Studies on Occurrence, Distribution and Sustainability of Natural Springs for Rural Water Supply in parts of Western Ghats, India

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ABSTRACT

The Western Ghats of the Indian Peninsula is dotted with innumerable springs, many of which are utilized for local water supply and many flows unnoticed unrecognized of the vast potential they possess for the service of the humankind. This is an attempt to study these springs in the Koyna River basin, a headwater basin, that characteristically represents the Western Ghats region in Maharashtra State. The objective is to explore the possible use of these springs for the regeneration of forests in the Western Ghats, once a thickly forested tract, but now a barren piece of denuded land. Close examination of more than 50 springs reveals that their origins are highly dependent on the lithological characters of different basaltic flow units and the existing terrain physiography. Their discharges vary between 4-400 m^3/d in the winter and 2-200 m^3/d in the summer. 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. Chemically, these springs offer a very high quality of groundwater, their chemical concentrations depending heavily on the lithological compositions of the source-aquifers and the residence time of ground water issuing as springs in these aquifers.

Regeneration of forests needs water throughout the year. Springs untapped for any human use may be harnessed effectively for reforestation purposes in the hills of the Western Ghats. Even if they are in use, because they flow continuously, part of their discharges could be diverted for reforestation purposes. However, while tapping springs for reforestation/irrigation/drinking purposes, it must be remembered that they also sustain thousands of other life forms vital to a balanced eco-system. 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. With the above objectives, during the first phase of the project, primarily an attempt has been made to study these springs of the Western Ghats area and to classify them with respect

to their origin, distribution, discharge and quality for possible use as a potable source of water. A total of about 9-10 springs have been investigated at or very close to their origins in parts of Western ghats covering Satara, Ratnagiri, SIndudurg and Kolhapur districts of Maharashtra. In addition, spring inventories have been made in the head water catchments of Malaprabha and Ghataprabha sub basins. A Case study carried out in collaboration with GSDA Maharashtra is presented with regard to water availability issues in the higher elevations of Western ghats.

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1 INTRODUCTION

Springs are natural resources and considered as a hydrologic refugia during the time of climate change, that is, persistently wet microenvironments and are relatively decoupled from regional climate forcing and thus could support climate resilience in natural communities (McLaughlin et al. 2017). Hydrologic refugia may be particularly important in regions where droughts intensify (become more frequent or severe) as a result of climate change (Dai 2012, Bogan et al. 2015) during hydrologic extreme events. In arid and semi-arid landscapes, springs are critically important sources of soil moisture, aquatic and riparian habitat, and surface water for terrestrial wildlife (Sada et al. 2005, Barquin and Scarsbrook, 2008, Sada and Lutz, 2016). Indeed, springs globally have served as evolutionary refugia, supporting concentrations of relict and endemic species that require habitat stability (Sada and Pohlmann, 2004, Davis et al. 2013, Jyvasjarvi et al. 2015). The dual role of springs as current biodiversity hotspots and possible future climate refugia makes them especially promising targets for conservation investment (Cantonati et al. 2012, Costelloe and Russell, 2014).

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.

The response of spring discharge to climate-induced changes in precipitation can be anticipated, at least in part, from an understanding of the fundamental controls on spring occurrence and hydrology. The distribution of springs is largely controlled by the volume and extent of groundwater recharge, the permeability of the geologic materials through which groundwater moves, geologic structure and faults, and topography. Springs in areas of low geologic permeability generally are fed by groundwater moving through short, shallow flow paths with mean residence times on the order of months to years (Focazio et al. 1997, Plummer et al. 2001). These springs may be part of the larger groundwater flow system or may occur as independent, perched systems. By contrast, large-volume springs with relatively stable discharge are commonly associated with extensive, high-primary-permeability geologic units or with geologic structure or faulting that provide secondary permeability (Meinzer 1927, Manga 1997, Jefferson et al. 2006). These springs often are characterized by long subsurface flow paths and mean residence times on the order of decades to centuries (Focazio et al. 1997, Caldwell, 1998, James et al. 2000). Discharge from large-volume springs commonly forms or contributes to streams in defined channels (i.e., rheocrene springs), whereas springs with smaller discharge volumes and diffuse seepage areas may support wetlands (helocrene or hillslope springs) or stands of groundwater-dependent vegetation where flow does not reach the surface (hypocrene springs; Springer and Stevens, 2009).

