catchment of the Himalayan regions is how to improve water availability for rural communities due to the ever increasing anthropogenic activities such as deforestation, unplanned agriculture and tourism developments without proper understanding of the watershed characteristics. Most interventions were not site-specific and did not take into account hydrogeology and preferential pathways in aquifers (Agarwal et al. 2012). Instead, a ‘one-size-fits-all’ approach was adopted in most interventions (Sharma et al. 2000a, 2000b; Sharma and Shakya 2006). Furthermore, studies to assess the impacts and sustainability of these interventions are rare, especially to quantify their impact on spring discharge. As a result, the impact of these interventions on increasing spring discharge is limited.

The Himalayan mountains are young and dynamic. Further, mountain slopes are tectonically active and potentially erosive. It is a fact that there is a pressure of population and anthropogenic activities which continuously disturbed the natural system of the Himalayan environment (Valdiya et. al., 1994; Negi et. al., 1998; Negi, 2001, 2004; Negi & Joshi, 2004). Fluctuation of water discharge in different seasons and increasing amount of sediment load in streams are one of the most important problems of the Himalaya. A study carried out by Rawat and Rawat (1994) reported that the annual discharge from the springs has been reduced by about 50%. According to Negi and Joshi (2002), spring water yield both during rainy and non-rainy seasons has been affected by both rainfall and the spring recharge zone characteristics. Rai et. al. (1998) found that the in the eastern Himalaya, the rate and total flow in springs can be correlated with rainfall pattern and recession of seasonal springs. The seasonal springs were completely dependent on the rainfall pattern and disappears more rapid than the perennial springs. The study further reported that there is a great variation in mean annual spring water yield (5-39 L/min) emanating from different recharge areas in this region. Valdiya and Bartarya (1991) explained that in the central Himalayas about 8 types of springs are recognized on the basis of the geology, nature of water-bearing formations, and conditions related to their formation. Bartarya (1991) reported that springs originating from fluvial deposits produced water at the highest rate (mean= 405 x 10^3 L/D) and those originating from colluvium at the lowest rate (7.2 x 10^3 L/D). Impact of the recharge zone characteristics and land use land cover changes on water quality has also been reported in this region (Kumar et. al. 1997; Negi et al. 2001; Joshi & Kothyari, 2003).

Therefore, understanding the linkage between mountain water sources and basin aquifers is important [*de Vries and Simmers*, 2002; *Scanlon et al.*, 2006]. MBR influences the mountain groundwater flow system and inter-mountain basin aquifers. Moreover, bedrock groundwater contributes to surface water discharge up to 20%–50% in some systems [*Uhlenbrook et al.*, 2002; *Kosugi et al.*, 2006]. Modeling studies have shown that bedrock permeability and storage capacity have the largest impact on MBR rates [*Forster and Smith*, 1988; *Gleeson and Manning*, 2008]. One of the most interesting part of the hydrologic system in a mountainous catchments is the occurrence of natural springs either in the form of interflow or as artesian springs. These springs plays a significant role in agriculture and water supply to rural communities in the mountainous catchments. However, in the recent years due to population explosion and industrial growth, the sustainability of such Spring water is questionable?

Available literature reveals that little work has been done on the origin of springs in a basaltic terrain. Close examination of such springs in parts of Western Ghats covering Shindudrug district of Maharashtra, Uttara Kannada and Dakshina Kannada districts on the western side and Kodagu district in eastern part of the state of Karnataka faces severe water crisis during the summer months in-spite of heavy rainfall for a period of about 4 months with an average rainfall of more than 3000 mm. A detailed investigations in Koyna area of Maharshtra by Naik et al (2002) reveals that their origins are dependent on the lithologic character of different basaltic flow units and the existing physiography. Although rainfall, its seasonality and areas of recharge, play vital roles in the recharge of these springs, their yields are also controlled by lithological variations and hydraulic characteristics of their source-aquifers.

Previous literature on water availability in the mountainous catchments, indicated that, the water stress is said to be primarily due to the fast growing cities combined with the change in land use/land cover changes occurring in most part of the country. It is a fact that land use and land cover change profoundly transformed terrestrial hydrological budgets and processes (Vorosmarty and Sahagian, 2000; Stonestrom et al., 2009). Although the effects occur at multiple spatial scales from local (small basins) to global, the scaleat which local communities and land-use managers are affected is of special concern as decision making on ecosystem services, especially hydrologic services. Despite the hydrologic importance of mountainous catchments in providing freshwater resources, little is known about key hydrological processes in these systems, such as mountain block recharge (MBR) [*Viviroli et al.*, 2007]. The intrinsic complexity of recharge processes and the fact that such processes are extremely difficult to observe contribute to this problem. Without understanding this key hydrological process in mountainous catchments, assessing the impact of climate variability and land cover change in these vulnerable systems will be incomplete and possibly inaccurate. Mountain system recharge (MSR) is the main groundwater recharge component [*Wilson and Guan*, 2004], and it includes infiltration of mountain stream runoff in alluvial fan streambeds (mountain front recharge, MFR) and precipitation infiltration through mountain bedrock (MBR). Although most studies have focused on recharge processes at the mountain front, a possibly large but unknown contribution of recharge comes from MBR in the sky islands of the southwestern United States [*Manning and Solomon*, 2003; *Blasch and Bryson*, 2007].

Hao et al (2006, 2009) studied the response of karst springs to climate change and human activities for the Niangziguan Springs, China, and found that discharge has been declining since the 1950s. The response of springs to climatic change and anthropogenic influence were studied using a model-based discrimination between phases in the stream discharge record. The results show that the contribution of climate change to depletion of Niangziguan Springs is 2.30 m^3/s and the contribution of human activities ranges from 1.89 to 2.90 m^3/s. Karst aquifers at the Liulin springs respond remarkably to climate changes, in particular to changes in precipitation input.

Rock outcrops of Africa, the Americas and Australia have been extensively studied for more than three decades. The distinctness of rock outcrops from surrounding habitats is a major factor whichleads to exclusivity of the plant diversity on them. Hence they have been described as “terrestrial habitat islands” and the microhabitats on them as “islands upon islands” (Porembski et al. 2000a). Azonal vegetation on tropical inselbergs in Africa, Australia and America has been studied by several researchers such as Burbanck & Platte (1964), Wyatt (1997), Porembski & Barthlott (2000b), and Burke(2003). But there is in general a scarcity of information regarding rock outcrop habitats of India. Globally, inselbergs of granite, sandstones, schists etc. have been studied in detail, but the same is not true for ferricretes and mesas. Ferricretes are known to be rich in species diversity, endemics and edaphic specialists (Verboom & Pate 2001), but only a few studies describe their vegetation (Porembski et al. 1994, 1997; Porembski & Watve 2005).

The only detailed information available on the distribution of ferricretes and mesas of the study area is from the geomorphological and geological literature. Geological Survey of India has published data on bauxite deposits of Maharashtra ferricretes. However, data on floristic and faunistic diversity remains scarce and widely scattered.

Bharucha & Ansari (1963) were the first to analyze the herbaceous vegetation of slopes and scree of Western Ghats in relation to soil, slope and aspect. Chavan et al. (1973) studied the Kas Plateau area (Satara District) but the study also includes cliff, forest and slopes around the Kas ferricrete. Regional floristic studies have reported the occurrence of many narrow-niched endemic and habitat specialist angiosperms from lateritic plateaus (Bachulkar 1983; Deshpande et al. 1993, 1995; Yadav & Sardesai 2002). Mishra & Singh (2001) have documented threatened plants of Maharashtra, of which many are reported exclusively from ferricretes or basalt outcrops. The first detailed enumeration of endemics from Goa by Joshi & Janarthanam (2004) includes many species specific to lateritic plateaus. The most recent study on floristics of lateritic plateaus by Lekhak & Yadav (2012) analyses angiosperm diversity in 10 sites of high level ferricretes.

Ecological studies and floristic and faunal observations on basalt and laterite outcrops have been published by Watve (2003a,b, 2006, 2007, 2008), and Watve & Thakur(2006). A review paper on the biodiversity and ecology of rocky plateaus (Watve 2010) has been included as a part of the Western Ghats Ecology Expert Panel (WGEEP) report on ecologically sensitive areas of the Western Ghats.

In spite of these studies there is little awareness at policy level regarding the special nature of rocky plateau biodiversity, and their conservation requirements need to be emphasized. Within the last decade many rocky plateaus have been taken over by mining, windfarms, construction of townships and industries. Tourism has been growing in some of the scenic areas putting severe pressure on fragile habitats. The management of these pressures is often misguided due to poor understanding about the special ecological features of the habitat. The measures used for protection of forest or grassland habitats are not appropriate, as the ecological processes on rocky plateaus are different in nature. The lack of baseline information regarding rocky plateau ecology has severely hampered efforts of management and conservation. Thus this is an effort to collate baseline information with a view to highlight conservation and management priorities.

The review will begin with an explanation

In the Western Ghats, natural springs are a source of drinking water for many vulnerable rural communities. The springs serve as an essential component for the functioning of our forest cover and dependent ecosystem, yet their conservation is a completely neglected affair. Spring discharge is declining due to groundwater pumping under increased demand, changing land use patterns, ecological degradation and a changing climate. [5]

In the Western Ghats, natural springs are a source of drinking water for many vulnerable rural communities. The springs serve as an essential component for the functioning of our forest cover and dependent ecosystem, yet their conservation is a completely neglected affair. Neither the Maharashtra state policy nor our national policy framework for natural resource management address this issue. There is an urgent need for a paradigm shift from source exploitation to resources management, especially in lieu of climate change. In this post we take a look at springs located in the hilly regions of

Akole and Sangamner in Ahmdednagar district. Spring sources that we have surveyed are on a declining trend (both in terms of numbers and discharge), wherein some of the perennial springs have dried up or have been encroached upon, contaminated or destroyed – making it a serious issue for water resource management.

"कडक उन्हाळ्यात आमच्यासाठी हे पिण्याच्या पाण्याचे एकमेव सुरक्षित स्रोत आहे", which means "This is the only source of safe drinking water for us during lean summer months*",* a woman from Kandobachiwadi of Pimpaldhari village responded as she leaned forward to grab water collected in a small pool inside a horizontal rock crevice. She had come to collect 3 *handas* (vessels) of water, while we were busy surveying in the hot afternoon, trying to understand the springshed (the catchment area of spring source and the associated ecosystem) and its supporting micro-habitat.

The rural landscape of Akole and Sangamner situated close to the Western ghats is unique for its majestic mountain ranges, geology and biodiversity. Most of the remote and poorer village communities in these regions rely on natural perennial spring water for their drinking needs. These springs exist as a result of the unique geology of the Deccan traps that consists of multi-layered alternating layers of pervious (vesicular basalt) and impervious (hard massive basalt) strata. The rain water that falls over this landscape infiltrates through root zones of forested areas, percolating through pervious surfaces (top soil and weathered rock) and moving along the gaps between stratas, vertical and horizontal cooling joints to recharge subsurface aquifers.

This groundwater moves slowly down the different units reemerging as springs when it comes across an impervious unit. The Western ghat region is dotted with many such springs sources that are an integral component for the functioning of the stream ecosystem and source of drinking water for many communities.

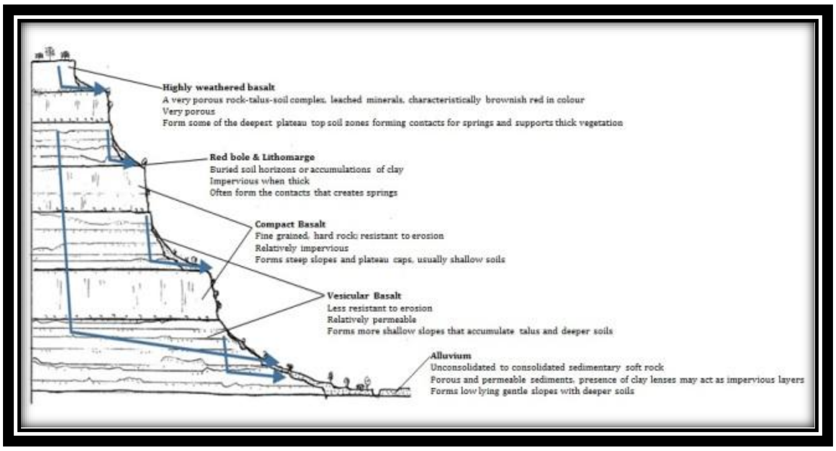

Figure 1: Typical framework of Hydrogeological units with genderalised groundwater flow paths (modified and adapted from Buono et al. 2015)

While assessing the situation, we observed that majority of these basalt units are massive and impervious, and groundwater occurrence and movement in these hard basalts depend primarily on differing hydrological properties of the rock types, degree of weathering and their intrinsic jointing patterns and fractures that provide pathways for water to move to lower aquifers down the valley. The rainfall plays a significant role in the distribution and availability of water for recharge in these regions, however, changes in upstream forest cover significantly impact how water is discharged along such springs and its slow release downslope. With reducing rainfall trends in the region and upstream land cover changes, recharging of the groundwater has dropped considerably and so has the discharge of many springs.

As a part of our comparative spring's assessment and springshed mapping from Akole and Sangamner villages, a total of 63 springs from 13 villages (8 villages from Akole and 5 from Sangamner) have been marked and recorded. We focussed on mapping perennial springs and excluded springs that have shorter life span post monsoon and hardly get recharged upon rainfall due to lower springshed area.

Pradeep K. Naik et al., (2002), examined the origin and distribution of springs in about 2,000 km^2 of the upper Koyna River basin in the Deccan Trap country of the Western Ghats (hills), India, reveals that their ori- gins are dependent on the lithologic character of different basaltic flow units and the existing physiography. Although rainfall, its seasonality and areas of recharge, play vital roles in the recharge of these springs, their yields are also controlled by lithological variations and hydraulic characteristics of their source-aquifers. Chemical concentrations of these springs are heavily dependent on the lithological compositions of the source-aquifers and the residence time of groundwater in these aquifers. Currently, basaltic springs are classified with those issuing from other terrains. However, because the emergence of groundwater in the form of springs is largely con- trolled by the lithology and the resulting water-bearing properties of the formations, a new classification scheme is proposed that classifies the springs on the basis of their source-aquifers. While tapping springs for drinking/irrigation purposes, it must be remembered that they also sustain thou- sands of other life forms vital to a balanced ecosystem. Changes in the uses of these springs may also affect other human communities downstream. Therefore, before developing spring flow, a trade-off must be made considering local needs and downstream users. Emphasizing only local human needs may lead to severe intercommunity conflict and negative environmental consequences.

2.1 Land use and land cover (LULC):

Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. [6] Land use and land cover (LULC) are the main determinants of the structure, functions, and dynamics of most landscapes throughout the world. [7] Land use and land cover change (LULCC) also known as land change is a general term for the human modification of Earth's terrestrial surface. Though humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of LULC are far greater than ever in history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. These changes encompass the greatest environmental concerns of human populations today, including climate change, biodiversity loss and the pollution of water, soils and air. [8]

LULC can lead to changes in the infiltration capacity of the land, therefore, changing the dynamic of the runoff. The increase in population with increase in land use for agricultural, urbanization lead to direct impacts on runoff and stream flow. Land cover plays an important role in the ecosystem, its change can lead to the modification of the micro-climate, and therefore, the hydrological cycle of that basin. Change in land cover can affect the microclimate of the given area and the infiltration rates can be reduced on cultivated land compared to natural land cover.

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Vries and Simmers, 2002; *Scanlon et al.*, 2006]. MBR influences the mountain groundwater flow system and inter-mountain basin aquifers. Moreover, bedrock groundwater contributes to surface water discharge up to 20%–50% in some systems [*Uhlenbrook et al.*, 2002; *Kosugi et al.*, 2006]. Modeling studies have shown that bedrock permeability and storage capacity have the largest impact on MBR rates [*Forster and Smith*, 1988; *Gleeson and Manning*, 2008]. One of the most interesting part of the hydrologic system in a mountainous catchments is the occurrence of natural springs either in the form of interflow or as artesian springs. These springs plays a significant role in agriculture and water supply to rural communities in the mountainous catchments. However, in the recent years due to population explosion and industrial growth, the sustainability of such Spring water is questionable?

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The research challenges of Spring flow analysis are as follows:

(1) How can streamflow recession analysis can be used to improve understanding of Mountain Block Recharge(MBR, as stated by Ajami et al., 2011)processes in a tropical mountainous catchments?

(2) What is the sensitivity of MBR estimates to uncertainty in the derivation of the catchment storage-discharge relations?

(3) What are the contributions of seasonal precipitation (winter versus summer monsoon) to MBR?

(4) What can we infer from storage-discharge relations across nested catchments of increasing size to describe Mountain System Recharge processes in a mountainous catchment?

CHAPTER - 3

3.0 Study Area

The Western Ghats region of peninsular India is one of the most important regions from the point of view of understanding hydrological service impacts of forest cover change and also represents the complexities of the social use of forests. On the one hand, the heavily forested Ghats region is the site of historically intense use of forests by local communities for meeting their needs of fuelwood, fodder, grazing, leaf manure, etc., as well as felling by the state forest department for meeting regional needs of timber. This has resulted in a complex mosaic of relatively undisturbed forest, savannah, grassland and barren lands, interspersed with mono-cultural plantations established by the forest department. It is also the site of major shifts in land-use from “forest” to “non-forest”, including agriculture or plantation crops. State forestry activities have also significantly affected the composition of these forests. On the other hand, virtually all the major rivers (particularly the important east-flowing rivers) in southern India originate in the Western Ghats. The changes in land-use and land-cover in the upstream catchments of these rivers are therefore of critical importance to the millions off armers on the eastern portion of the Deccan plateau, especially the increasing numbers depending upon river flows (direct or dammed) for irrigation. They are also likely to be of importance to the community local to the Western Ghats themselves, because even in this high rainfall region, seasonal scarcity of water is ubiquitous, and fertile soil is at a premium. This study is an attempt to contribute to an improved understanding of the forest-water community linkage through field investigations in the Western Ghats that lie within Karnataka state (see Figure 2). The study is distinctive in its attempt to integrate the biophysical investigation of forest-hydrological changes with the socio-economic investigation of impacts of such changes. We describe below the questions investigated, the framework within which they are answered, the analytical approach, methods used for site selection and for thehydrological and socio-economic studies.

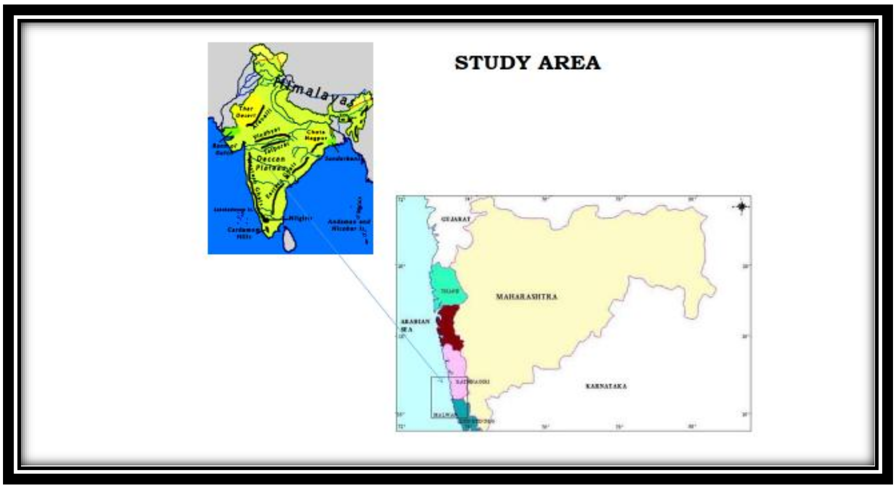

Figure 2. Study Area

One of the important source of water in parts of Western Ghats are the occurrence of springs. Therefore, spring discharge measurements are of importance for water resources assessment, especially in fractured rocks. Many of the villages in Maharashtra, Karnataka and Kerala are fully dependent on spring water. However, the sustainability of spring water is not studied in detail. Since, the spring water plays a major role in socio-economic development of the forest dwellers as well as the local communities, a detailed study on the occurrence, classification of springs, extent and distribution and sustainability are highly essential. Therefore, the present study is proposed with the following objectives

Chapter 4

4.0 MATERIALS AND METHODS

4.0 General

Quantification of Mountain block recharge processes in mountainous catchments. Catchment storage dynamics in response to precipitation seasonality will be investigated by means of recession flow analysis. Further storage-discharge relations may be developed to quantify Mountain block recharge rates for those periods in the catchment that change in discharge is only a function of bedrock storage.

Hydrologic Data collection and Analysis

Streamflow and precipitation data will be obtained for the selected headwater catchments in Western Ghats. Streamflow measurements as well as spring discharges will be monitored during both wet and dry periods.

Spring Flow Discharge measurements

Standard methods such as rectangular notch or V-notches will be used for spring discharge measurements both during pre and post monsoon seasons. This is understand the sustainability of the spring water.

Recession Flow Analysis

The recession flow analysis of *Brutsaert and Nieber*[1977] will be primarily applied to humid catchments. This region is characterized by steep hillslopes with fractured bedrock.It is proposed to apply recession flow analyses of *Brutsaert and Nieber*[1977] for the selected catchments in parts of Western ghats.

Estimation of Soil Hydraulic Properties

Hydrological soil parameters such as infiltration, hydraulic conductivity, porosity and permeability will be determined in the field. Soil moisture characteristics and retention characteristics will be studied in the laboratory.