The stability of spring discharge is ultimately determined by precipitation variability in the spring's recharge area; however, the degree to which spring discharge is coupled to climate drivers largely depends on the nature of the recharge, flow-path length, and groundwater residence time. Typically, temporal variability in groundwater recharge is dampened and lagged compared to variability in precipitation, with greater unsaturated zone thickness and less permeable geologic materials increasing these effects. Movement of water through the groundwater system further dampens and lags the precipitation signal, with dampening generally increasing with residence time due to dispersion and mixing with water following different flow paths through the subsurface. Springs with small discharge volumes and short subsurface flow paths are expected to respond relatively quickly to changes in precipitation volume and type (e.g., snow-to-rain transitions) and may run dry seasonally or during years of reduced precipitation. Large-volume, long-flow-path springs are sustained by larger reservoirs that are generally expected to buffer them against desiccation in dry years. Solder et al. (2016) demonstrated that springs with longer groundwater residence times respond more slowly to inter-annual variation in precipitation and also noted that such springs may be slower to recover from long-term droughts. In low-gradient groundwater systems, however, even large-volume springs with relatively long groundwater residence times may respond quickly to inter-annual changes in recharge due to a loss of hydraulic head during dry periods. Landscape features and surface processes in recharge areas can also influence the coupling of precipitation to recharge. For example, snow accumulation in microenvironments of topographic shading and sheltering from wind may delay snow ablation until later in the growing season (Flerchinger et al. 1992, Winstral et al. 2013) and thus affect recharge dynamics for some high-elevation montane springs.

Despite understanding of such general controls on spring hydrologic responses to climate drivers, data limitations remain a major obstacle to predicting climate-change effects for individual springs or clusters of springs, and thus for identifying stable hydrologic refugia. In regions such as the Western Ghat regions of India, thousands of springs are distributed over vast landscapes, particularly on hilly terrains. Long-term monitoring of spring hydrology is difficult, expensive, and rare (Weissinger et al. 2016). For many springs, no hydrologic data exist at all. For most others, hydrologic records are of insufficient temporal extent and resolution to quantify responses to climate variability. Comprehensive hydrogeologic descriptions of springs—including delineation of recharge areas, measurements of geologic permeability and groundwater flow rates, and mapping of subsurface flow paths—could in theory be used to predict hydrologic responses to climate change but are rarely available in practice (Van der Kamp, 1995).

Conservation and management decisions are complicated, however, by the idiosyncratic nature of springs (Stevens and Meretsky, 2008), including the likelihood that climate-change resilience will be highly variable even among springs in close proximity. Springs can vary dramatically in their hydrology, water chemistry, and biology within a region (Patten et al. 2008, Sada and

Lutz, 2016) and even within a watershed (Erman, 2004). Discharge responses to climate fluctuations can vary over small geographic areas, even for springs with similar aquifer characteristics and regional climate exposure (Weissinger et al. 2016). Spring discharge that is sufficiently decoupled from climate variability could, in theory, produce stable hydrologic refugia (sensu McLaughlin et al. 2017) from future warming and drying. For other springs, refugial capacity may decrease in proportion to climate change (relative refugia) or disappear entirely (transient refugia) if springs eventually run dry once climate-related temperature and moisture thresholds are surpassed.

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. Their 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.

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 which leads 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.

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 Mountain 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 catchment 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.

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 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. 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.