Isotope Studies

Spring water, groundwater and surface water will be collected for isotope analyses to understand the origin of spring water. An attempt will be made to find out the recharge factor using isotopic methods.

Water Quality Investigations

Water samples will be collected from surface water bodies, groundwater and springs and will be checked for its suitability for water supply to the rural mass. Attempts will also be made to compare the changes in water quality with respect to change in land use/land cover changes.

4.2 Materials:

4.2.1 Rain gauge:

The standard instrument for the measurement of rainfall is the 203mm(8inch) rain gauge. This is essentially a circular funnel with a diameter of 203mm which collects the rain into a graduated and calibrated cylinder. The measuring cylinder can record up to 25mm of precipitation. Any excess precipitation is captured in the outer metal cylinder. The top of the rain gauge is 0.3m above the ground.

Figure 3. Rainfall Measurement from Ordinary Raingauge

In modern automatic weather stations, a tipping bucket rain gauge (TBRG) is employed, which also has an aperture of 203mm. There are two advantages of this type of rain gauge. Firstly, it never needs to be emptied, and secondly the amount of rainfall (and even the rate at which the rain is falling) can be read automatically. An electronic pulse is generated each time the volume of water collected in one of the small brass buckets causes the bucket to tip. This is equivalent to 0.2mm of precipitation. a snow gauge is used to measure precipitation at several locations within Australia where snow falls. In one form of snow gauge the snow is melted using electric element. With another type of snow gauge, snow falls in to a tank containing an antifreeze agent, which causes the snow to melt. Measurements However, to a first approximation the relationship,1cm of fresh snow= 1mm of water can be used to estimate long term average precipitation are taken by observing the change in fluid level in the tank.

Since the density of snow can vary significantly, it is difficult to derive precipitation amount from snow depth.

Observation: Daily rainfall is nominally measured each day at 9am local time. However, there are a number of sites which report 48 or 72-hour totals (or occasionally longer) over weekends if the observer is unable to be present. These are known as accumulated observations. At the vast majority of rainfall sites observations are taken by volunteers who check in a monthly record of daily precipitation at the end of each month. A subset of observers at strategic locations send their observation electronically to the bureau each day

Rainfall has tradionally been measured to the nearest 0.2mm (1point, or 1/100th of an inch prior to 1970), although in recent years some observation are being reported to 0.1mm. any moisture less than this is recorded as a trace.

4.3 Water Quality Parameters

4.3.1 PH Meter/Paper:

pH strips allow you to test the acidity of a liquid. The strips measure on a scale of 14, where seven is neutral. Lower numbers are increasingly acidic, while higher numbers are increasingly alkaline (or basic). Water, being a neutral liquid, should register a seven. If a pH strip shows (figure 4) that it is another number, pH strips are fast and easy to use Fill a beaker with the water that you wish to test. Make sure that the beaker is completely clean of foreign contaminants that may affect your test. Dip the strip into the water briefly. The time required depends on the brand of strips that you are using. Compare the colour of the strip to the chart provided with the strips. Acids are represented with warmer colours (red, orange, etc) while alkaline are represented with cooler colours (blue, green, etc).

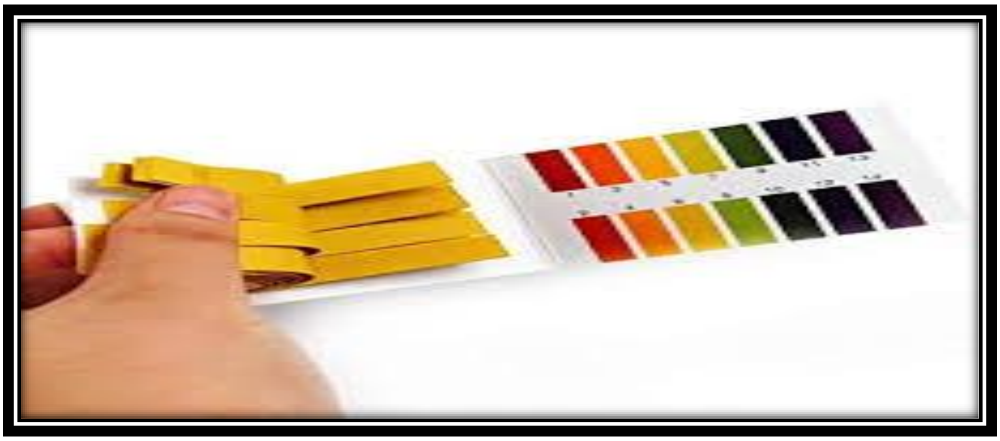

Figure 4. pH paper

4.4 Measuring Jar/Measuring flask and measuring bucket :

A measuring cup/ measuring jar is a kitchen utensil used primarily to measure the volume of liquid or bulk solid. The jar is usually marked have a scale of 1000ml that is 1liter(we have used), measuring jar may be made of plastic, glass or metal. Transparent (or translucent) jars can be read from an external scale; metal ones only from a dipstick or scale marked on the side, as shown in the figure 5.

Figure 5. Measuring jar, Measuring cup and Measuring bucket, Instrument used during Experiment

4.5 Software used for the survey:

4.5.1. ArcGIS:

ArcGIS is a geographic information system to create, manage, share, and analyse spatial data. It consists of server components, mobile and desktop applications, and developer tools.

4.5.2 Google Earth Pro:

Google Earth Pro comes with a number of handy advantages over the free version, including the ability to print ultra-high-resolution images and a feature that allows you to measure and superimpose your own 3D building mock-ups. Find the location and notice the changes in the site over the months and years of the attack using the Historic Imagery function in Google Earth.

4.6 PROCEDURES OF WATER ANALYSIS:

4.6.1 Determination of CHLORIDE:

- Take 50ml sample in clean conical flask.
- Adjust the pH between 7 to 8 either by adding sulfuric acid or sodium hydroxide. Otherwise AgOH will be formed at high pH level (alkaline range) or CrO_4^{-2} is converted $Cr_2O_7^{-2}$ at low pH levels (acidic range).
- Add 01ml potassium chromate (K_2CrO_4) indicator to get yellow colour.
- Titrate with $AgNO_3$(0.014) till colour changes from yellow to brick red
- Note down the volume of titrant added as A ml.
- For better accuracy, titrate chloride free distilled water (blank) in the same manner and note down the volume of the titrant added as B ml.
  - 1000 ml of 1M $AgNO_3$ = 35.46g Cl^-

Chloride concentration in given water sample (mg/L) =

$$\frac{\text{(A- B) x Normality of titrant (AgNO3) x 35.46 (equivalent weight of Cl) x 1000}}{\text{50 ml of water sample taken}}$$

4.6.2 DETERMINATION OF ALKALINITY (By Titrimetric method):

- Take a 50 ml sample in a clean conical flask. Add 1 drop of sodium thiosulfate ($Na_2S_2O_3.5H_2O$) of 0.1 N to remove residual chloride if present.
- Add 2 to 3 drops of phenolphthalein indicator, if sample turns to pink color presume that the pH of water is more is more then 8.2 and it contains phenolphthalein alkalinity, titrate with sulfuric acid (H_2SO_4) of 0.02 N till pink color changes to colorless. Note down the ml of titrant used as V_1 ml.
- If sample does not turn to pink color, (then pH of the sample must be less then 8.2) add 2 to 3 drops of methyl orange indicator, sample turns to orange and note down total titrant used as V_2 ml.
- Run a blank (distilled water) also with the same procedure as above and find out its alkalinity in mg/L.

Calculations:

- **For Distilled water (blank):** Phenolphthalein (P) Alkalinity = Zero
  Total (T) Alkalinity = Burette Reading in ml.

$$\text{Alkalinity as } CaCO_3 \text{ in mg/L for distilled water} = \frac{BR * 0.02 * 1000 * 50}{50 \text{ ml sample taken}}$$

- **For water sample:** Phenolphthalein Alkalinity (P) as $CaCO_3$ in mg/L =

$$\frac{(V_1 \text{ ml}) * \text{Normality of titrant} * 1000 * 50 \text{ (Eq. wt of } CaCO_3)}{50 \text{ ml of sample taken}}$$

- **For water sample:** Total Alkalinity (T) as $CaCO_3$ in mg/L =

$$\frac{(V_2 \text{ ml}) * \text{Normality of titrant} * 1000 * 50 \text{ (Eq. wt of CaCO3)}}{50 \text{ ml of sample taken}}$$

Table 1. Alkaliity Table

VALUE OF P & T	ALKALINITY DUE TO		
	OH^-	**CO_3^-**	**HCO_3^-**
P = 0	0	0	T
P = < $^1/_2$ T	0	2P	T-2P
P = $^1/_2$ T	0	2P	0
P = >$^1/_2$ T	2P-T	2T-2P	0
P = $^1/_2$ T	T	0	0

Find out the Alkalinity due to OH^-, CO_3^-, & HCO_3^- with respect to P & T Values.

For example:If P =< $^1/_2$ T, then from alkalinity table OH^- = 0, CO_3^- = 2P, HCO_3^- = T-2P

Total Alkalinity as $CaCO_3 = (OH^- + CO_3^- + HCO_3^-)$- Blank.

= (0+2P+[T-2P]); = …….. mg/L

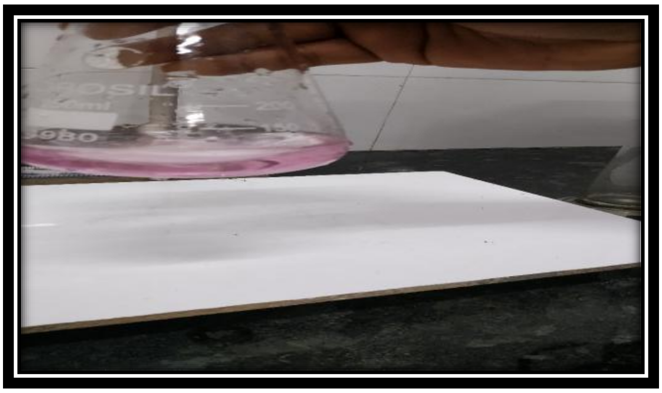

Figure 6. Determination of alkalinity (By Titrimetric method)

4.6.3 DETERMINATION OF ACIDITY (By Titrimetric method):

- Take 50 ml of water sample in a clean conical flask. Add 01 drop of Sodium thiosulfate of 0.1 N to remove residual chlorine if any.
- Add 02 drops of methyl orange indicator, if samples turn to pink colour, titrate against NaOH (0.02 N) till colour changes from pink to yellow. Note down the volume of titrant added as V_1 ml.
- Take a 50 ml of fresh sample in clean conical flask and add 02 drops of phenolphthalein indicator to get temporary pink colour and titrate till the temporary pink turns to permanent pink. Note down the volume of titrant added as V_2 ml.
- Similarly do the above steps for distilled water (blank).

Calculations:

- **For Distilled water: Mineral acidity (V) =0 ml.** Therefore Mineral acidity = NIL

  Total acidity as $CaCO_3$ in mg/L for distilled water (Blank) $= \frac{BR * 1000}{50 \text{ ml of sample}}$

  CO_2 acidity as $CaCO_3$ = ……. mg/L
- **For water sample:**

  Mineral acidity as $CaCO_3$ in mg/L $= \frac{V_1(\text{average}) * 1000}{50 \text{ ml of sample}}$

  = ……. mg/L

  CO_2 acidity as $CaCO_3$ in mg/L $= \frac{V_2(\text{average}) * 1000}{50 \text{ ml of sample}}$

  = ……. mg/L

Total Acidity as $CaCO_3$(mg/L) = [Mineral acidity+CO_2 acidity]-acidity of blank

4.6.4 DETERMINATION OF TOTAL HARDNESS (By EDTA titrimetric method):

- Take 50ml of water sample in clean conical flask.
- Add 02 drops of buffer solution to maintain pH.
- Add 2 to 3 drops of Erichrome Black T indicator to get wine red colour.

- Titrate against EDTA solution (titrant) of 0.01 M till colour changes from wine red to blue.
- Note down the volume of titrant added as A ml.

- Similarly run a blank (distilled water) and note down the volume of titrant added as B ml.

➢ **Total hardness as $CaCO_3$(mg/L)=** $\frac{\mathbf{(A-B)*100}}{\mathbf{50\ ml\ of\ sample\ taken}}$

Figure 7. Determination of total hardness (by EDTA titrimetric method)

4.6.5 DETERMINATION OF CALCIUM HARDNESS:

- Take 50 ml of sample in a clean conical flask.
- Add 2 to 3 drops of NaOH to raise pH≥12 and add a pinch of murexide (ammonium purpurate) indicator to get pink colour.
- Titrate with EDTA (0.01M) titrant till colour changes from pink to purple.
- Note down the volume of titrant added as A_1 ml.
- Run a blank (distilled water) as per above procedure and note down the volume of titrant added as B_1 ml.

➢ **Calcium hardness as $CaCO_3$(mg/L) =** $\frac{\mathbf{(A_1 - B_1)*100}}{\mathbf{50\ ml\ of\ sample\ taken}}$

4.6.6 DETERMINATION OF MAGNESIUM HARNESS:

Magnesium hardness as $CaCO_3$(mg/L) = Total hardness – Calcium hardness

4.6.7 JAR TEST FOR OPTIMUM DOSAGE OF COAGULANT:

- Take 500 ml of sample in 06 cleaned Borosil beakers. The ph of the samples shoud be adjusted to above 11(i.e. highly alkaline).
- Add the known dosage of alum at a time to all the six beakers i.e. 2.5 ml, 5 ml, 7.5 ml,10 ml, 12.5 ml, and 15 ml.
- Switch on the motor and adjust the speed initially to 100 rpm for 01 minute and later at 40 rpm for 15 to 30 minutes depending upon the turbidity of the water samples.
- Switch off the motor and allow the floc formation and their settlement.
- Collect the supernatant liquor without disturbing the sediment and measure the turbidity of all the samples from the beakers, using Nephelometer.
- The least residual turbidity will be the optimum dose.
- Repeat the same for varying dosage with varying pH values.
  - **Concentration in first jar =** $\frac{\mathbf{2.5\ ml * 01 * 1000}}{\mathbf{500}}$

a) DETERMINATION OF TURBIDITY by NEPHELOMETER:

- Calibrate the instrument by using distilled water for zero NTU and 100 NTU standard solution.
- Take the water sample in a glass cuvette and keep the cuvette in the nephelometer and deserve the constant display of the reading on the screen. Lesser value of NTU for less turbid waters and higher value of NTU for more turbid waters will be displayed on the digital screen of the instrument.
- If the readout goes beyond 100 NTU or if ‘1’ is observed on the display, dilute the sample with distilled water for suitable proportion and then note down the value of turbidity in NTU(Nephelometric Turbidity unit).

4.6.8 DETERMINATION OF pH, ELECTRICAL CONDUCTIVITY and TDS (by pH metry):

- Give the identification numbers for the water samples whose pH is to be determined.
- Check the electrical connections and attach the electrodes to the instrument and rinse them in distilled water thoroughly.
- Perform the calibration of the pH instrument with buffer capsules of 4, 7, and 9.2 pH, if “Calibration Due” message is observed on the display screen, otherwise continue with next step.

- Take sufficient quantity of water sample in clean glass beaker and place it below the electrode and start the magnetic stirrer. Adjust the speed of magnetic stirrer to medium speed. Rinse the electrode with distilled water between one sample to another to avoid interference and wipe it with a tissue paper.
- Note down the pH of water sample.

4.6.9 For Electrical Conductivity/TDS(Total Dissolved Solids):

- Use Conductivity/TDS meter after calibration (for 100 value at 25^0 C) for determination of TDS and SC of given water sample.

Application of Remote Sensing technique & Socio-economic Assessment

Satellite data will be procured for different periods to understand the variation of land use/Land cover changes over the last 2-3 decades. Using the satellite data attempt will be made to identify the spring water locations and its increase/decrease over the years.

DESCRIPTION OF SWAT MODEL:

SWAT is a physically based, semi distributed river basin or watershed scale model developed by Arnold et al (1998) in order to predict impacts of land management practices on water, sediments, and agricultural chemicals yields in large complex watersheds with varying soil, land use and management conditions over long period of time. SWAT operates on a daily time step and is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is process based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, topographical, and soil characteristics. The HRUs are represented as a percentage of the sub-watershed area and may not be contiguous or spatially identified within a SWAT simulation. Alternatively, a watershed can be subdivided into only sub-watersheds that are characterized by dominant land use, soil type, and management.

Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens. Simulation of watershed hydrology is separated into the land phase, which controls the amount of water, sediment, nutrient, and pesticide loadings to the main channel in each sub-basin, and the in-stream or routing phase, which is the movement of water, sediments, etc., through the channel network of the watershed to the outlet. The hydrologic cycle is climate driven and provides moisture and energy inputs, such as daily precipitation, maximum/minimum air temperature, solar radiation, wind speed, and relative humidity, that control the water balance. SWAT can read these observed data directly from files or generate simulated data at runtime from observed monthly statistics. Snow is computed when temperatures are below freezing, and soil temperature is computed because it impacts water movement and the decay rate of residue in the soil. Hydrologic processes simulated by SWAT include canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow, tile drainage, redistribution of water within the soil profile, consumptive use through pumping (if any), return flow, and recharge by seepage from surface water bodies, ponds, and tributary channels. SWAT uses a single plant growth model to simulate all types of land cover and differentiates between annual and perennial plants. The plant growth model is used to assess removal of water and nutrients from the root zone, transpiration, and biomass/yield production. SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) to predict sediment yield from the landscape. In addition, SWAT models the movement and transformation of several forms of nitrogen and phosphorus, pesticides, and sediment in the watershed. SWAT allows the user to define management practices taking place in every HRU.

Water balance equation

$$\mathbf{SW_t = SW + \sum_{t=1}^{t}(Ri - Qi - ETi - Pi - QRi)}$$

Where, SW is the soil water content minus the 15-bar water content, t is time in days, and R, Q, ET, P, and QR are the daily amounts of precipitation, runoff, evapotranspiration, percolation, and return flow; all units are in mm.

Ground water flow contribution to total streamflow is simulated by creating a shallow aquifer storage. The water balance for the shallow aquifer is

$$\mathbf{Vsa_i = Vsa_{i-1} + Rc - revap - rf - perc_{gw} - WU_{SA}}$$

where Vsa is the shallow aquifer storage (mm), Re is recharge (percolate from the bottom of the soil profile) (mm), revap is root uptake from the shallow aquifer (mm), rf is the return flow (mm), $perc_{gw}$ is the percolate to the deep aquifer (mm), WU_{SA} is the water use (withdrawal) from the shallow aquifer (mm), and i is the day.

CONVENTIONAL METHODS

Formulae for estimation of catchment runoff from rainfall are below.

Inglis formula for ghat area

$$R = 0.85P - 30.5$$

Inglis formula for non-ghat areas

$$R = \frac{(P - 17.8)}{254} * P$$

Lacey's formula

$$R = \frac{P}{1 + 304.8f/PS}$$

Khosla's formula

$$R = P - \frac{T - 32}{3.74}$$

Where R=runoff in cm

P=rainfall in cm

F=monsoon duration factor:

S= a value dependent on catchment class characteristic :

0.25---flat, cultivated B.C. soil(A)

0.60---flat, partly cultivated soils(B)

1.00---average(C)

1.70---hills and plains, little cultivation (D)

3.45---very hilly and steep with hardly any cultivation (E)

T= mean temperature in ^{0}F on the entire catchment.

SCS Curve Number method:

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS — the number is still popularly known as a "SCS runoff curve number" in the literature. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hillslope plots monitored by the USDA. It is widely used and efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area .

The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition. References, such as from USDA indicate the runoff curve numbers for characteristic land cover descriptions and a hydrologic soil group.

The basic assumption of the SCS curve number method is that, for a single storm, the ratio of actual soil retention after runoff begins to potential maximum retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions, results in the following equation found in Section 4 of the National Engineering Handbook (NEH-4) (USDA-SCS, 1985), where curve number (CN) represents a convenient representation of the potential maximum soil retention, S (Ponce and Hawkins, 1996).

$$\boldsymbol{Q = \frac{(P-0.2S)^2}{P+0.8S}} \textbf{ for } \mathbf{P>0.2S}$$

Q is runoff, P is rainfall , S is the potential maximum soil moisture retention after runoff begins ([L]; in) Ia is the initial abstraction ([L]; in), or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and $I_a = 0.2S$

For Indian condition applicable equations are below

$$\boldsymbol{Q = \frac{(P-0.1S)^2}{P+0.9S}} \textbf{ for } \mathbf{P>0.1S}$$

$$\boldsymbol{Q = \frac{(P-0.3S)^2}{P+0.7S}} \textbf{ for } \mathbf{P>0.3S}$$

The runoff curve number, CN, is then related

$$S = \frac{1000}{CN} - 10$$

CN has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential values are tabulated in Chapter 9 of NEH-4 for various land covers and soil textures. These values were developed from annual flood rainfall-runoff data from the literature for a variety of watersheds generally less than one square mile in area (USDA-SCS, 1985).