1.1 WHAT IS A SPRINGSHED?

The source of every major river in the country is symbolically represented by a system of springs that is often religiously revered. Springs are natural point sources of groundwater discharge. Although springs emerge onto the surface and may be treated as surface water after they discharge, they are part of a sub-surface system of aquifers that follows hydrogeological principles. Springs have been a vital source of groundwater in all the mountainous regions across the world. Millions of springs form the life-line for people in the Himalayan and sub Himalayan regions, the Eastern and Western Ghats as well as in the smaller mountain ranges across the country. An increased demand in these regions has accompanied a decline in spring discharges, due to various factors, one of which is the change and variability in climate. A 'springshed' approach includes a combination of landscape, watershed and aquifer as units of spring water management and holds the potential to focus on groundwater management for the mountain regions that form such an integral component of India's diverse landscape. A new approach adopted for recharge/rejuvenation of groundwater and dying springs. This initiative is basically a result of a long and continuous watershed learning and experience.

Presently, springs as a pilot project targeted one village in each district during the study period. The springshed program is aimed at achieving increased discharge of springs, duration of discharge to mitigate water scarcity in rural areas during lean season, enhance availability of water for domestic and agricultural purpose, reducing waterborne diseases and providing safe drinking water. A typical cross section of a spring water system is shown in Figure 1.