4.7. Groundwater Recharge estimation methods

4.7.1 Chaturvedi Formula

Based on the water level fluctuation and rainfall amounts in GangaYamunadoab,Chaturvedi derived an empirical relationship to arrive at the recharge as a functionof annual precipitation (when rainfall exceeds 40cms).

$$\boldsymbol{R = 2.0\ (P - 15)0.4}$$

where,
R = net recharge due to precipitation during the year, in inches
P = annual precipitation, in inches
This formula was later modified by further work at the UP Irrigation Research Institute ,Roorkee, and the modified form of the formula is,

$$\boldsymbol{R = 1.35\ (P - 14)0.5}$$

The Chaturvedi formula has been widely used for preliminary estimation of ground water recharge due to rainfall. It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage ofrainfall recharged commenced from zero at P = 14 inches, increases upto 18% at P = 28inches, and again decreases. The lower limit of rainfall in the formula may account for thesoil moisture deficit, interception losses and potential evaporation. These factors beingsite specific, one generalised formula may not be applicable to all the alluvial areas.

Krishna Rao's method

Krishna Rao gave the following empirical relationship to determine the ground water recharge in limited climatological homogenous areas.

$$\boldsymbol{R} = \boldsymbol{K}\,(\boldsymbol{P} - \boldsymbol{X})$$

The following relation is stated to hold good for different parts of Karnataka;

$R = 0.20\,(P - 400)$for areas with P between 400 and 600mm

$R = 0.25\,(P - 400)$for areas with P between 600 and 1000mm

$R = 0.35\,(P - 600)$ for areas with P above 2000mm

where, R & P are expressed in millimetres.

4.8 Results And Discussion

Application of SWAT Model

The SWAT model was set up for the Ghataprabha sub basin, following the step by step procedure outlined in the SWAT user guide (Luzio et al., 2002). The basin was divided into 3 major sub-basins and each sub-basin sub divided into smaller sub-basin based on the DEM and stream network of the study area. The minimum and maximum sizes of the sub-basins were 13.09km^{2}and 1229.28km^2, respectively. The sub-basin delineation was followed by automatic parameterization of streams and subdivision of the sub-basins into Hydrologic Response Units (HRUs) based on soil and landuse data and a predefined threshold of 05% soil and 05 % landuse. The maximum HRU size was446.27 km^2 and the minimum was 0.17 km^2. The model was simulated for the period: 1990-2005.

The sensitivity of SWAT-simulated discharge to model input parameters was analyzed using the automatic sensitivity analysis technique. The purpose of the sensitivity analysis was to determine the most sensitive model parameters that needed to be given high priority during model calibration. Two cases of sensitivity analysis were done. The abstraction coefficient, soil evaporative compensation factor (ESCO), and the threshold water depth in the shallow aquifer for revap (GWQMN) were the three most sensitive model parameters for the Ghataprabha sub-basin.

In SWAT, the first level of sub-division is the sub-basin. The number of sub-basins obtained in a watershed is determined by the minimum threshold input value for defining a drainage area. The number of sub-basins modeled in SWAT influences the number of climate stations (more importantly, the number of rainfall stations) that are utilized in the modeling of the output. Since rainfall is the major input to the hydrological system, the modeled output can be affected. Generally, the higher the number of sub-basins modeled in a watershed, the higher the number of rainfall stations utilized by the model. Consequently, the model output is more accurate. The HRU is the lowest sub-division in SWAT, and the number of them modeled is determined by the land use and soil threshold defined by the user. Increasing the number of HRUs in a watershed with diverse plant cover increases the accuracy in the prediction of loadings from sub-basins, which in turn results in a more accurate output (Neitsche et al., 2005). Prior to the calibration of the Ghataprabha sub-basin SWAT, the effects of the number of rainfall stations and land use on the model output were assessed through different scenarios which were developed from 3 sub-basin thresholds and 3 land use/soil thresholds within each of the sub-basin thresholds. The results show that increasing the number of major sub-basins (from 1 to 3) basically, to define the runoff coefficient with regard to the larger catchment. As there was a larger variation with regard to the estimated runoff and observed flow in Daddi, the present exercise provided more and more accuracy in runoff prediction due to the number of HRU's characterized by different land use and soil characteristics.

4.9 Model Output:

Ghataprabha Sub basin

The SWAT model was run for 16 years data (1990-2005) drawn from SWAT India data base. Initially, the model was run on monthly basis. The average monthly rainfall varied between 0.01 mm during January month to a maximum of 411.2 mm in the month of July. Further, it is noticed that there is a considerable quantity of baseflow in the stream from November to February. ET shows variation between 7 mm to 66.7 mm. In the small basin Average rainfall ranges from 0.01 mm to 411.20 mm. Runoff ranges from 0.09 mm to 241.51 mm. In the medium sub-basin, it showed slightly reduced runoff as compared to the smaller sub-basin. This is quite expected as the rainfall is quite higher than the medium and larger basin. However, monthly average of runoff, baseflow, ET etc were quite comparable. Table 5.1 shows the output (annual average) of SWAT model.

Table 2. Comparison of SWAT output of Ghataprabha sub-basin with varying catchment areas

BASIN VALUES	Large basin (CA = >8000 sq km)	Medium basin (CA = > 2500 sq km)	Small basin (CA = > 1000 sq km)
Precipitation (mm)	930.5	964.7	1343.5
Surface runoff (mm)	296.95 (31.93%)	306.88 (31.81%)	641.84 (47.7%)
Lateral soil flow (mm)	0.97 (0.001%)	2.14 (0.022%)	3.68 (0.027%)
GW(shallow AQ) (mm)	111.70 (12.11%)	115.59 (11.99%)	220.88 (16.44%)

Revap(shallow AQ soil/plants)(mm)	7.14 (0.07%)	8.07 (0.083%)	10.86 (0.08%)
Deep AQ recharge (mm)	6.26 (0.06%)	6.51 (0.067%)	12.20 (0.09%)
Total AQ recharge (mm)	125.11 13.56	130.17 13.05	244.00 18.16
Total water yield (mm)	402.81 (43.28%)	416.59 (43.1%)	858.94 (63.95%)
ET (mm)	519.2 (55.79%)	533.6 (55.35%)	461.3 (34.33%)
PET (mm)	1829.9	1919.8	1920.2
Area of basin (Sq.km)	8615.23	2626.78	1005.18

Figure 8 shows the variation of runoff in 3 sub-basins varying in size. It is observed that the highest runoff (47.7%) is in the smaller basin which is having highest rainfall. However, in the medium and larger catchments, runoff is found to be almost identical.

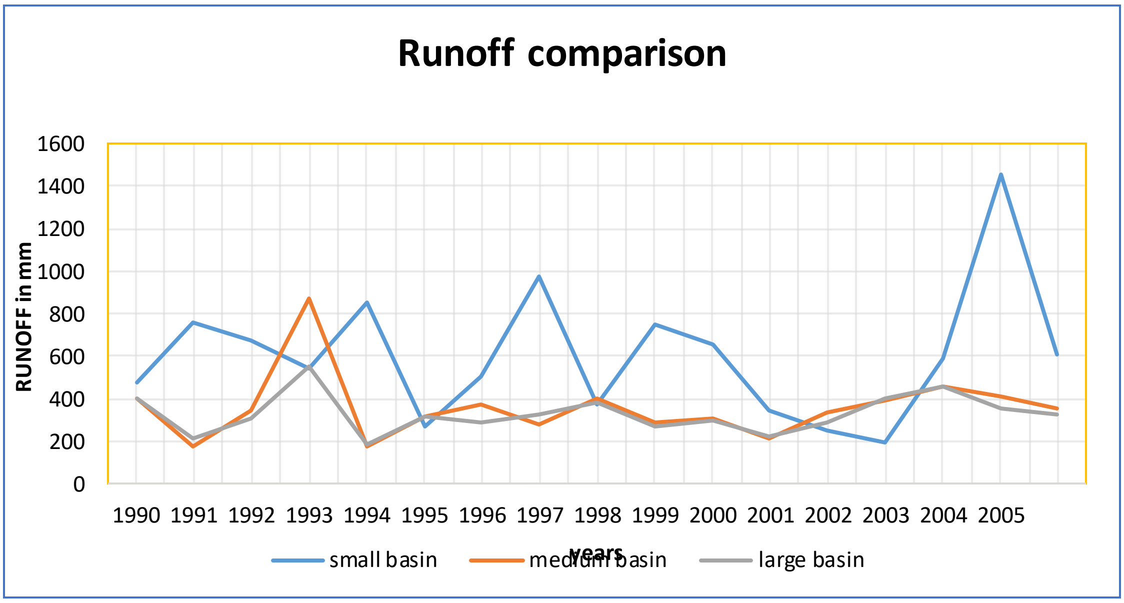

Figure 8. Comparison of estimated runoff in three sub-basins

Table 2 shows the annual variation of runoff in three catchments. It is noticed that both rainfall and runoff significantly high during 1997 and 2005. Maximum rainfall of 2348 mm and the estimated runoff was 1456 mm during 2005. However, in the medium and larger basin there was no significant increase in the rainfall or runoff. This clearly indicates the role of catchment area and characteristics on runoff.

Table 3. Annual Variation of Runoff in three Catchments.

Year	Rainfall (mm)	Small basin Runoff (mm)	Rainfall (mm)	Medium basin Runoff (mm)	Rainfall (mm)	Large basin runoff (mm)
1990	1129.15	473.38	1138.52	399.73	1116.54	402.93
1991	1499.19	759.49	648.28	177.17	722.05	211.88
1992	1303.54	671.02	1129.45	345.72	1052.02	312.02
1993	1174.73	544.22	1563.25	868.65	1224.74	549.76
1994	1585.45	856.4	713.28	179.79	712	185.34
1995	697.38	272.93	942.29	317.9	925.96	315.98
1996	1123.74	509.64	972.26	373.67	851.69	288.84
1997	1725.81	976.31	946.51	281.89	998.49	322.16
1998	1007.12	377.72	1089.68	397.84	1029.92	384.49
1999	1381.47	750.75	922.14	290.07	874.58	269.41
2000	1327.22	651.95	1031.81	308.92	984.03	299.77
2001	937.76	346.11	876.12	215.34	887.11	224.5
2002	729	247.9	1020.85	335.66	908.78	288.63
2003	628.37	195.87	1092.54	389.66	1088.24	399.8
2004	1331.3	589.27	1204.52	455.37	1214.19	461.48
2005	2347.91	1455.56	1129.42	409.98	1024.82	354.81
Average	1245.57	604.90	1026.30	359.21	975.94	329.48
Percentage		48.56		35		33.76

Runoff Estimation using SCS CN method:

The runoff was estimated using curve number method. Data pertaining to soil type, texture, organic matter, infiltration rates and hydraulic conductivity were collected from NIH, Belagavi. Curve numbers were fixed accordingly. Rainfall data was collected from the SWAT India data base. 102 events have been selected from 16 years data (1990-2005). The estimated runoff for each event is shown in Table 4.

Table 4. Estimated Runoff using SCS method (small basin)

Events	Rainfall in mm	SCS Runoff in mm	Events	Rainfall in mm	SCS Runoff in mm	Events	Rainfall in mm	SCS Runoff in mm
1	35.57	0.298	36	35.1	0.2668	71	303.95	102.84
2	65.67	0.574	37	320.45	114.65	72	190.05	123.211
3	210.09	155.622	38	134.02	9.27	73	95.96	22.26
4	375.55	316.97	39	98.53	39.33	74	31.06	0.076
5	303.57	233.478	40	146.28	13.41	75	34.56	0.3
6	71.74	9.66	41	343.01	131.28	76	228.68	53.66
7	21.65	0.091	42	369.2	151.19	77	296.96	98.01
8	65.27	0.539	43	179.83	27.507	78	208.04	106.14
9	57.35	0.068	44	205.65	40.63	79	113.56	3.86
10	31.94	0.087	45	158.5	106.71	80	68.91	28.14
11	77.47	2.06	46	127.62	7.37	81	231.6	55.401
12	397.9	326.48	47	44.2	1.09	82	92.6	20.31
13	599.08	362.416	48	385.93	164.216	83	330.43	121.95
14	298.6	241.46	49	507.32	447.33	84	114.23	4
15	107.27	2.61	50	631.8	570.46	85	49.04	3.96
16	315.82	111.3	51	22.82	0.052	86	227.29	52.85
17	425.67	195.95	52	106.8	2.53	87	175.06	78.87
18	346.78	288.706	53	43.07	0.97	88	105.83	58.82
19	61.7	5.61	54	37.44	0.43	89	41.68	0.81
20	150.34	14.91	55	70.43	1.07	90	91.99	0.556
21	26.84	0.003	56	238.46	58.32	91	67.76	0.77
22	35.73	0.309	57	341.66	283.67	92	364.66	274.25
23	264.55	76.013	58	172.34	76.69	93	290.42	178.72
24	437.78	205.83	59	152.93	15.899	94	419.06	359.95
25	278.24	221.58	60	129.41	79.88	95	152.85	15.86
26	58.24	0.099	61	26.82	3.38	96	58.76	0.12
27	259.44	72.77	62	86.6	0.222	97	43.88	1.06
28	44.28	1.114	63	390.03	167.24	98	418.62	190.249
29	87.41	0.22	64	658.41	529.6	99	940.13	878.12
30	471.19	233.5	65	153.75	102.29	100	450.51	391.05
31	615.24	554.49	66	89.55	0.369	101	475.55	352.45

32	253.64	184.63	67	270.29	79.78	102	173.39	77.53
33	143.24	92.56	68	86.41	0.1724			
34	201.42	58.05	69	244.37	63.16			
35	82.22	0.02	70	494.64	253.26			

From the above analysis, it is evident that the runoff is significantly high during the monsoonal rainfall as compared to the rainfalls occurred during pre-monsoon and post-monsoon periods. The relationship between rainfall events and the runoff is shown in figure 9.

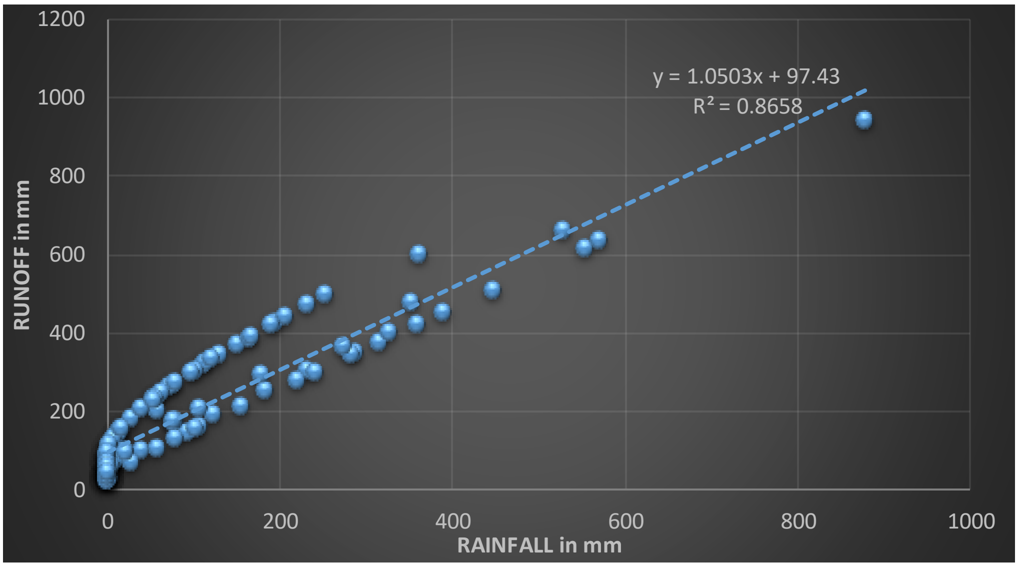

Figure 9. Graph showing Rainfall-Runoff relation of event based (SCS Method)

Runoff Estimation using Conventional Methods

Table 5 shows the runoff estimated by empirical methods such as Inglis, Lacey and Khosla methods for the Ghataprabha sub-basin up to Daddi (small basin). The results obtained by these methods are compared with the SWAT output. The runoff value estimated by SWAT model varies between 31% and 62% with an average of 45.91%. According to Inglis formula, the surface runoff vary from 36% to 67% with an average runoff of 57.57% . Lacey's methods showed variation between 26% and 57% and average is 39.92%. However, the runoff estimated by Khosla's method deviated far off from the predicted runoff using SWAT. Both Inglis and Lacey's method predicted relatively closer values as compared to Khosla's method.

Table 5. Estimated Runoff by SWAT model and Conventional methods

year	Rainfall in mm	Swat Runoff in mm	% Runoff	Inglis Runoff in mm	% Runoff	Lacey's Runoff in mm	% Runoff	Khosla's Runoff in mm	% Runoff
1990	1129.15	473.38	41.92	654.77	57.98	436.32	38.64	1013.90	89.79
1991	1499.19	759.49	50.66	969.31	64.65	682.70	45.53	1383.94	92.31
1992	1303.54	671.02	51.47	803.00	61.60	548.75	42.09	1188.29	91.15
1993	1174.73	544.22	46.32	693.52	59.03	465.00	39.58	1059.48	90.19
1994	1585.45	856.4	54.01	1042.63	65.76	744.03	46.92	1470.20	92.73
1995	697.38	272.93	39.13	287.77	41.26	195.29	28.00	582.13	83.47
1996	1123.74	509.64	45.35	650.17	57.85	432.95	38.52	1008.49	89.74
1997	1725.81	976.31	56.57	1161.93	67.32	846.44	49.04	1610.56	93.32
1998	1007.12	377.72	37.50	551.05	54.71	362.23	35.96	891.87	88.55
1999	1381.47	750.75	54.34	869.24	62.92	601.20	43.51	1266.22	91.65
2000	1327.22	651.95	49.12	823.13	62.01	564.55	42.53	1211.97	91.31
2001	937.76	346.11	36.90	492.09	52.47	322.03	34.34	822.51	87.71
2002	729	247.9	34.00	314.65	43.16	210.72	28.90	613.75	84.19
2003	628.37	195.87	31.17	229.11	36.46	163.07	25.95	513.12	81.66
2004	1331.3	589.27	44.26	826.60	62.09	567.29	42.61	1216.05	91.34
2005	2347.91	1455.56	61.99	1690.72	72.00	1331.29	56.70	2232.66	95.09
Avg	1245.57	604.90	45.91	753.73	57.57	529.61	39.92	1130.32	89.63

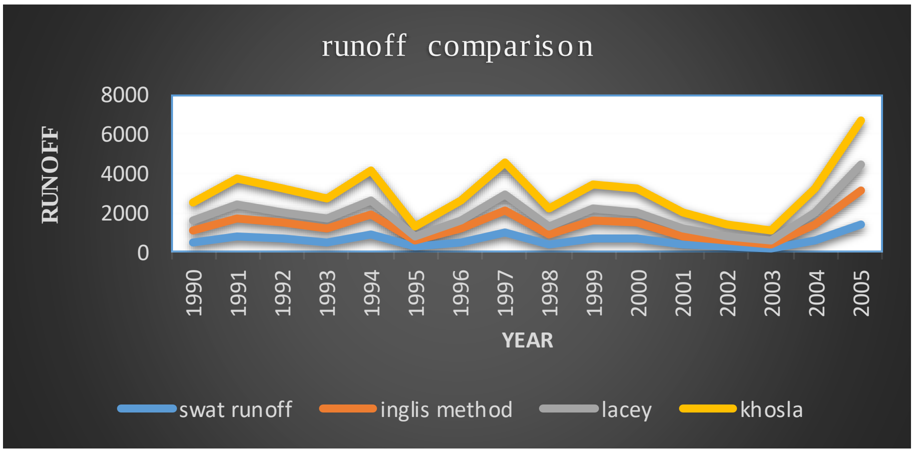

Figure 10. Comparison of Runoff estimated by different methods

Figures 7, 8, 9 and 10 show the relationship between rainfall and runoff estimated by SWAT model, Inglis method, Lacey formula and Khosla's method respectively.

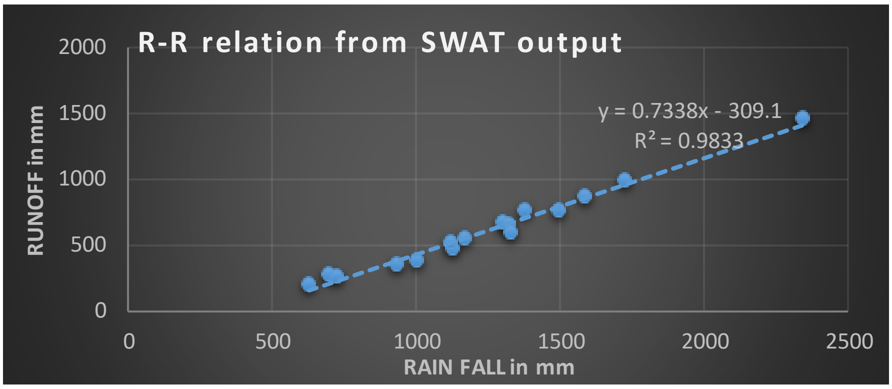

Figure 11. Rainfall – Runoff Relation from SWAT output

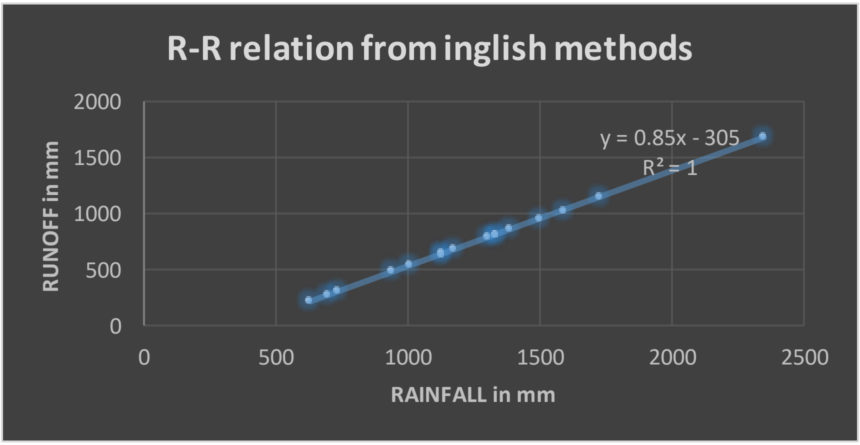

Figure 12. Rainfall Runoff Relation (Inglis method)