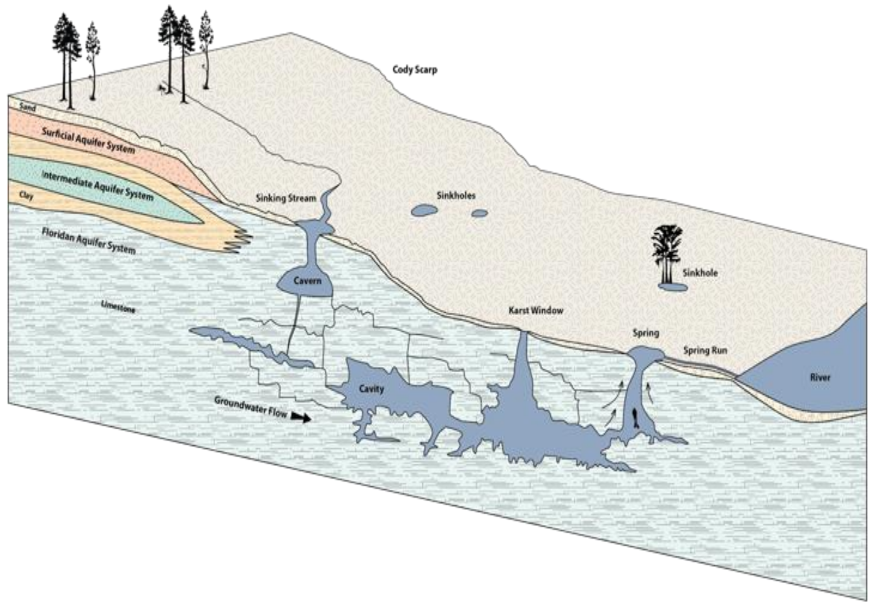


Figure 1 : A typical structure of Spring Occurrence

The Western Ghats Mountain range represents one of the world's biodiversity hotspots and spanning much of India's west coast, supports over 400 million people with water, food and other ecosystem goods and services (Walker and Meyers 2004). The provision of these services, however, is threatened by widespread environmental degradation. It is estimated that as little as 6% of the historic vegetation cover now remains intact due to high population density and intensive land use (Aravind et. al. 2011), with many remaining endemic species threatened (Watve 2006; Watve 2013). This loss of biodiversity is likely to have significant economic, social and environmental consequences for millions of people, but the precise impacts are not yet known and require additional study. The freshwater systems are of particular interest as India faces a deepening water crisis. The Western Ghats constitute the headwaters for almost all river basins in central and south India. The rivers, lakes, wetlands, springs and aquifers are used for drinking water, household use, irrigation, power generation, industry, and tourism across eight states. They also provide unique habitats on which millions of people depend for livelihoods and food sources (Aravind et. al. 2011). These water bodies, although a small fraction of the total land area, can support entire ecosystems, and areas covered by wetlands are responsible for one fifth of local biodiversity (Space Applications Centre, 2011). Freshwater systems are also some of the most sensitive and threatened ecosystems (Bassi et. al. 2014), the main threats in the Western Ghats being construction, agriculture, pollution, groundwater exploitation, invasive species and deforestation (Figure 1). Many freshwater plants and animals are routinely harvested for food and livelihood activities. These systems face such intensive anthropogenic pressure, that at least 18% of freshwater taxa are threatened with extinction (Aravind et. al. 2011). One of the lesser studied components of the Western Ghats is the natural springs which occur when groundwater intersects the landscape and flows onto to the surface. Although the number and extent of springs is not known, they appear ubiquitous across the mountain range and may be integral to the entire freshwater resource. For example, many if not most of the rivers, lakes and wetlands in the mountain range are spring derived. For the people of the mountains, springs have been used for generations as a source of safe, perennial drinking water, small-scale irrigation and distributed water points for domestic animals (Naik et. al. 2002). Springs also provide cultural and religious value as many temples are built on and around springs, such as the Old Mahabaleshwar Temple at the source of the Krishna River in Maharashtra. But there are signs that springs are under threat and there is increasing concern about declining spring discharge and water quality. Temple springs are going dry, spring-fed village water tanks no longer provide adequate household supply, and community drinking water springs are being abandoned due to contamination. Most of these occurrences appear to be related to increasing human impacts such as groundwater exploitation, deforestation of recharge areas, and improper sanitation. However, few of these anecdotal examples have been documented and there is little baseline information on springs in general. The present study was conducted to expand our understanding of the role and current status of springs in the North-Western Ghats. In particular, the objective was to advance a general description of springs in the Western Ghats to develop a baseline for future monitoring and management.

2 STUDY AREA

The North-Western Ghats which is hydrologically distinct from the southern part of the range. The section extending from the Karnataka border towards north up to Gujarat is dominated by the Deccan Volcanic Province, i.e. volcanic rocks formed by outpouring of basaltic lava flows (approx. 65 my) with near horizontal layers called flood basalts, which occur in simple and compound pahoehoe type flows (Deolankar 1980, Deshmukh 1988). This is what creates the characteristic landscape of flat-topped plateaus and horizontal banding of the mountains (Figure 2). Administratively the study area is selected in parts of western ghats of Sindhudurg, Ratnagiri, Satara, Sangli, Kolhapur districts of Maharashtra and Belgaum, Khanapur taluks of Karnataka. Few stretches of Central Western Ghats and Northern Western ghats are considered in this study. The stretch extends to nearly 300 km of either side of Western Ghats ridge.