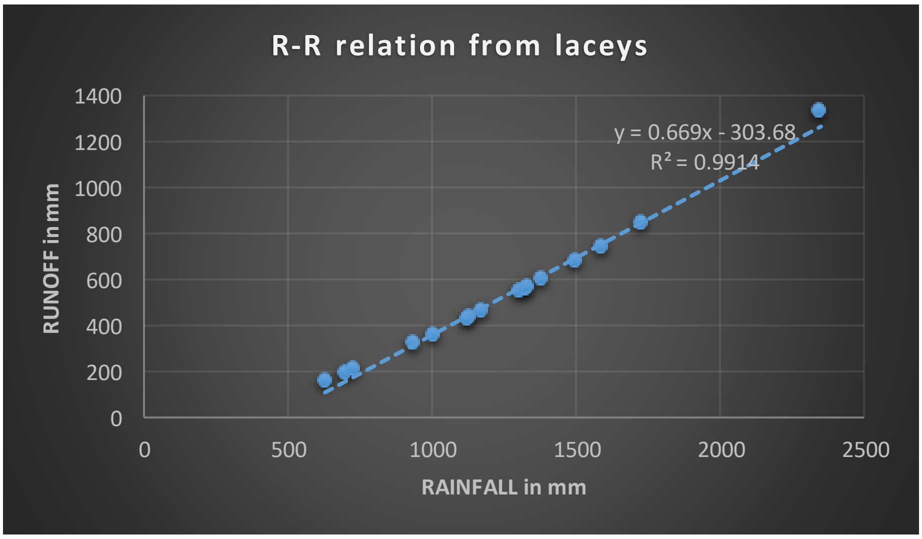

Figure 13. Rainfall Runoff Relation (Lacey's method)

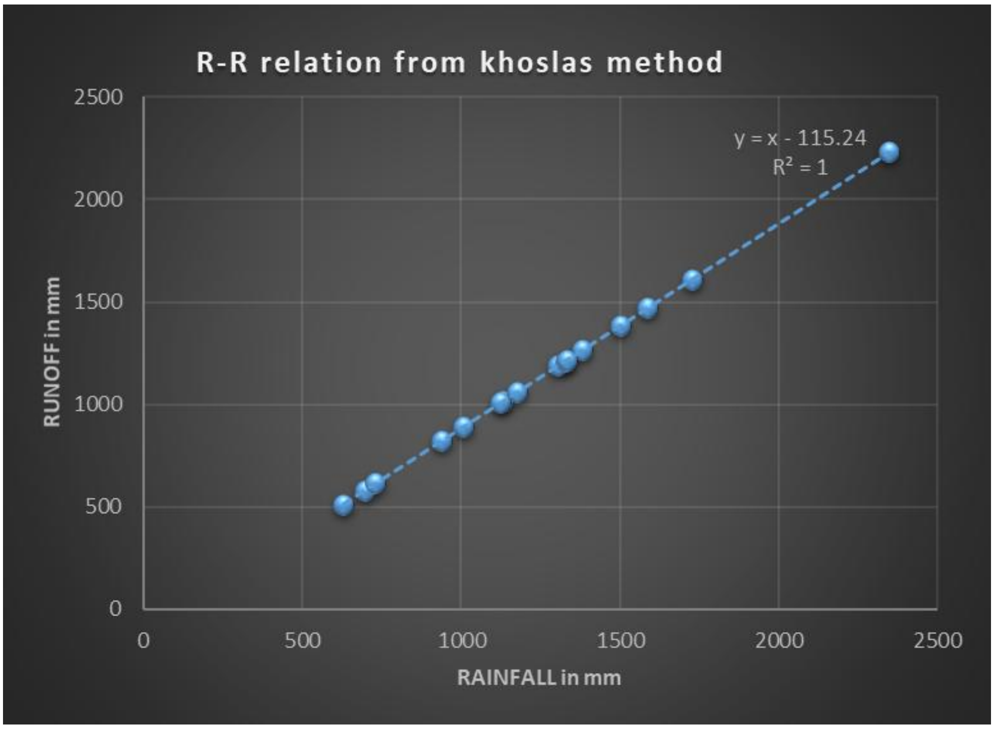

Figure 14. Rainfall Runoff Relation (Khosla's method)

Groundwater Recharge Estimation using ArcSWAT and Conventional methods

Table 6 illustrates the mean of annual rainfall, runoff, evapotranspiration and recharge during 1990 to 2005. Groundwater recharge and surface runoff increases and decreases with precipitation and they show the same trends throughout the years. However, evapotranspiration shows a constant trend throughout the years. This is not unexpected since ET is a function of solar radiation, wind speed and daily dew point (Linsley et al. 1982).

Table 6 Estimated Ground water recharge using SWAT model and Conventional methods

Year	Rainfall in mm	GW R in mm	% Recharge	Chaturvedi (mm)	% Recharge	Krishna Rao (mm)	% Recharge
1990	1129.1	218.7	19.37	205.2	18.17	204.14	18.07
1991	1499.1	274.1	18.28	236.4	15.76	292.92	19.53
1992	1303.5	227.9	17.48	224.7	17.24	257.422	19.74
1993	1174.7	217.9	18.55	225.8	19.22	258.57	22.01
1994	1585.4	305.7	19.28	252.7	15.94	346.71	21.86
1995	697.38	94.56	13.55	162	23.22	110.915	15.90
1996	1123.7	225.0	20.02	223.2	19.86	252.46	22.46
1997	1725.8	283.7	16.43	256.0	14.83	358.15	20.75
1998	1007.1	195.3	19.39	197.1	19.57	184.132	18.28

1999	1381.4	271.5	19.65	242.8	17.57	312.94	22.65
2000	1327.2	230.1	17.34	224.4	16.90	255.795	19.27
2001	937.76	178.9	19.07	182.8	19.50	151.66	16.17
2002	729	130.2	17.86	162.0	22.22	110.83	15.20
2003	628.37	84.79	13.49	143	22.75	79.87	12.71
2004	1331.3	289.5	21.75	221.4	16.63	247.56	18.59
2005	2347.9	451.5	19.23	299.2	12.74	672.455	28.64
Avg	1245.57	230	18.17	216.19	18.26	256.03	19.49

From the analysis, it is observed that the groundwater recharge varies from 13% to 22% with an average of 18%. Interestingly, both Chathurvedi formula and Krishna Rao methods also shows similar recharge values. This clearly demonstrates the applicability of ArcSWAT model in predicting groundwater recharge.

The second goal in this study was to assess the correlation between the groundwater recharge and precipitation. Figures 15,16, 17 show the relationship between rainfall and groundwater recharge.

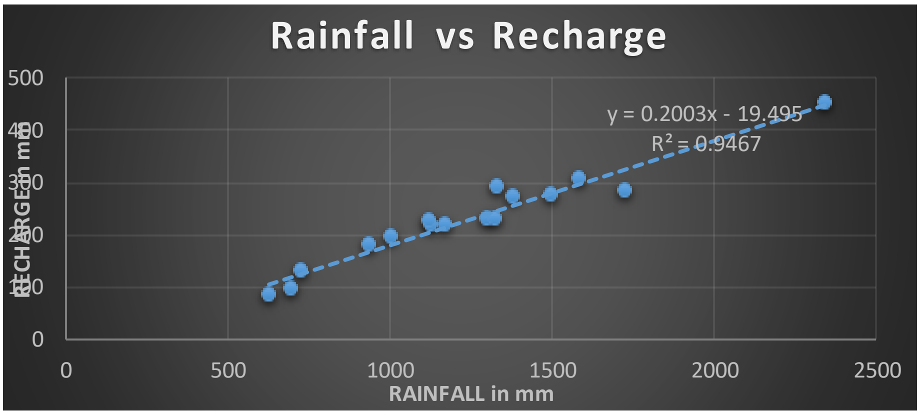

Figure 15. Rainfall-Recharge Relation (SWAT output)

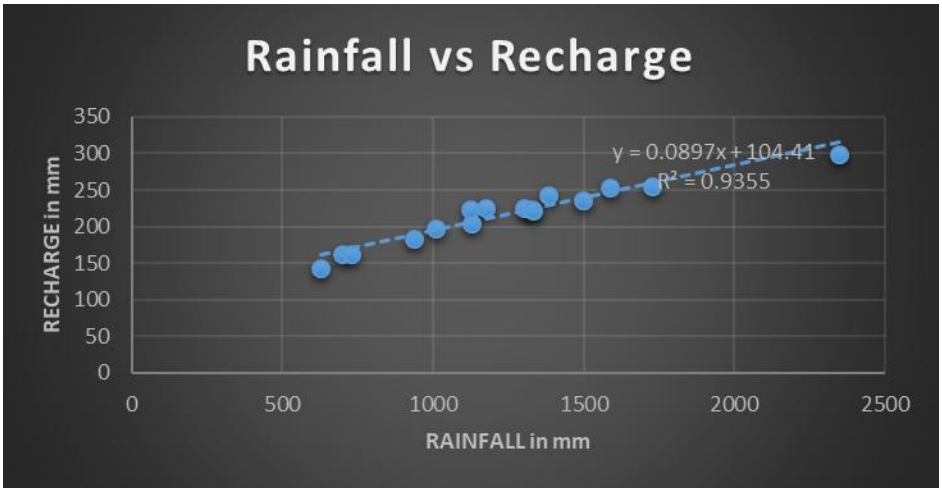

Figure 16 Relationship between Rainfall and Recharge using Chaturvedi method

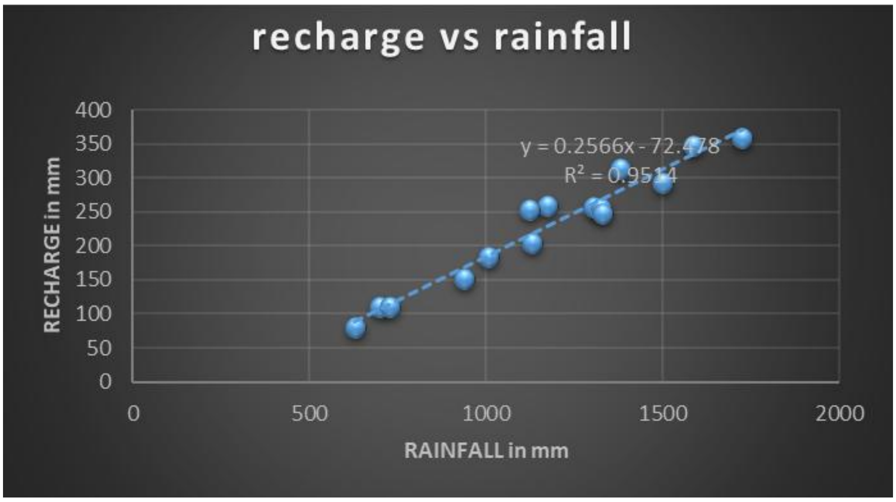

Figure 17. Rainfall Recharge Relation. (Krishna Rao's method)

In all the above methods, the regression coefficient R^2 values vary between 0.93 and 0.95. This substantiates that the well developed regression equations are also quite efficient in estimating the groundwater recharge.
The following are the important sites were springs are distributed and used for water supply. S

1. Kormalwdi 2. Devalkadilwadi 3. Masure 4. Nerur K Nerur 5. Devasu 6. Sawarwad 7. Kalmbist 8. Shirshinge.

Investigations were carried out in the above areas to identify, demarcate and to understand the socio-economic importance of the springs. It was noticed that the above villages are fully fed by springs for both drinking and agriculture purposes. In each village the population is about 500-800.

Table 7. Values of the Concentrations (mg/l) obtained by analysis

Samples	pH	Conductivity (µS/cm)	TDS (mg/l)
Bore well 1	7.69	800	560
Bore well 2	7.33	800	480
Bore well 3	7.47	120	78
Bore well 4	7.35	190	133
Spring water 1	9.31	78	49
Spring water 2	8.94	40	22

Spring water 3	9.23	39	24
Spring water 4	8.74	48	32
Spring water 5	8.30	41	28
Spring water 6	8.33	38	26

Table 8: Chloride-Alkalinity and Hardness of Spring water in parts of Ghataprabha Sub-basin

Samples	**Chlorides (mg/L)**	**Alkalinity (mg/L)**	**Acidity (mg/L)**	**Hardness (mg/L)**
Bore well 1	11.91	180	0	76
Bore well 2	37.72	308	16	32
Bore well 3	13.92	200	24	124
Bore well 4	13.9	332	12	96
Spring water 1	9.92	40	2	40
Spring water 2	9.92	20	2	0
Spring water 3	0	30	2	90
Spring water 4	0	20	12	0
Spring water 5	9.92	30	2	40
Spring water 6	9.92	30	12	30

4.9 Conclusions

Detailed investigations on springs of Western Ghats in parts of Maharashtra (Koyna region) have been carried out by Naik et al (2002). They classified the springs of the Western Ghats as contact springs (89%) and fracture springs (11%). However, because the emergence of groundwater in the form of springs is largely controlled by lithology and the resulting water-bearing properties of the formations, a new classification scheme is proposed that classifies the springs on the basis of their source aquifers and nature of emergence. Thus, contact springs may be further classified into four different categories – ‘laterite springs’,‘talus springs’, ‘vesicular basalt springs’ (or ‘vb springs’), and ‘massive basalt springs’ (or ‘mb springs’).This new classification could also be applied to similar basaltic terrains elsewhere in the world.

The chemical concentrations of the spring waters are heavily dependent on the lithological compositions of the source-aquifers and the residence time of groundwater in these aquifers. The waters are dominated by alkaline earths (Ca2+, Mg2+) and weak acids (HCO3–, CO32–

),and are mostly calcium type (84%) and calcium–magnesium type (10%). Chemical qualities of the spring waters are well within the ISI (1983) and WHO (1998) drinking water standards, except for that of iron (ISI) in about 40% of the samples.

Authors strongly emphasized that the springs of the Western Ghats be tapped effectively for the benefit of humankind. However, it mustbe remembered that they also sustain the life of thousands of plants, animals and other organisms and that the diversion/development of these springs would greatly affect these life forms. Moreover, as these springs flow downhill, they also recharge the lower aquifers, thus enhancing the life of the existing springs at lower levels. Therefore, depending on the situation, a trade-off must be made considering local needs and downstream users. Emphasizing only local human needs might lead to severe intercommunity conflict and negative environmental consequences.

Causes of Drying of Springs in Western Ghat area

1. Impacts on stream flow:

- The rapid change in land use and land cover may be attributed to population growth with the extension of agricultural lands, urbanization, and deforestation. Some research showed that the increase in land use (Urbanization and farm land) is the main factor that contributes to the increase in runoff generation and runoff coefficient depends on the land cover types. For instance land use and water areas have higher runoff coefficient due to their low infiltration rate; while the grass land, shrubs and forest areas have low runoff coefficient. The rainfall runoff experiments indicate that degraded and abandoned land generate surface runoff within a few minutes after the start of the rainfall event. One of the paper cited by showed that runoff coefficient of natural vegetation and fallows area, cultivated land and barren land are 13%, 20% and 50% respectively. However, from a comparison analysis of rainfall and stream flow at different angles, it is clear that the increase in stream flow is mainly due to land use land cover change. However, the main risk associated with dramatic land use change is the soil degradation, soil erosion, which will lead to silting of the river and, mainly, the reservoir. Another threat could be the water quality from sediment, as the climate change results in an increase in evapotranspiration, which could consequently reduce the amount of water available in the basin increasing the concentration of sediment
- This case study was conducted in some parts of Nepal namely Thulokhola watershed there the peoples don’t have much water for their survival. Frequent droughts and their adverse effects affecting the agricultural productions. Many water sources that were once perennial have become seasonal. Drying up and downhill migration of water sources have made less

water available for drinking, livestock, and irrigation and have negatively affected households' ability to wash clothes and maintain general cleanliness. Because of shortages of irrigation water, farmers in the Thulokhola watershed are reducing or abandoning winter rice cultivation, which has resulted in decreased grain production. Lack of irrigation water has also affected vegetable production, which is critical for family health, nutrition, and household income. Because of this they were implemented new agricultural practices and technologies, and have started visiting veterinary clinics for their animal's health. They have also begun planting fodder trees on their farmland. Because agriculture is the major economic activity in rural Nepal, rural communities are susceptible to climate change impacts.

Springs are the primary source of water for local communities, livestock, and agricultural and environmental uses in a mountain watershed. Drying up of springs because of changes in hydro-meteorological patterns and land uses has become a major concern for communities in the region. The local communities were said precipitation is decreasing significantly, severely affecting the drinking water supply, agricultural production, and ecological health. Impairment of surface water quality because of pathogens, nutrients, and sediments further limits the availability of drinking water for humans and livestock. [10]

2. Impacts on quality of spring fed streams

- Human activities at the landscape scale can impact stream water quality. Rapid human population growth has resulted in worldwide land-use alterations, greatly influencing stream and river ecosystems. The increased area of impermeable surfaces associated with urbanization changes the water quality of affected streams by reducing infiltration, and thus increasing surface runoff. Further, agricultural activities, such as livestock grazing, can often result in soil compaction which leaves nutrients and other contaminants susceptible to off-site transport. In these ways, runoff over a wide land area can result in nonpoint inputs of nutrients from fertilizers, metals, ions, pesticides, and sediments into streams. Accordingly, water quality can be impacted as the area of agricultural land within a catchment increases Due to rapid infiltration of surface pollutants to groundwater, ecosystems are highly susceptible to pollution from anthropogenic sources, such as agriculture. In addition to effluent from septic systems found prevalently in rural areas, the application of animal manure to pastures has been identified as a leading non-point source of pollution in streams leaving local groundwater systems at great risk of contamination. The topography and increasing area of agricultural land make water quality degradation by agricultural runoff to surface water and groundwater, a concern. These water chemistry data reflect distinct land-use differences that may become greater as land-use change continues.

- Globally, numerous studies are focused on the impact of LULC on the physicochemical parameters of water. A case study was conducted on Wular Lake in Kashmir Himalaya, which highlights the relationship between LULC and water chemistry. The study emphasizes that the watershed (drainage basin) and scale factors influence the water chemistry of Wular Lake which in turn impacts the biotic setup of the aquatic ecosystems. The study provides us the information about the proportion of different land cover categories and their correlation with some limnological parameters of Wular Lake. Among the various physicochemical parameters, low dissolved oxygen (DO) was observed in the LULC class which has the highest percentage of agricultural land followed by horticultural land in its catchment. The study concluded that the catchment area with greater percentage of agricultural fields drains maximum fertilizers in the lake, resulting in growth of microorganisms that deplete the dissolved oxygen content in the water body. There are a number of factors in the catchment of the lake that are associated with the quality of water, and among these, the stresses (agricultural, horticultural and wasteland) are impacting largely on water quality. [12]

Other impacts on springs:

1. Geology of the surrounding area

The geology of the surrounding area and the precipitation also affects the spring water quality. In a case study conducted on the springs of Lysogory mountains The mountains which are built by the hard hard quartzitic sandstones, quartz sandstones, siltstones and claystones with very high SiO_2 content in cambrian quartzites and quartzite sandstones (98–99%) and very low contents of Ca, Mg and P predetermine extremely acidic nature of the rocks and their weathering products. Spring water supplied mainly by underground waters (not with rain), which may result in higher concentrations of the ions. The greater impact on chemistry of spring waters might have had local cambrian shale layers, since they are slightly richer in magnesium and sodium than basic rocks that build the main massif. The low pH value of precipitation impacts on mountain springs causing changes in water chemical properties. [4]

Being natural groundwater outflows respond well to any changes that occur in natural ecosystems, and therefore can be classified as important hydrogeological indicators. Recent climate change has contributed to the occurrence of extreme events such as droughts and floods, causing fluctuations in groundwater levels. Forest ecosystems play a very important role in the protection of aquatic environment and in climate change mitigation. In mountainous areas, and especially in national parks where conducting hydrogeological drilling is restricted, springs are an important element of groundwater. [4)

While tapping springs for drinking/irrigation purposes, it must be remembered that they also sustain thousands of other life forms vital to a balanced ecosystem. Changes in the uses of these springs may also affect other human communities downstream. Therefore, before developing spring flow, a trade-off must be made considering local needs and downstream users.

The research challenges of Spring flow analysis are as follows:

(5) How can streamflow recession analysis can be used to improve understanding of Mountain Block Recharge(MBR, as stated by Ajami et al., 2011)processes in a tropical mountainous catchments?

(6) What is the sensitivity of MBR estimates to uncertainty in the derivation of the catchment storage-discharge relations?

(7) What are the contributions of seasonal precipitation (winter versus summer monsoon) to MBR?

(8) What can we infer from storage-discharge relations across nested catchments of increasing size to describe Mountain System Recharge processes in a mountainous catchment?

Plate 1. Dried Up Natural Spring observed in a hilly track across Road cutting

Plate 2. Discharge measurement of Natural Spring in parts of Western Ghat

Plate 3: Natural Spring water collected to water tank (Village: Padamlimura)

Plate 4: Identification of Geological formation in a mountainous catchment

Plate 5: Natural Spring found in Sindhudrug district of Maharashtra

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