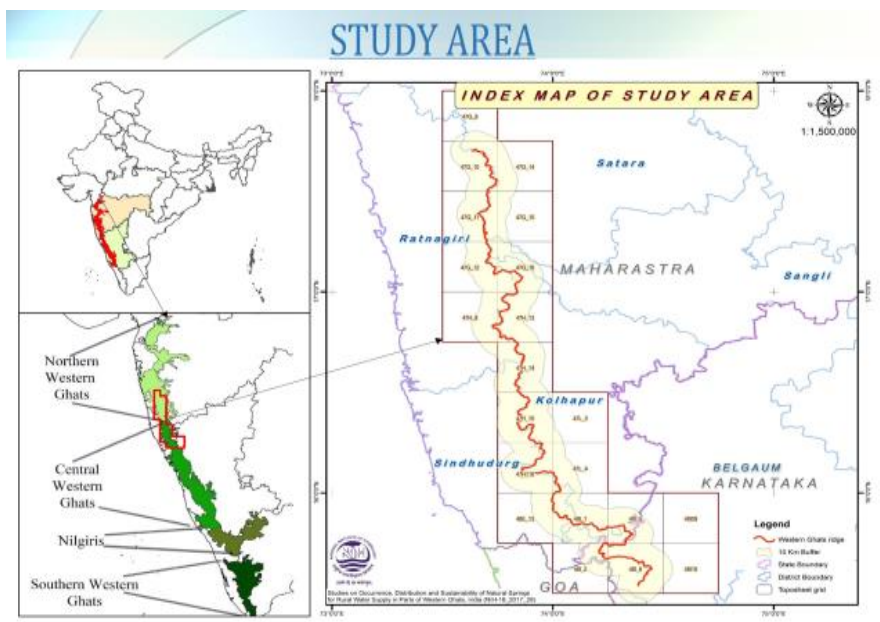
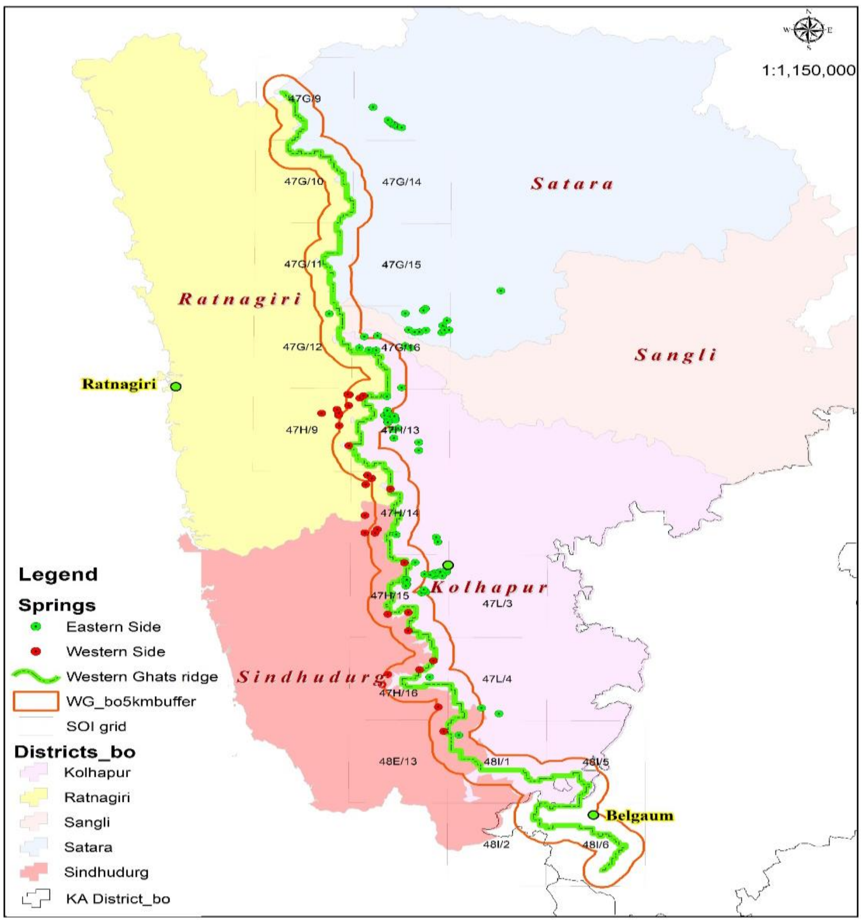
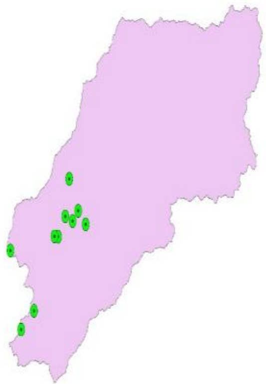


Figure 2 : Index map of Study area

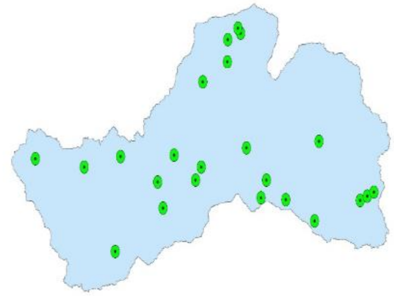
Table 1 : Springs inventory in various part of Western Ghats

Sl.no	Spring Catchment in Districts	No. of Springs	Observed Springshed area.. ha	Annual Rainfall (mm)	Annual Water potential (cum)
1.	Kolhapur		288.47	710.70	59,065
2.	Ratnagiri		4.23	3445.15	15,286
3.	Satara		5.01	3204.20	11,326
4.	Sindhudurg		4.30	3445.10	9,791
5.	Belagavi		15.15	1984.80	15,286



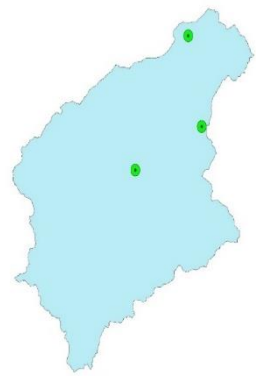


Gargoti, Kolhapur, Maharashtra

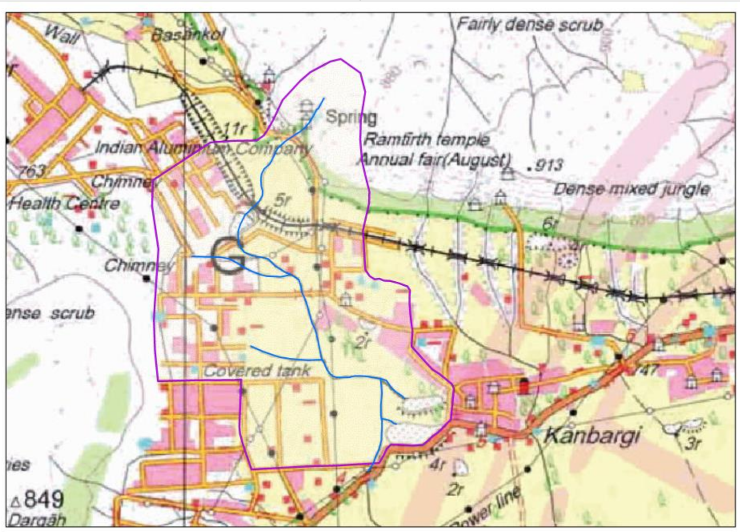


Devruk, Ratnagiri

Satara



Gotvewadi, Sindhudurg



Kanbargi, Belgaum, Karnataka

Figure 3 : Study catchments with observed springs

2.1 GEOLOGY OF STUDY AREA (PART OF WESTERN GHATS)

A typical geologic cross section in the study area consists of alternating units of relatively dense, compact basalt interspersed with layers of relatively porous, or vesicular sections. Further, the morphology of lava flows also affects the nature of weathering, joints and fractures between the two formations (Kulkarni and Deolankar 1995; Kale and Kulkarni 1992). Hydraulic conductivity in the vesicular basalts is greater than that in the compact basalts because, in addition to vesicular pore space, the former tends to be more heterogeneous and more prone to weathering while the compact basalt tends to be more homogenous, have less jointing and be more resistant to weathering (Deolankar and Kulkarni 1987). Therefore, the vesicular basalt tends to store and transmit groundwater while the compact basalt tends to limit groundwater.

Springs are formed when groundwater in the vesicular basalt percolates down to a compact basalt layer and moves laterally to emerge on the surface (Naik et. al. 2002). Springs such as this, formed when groundwater flow is impeded by an impervious material, are called fracture springs (Bryan 1919). Important water bearing rock formation in the area is laterite. This is highly weathered basalt that caps many of the plateaus (see Figure 2.b) and has a high porosity and specific yield relative to other basalt formations (Widdowson 1997; Widdowson and Cox 1996, Widdowson and Gunnell 1999). Many springs are associated with the contact between laterite and compact basalt or other impervious layers (Naik et. al. 2002). Finally, there are a series of fracture zones, or lineaments that cross the landscape. The superimposition of post volcanic tectonics, these N-S trending fractures increase hydraulic conductivity and often connect vertically separated water bearing formations contributing to movement of groundwater at the landscape scale (Kulkarni and Deolankar 1997; Duraiswami et. al. 2012, Duraiswami 2013). Some springs emerge directly from these fractures; these are defined as fracture springs (Bryan 1919). Other criteria for choosing these springs included accessibility, observed human impact and land use.

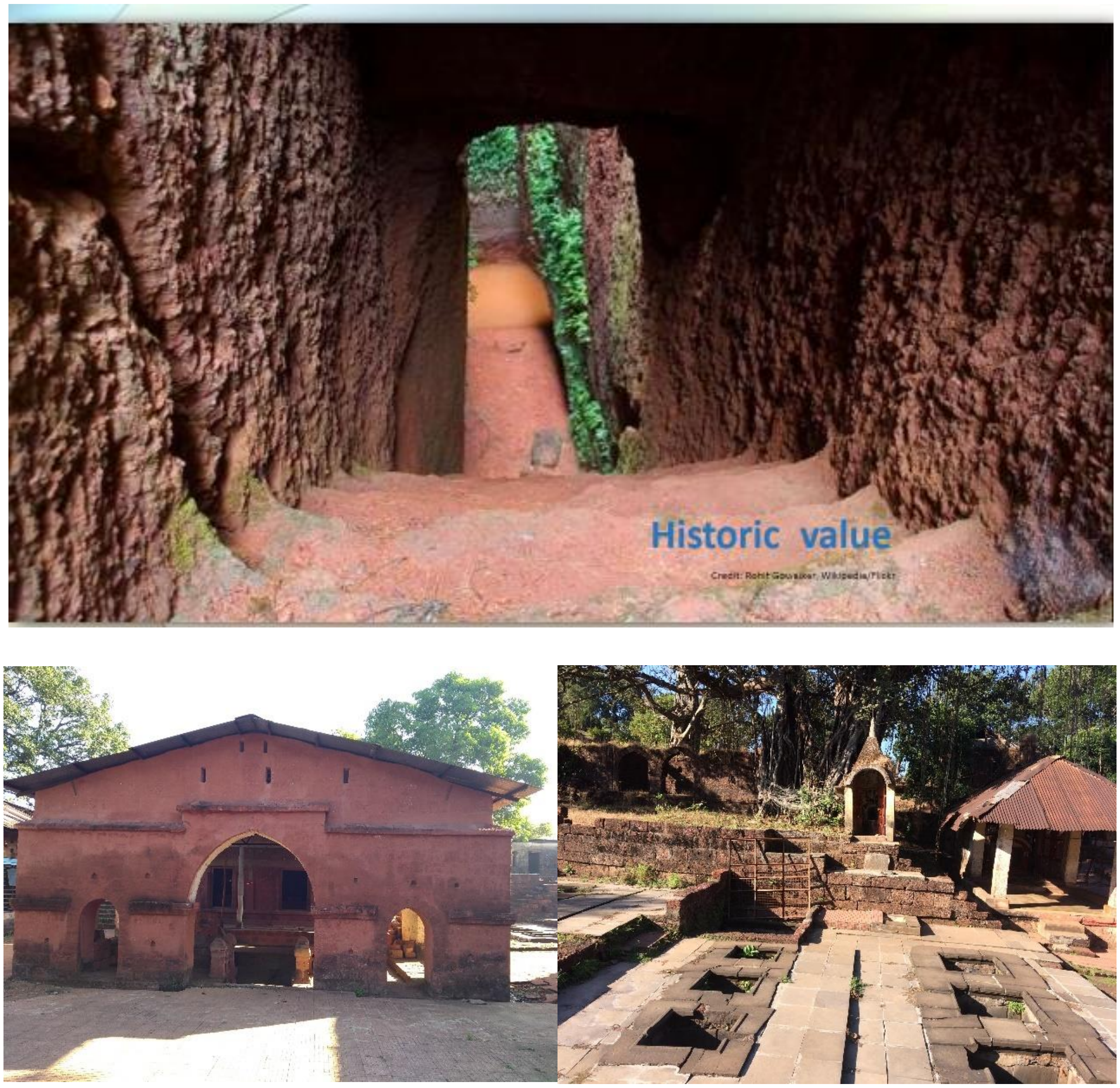


Figure 4: 'Rajapur ganga' a long siphon type occurrence of spring from Sahyadri range

The environment in which the spring orifice exists varies widely, from the special case of in-cave springs whose flow subsequently may or may not reach the surface, to subaerial emergence in a wide array of geomorphic settings, springs that emerge below glaciers, subaqueous freshwater lentic and lotic settings, on the floor of estuaries, and springs in a wide variety of subaqueous marine settings.

Figure 5 : Springs Inventoried in parts of Western Ghats

2.2 CLASSIFICATION OF SPRINGS

Geologists have traditionally classified the physical parameters of springs up to their point of discharge (e.g., Bryan 1919, Meinzer 1923), but little attention has been paid to springs after the point of discharge. Other geochemical, geomorphic, biological, and cultural classification systems have been developed for surface waters and riparian systems downstream from the point of discharge (e.g., Hynes 1970, Rosgen 1996); however, geomorphically based classification systems have largely ignored differences between spring-fed channels and surface-runoff dominated systems. Biologically oriented analyses have either focused on individual springs, or on individual taxa. An integrated springs classification system should include the major physical, biological, and socio-cultural variables. Such a classification system will permit assessment of the distribution of different kinds of springs within ecosystems, thereby improving resource inventory and development of conservation and restoration strategies (e.g., Sada et al. 2001). Alfaro and Wallace (1994) and Wallace and Alfaro (2001) updated and reviewed the historical spring classification schemes of Fuller (1904), Keilhack (1912), Bryan (1919), Meinzer (1923), Clarke (1924), Stiny (1933), and others. Of the previously proposed systems, Meinzer's (1923) classification system has been the most persistently recognized. He included 11 characteristics of springs based on various physical and chemical variables. Although Meinzer's (1923) scheme has been widely used, it is not comprehensive. Clarke (1924) considered three criteria to be most important for springs classification: geologic origin, physical properties, and geochemistry. However, none of the classifications proposed thus far include ecologically relevant variables, such as considerations of spatial and temporal degree of isolation, microhabitat distribution, biota, and surrounding ecosystem context. Thus, no comprehensive classification system has yet been developed or accepted (Wallace and Alfaro 2001). Meinzer's (1923) classes, integrate Alfaro and Wallace's (1994) recommendations, and then propose additional ecological elements.

Channel Dynamics: In the special case of sub-aerial springs that create or flow into channels, such discharge may support distinct geomorphic characteristics within the channel. If a subaerial flowing spring feeds the stream headwaters and there is little to no runoff contributing to the stream flow, the stream is classified as a spring dominated stream (Whiting and Stamm 1995). If the spring discharge is relatively constant and permanent, then the morphology of the channel will be distinctive. These types of channels often flow at bankfull stage or slightly above 20 percent of the time (Whiting and Stamm 1995). If the spring discharges to a channel that has significant components of runoff, it is classified as a runoff-dominated stream. Such systems may be classified with stream channel geomorphology terminology, such as Rosgen (1996). Some springs systems have components of both spring- and runoff-domination.

Meinzer (1923) categorized springs on the basis of the pressure exposing or forcing water out (i.e., gravity, thermal) and other pressures. Gravity-fed spring systems direct groundwater flow down gradient within the aquifer. Artesian springs discharge water under pressure, or may issue from an aquifer that has an upper confining layer, subjecting the flow to fluid pressures in excess of the pressure due to gravity at the point of discharge. Thermal springs emerge when groundwater comes in contact with magma or geothermally warmed crust, and is forced, sometimes explosively as in geysers, to the surface. Water is forced to the surface by explosive release of CO2 in the geyser-like “Coke-bottle” springs of Utah. Fluid discharge in submarine springs associated with methane seepage is often forced by diurnal tidal and spring-neap variation in pressure of overlying water (Tryon et al. 2001). Some springs do not flow and therefore are not subject to pressurized discharge, while other springs may have multiple forcing mechanisms. Anthropogenic factors, such as groundwater loading around large reservoirs, may create forces that also affect springs emergence.

Flow Persistence: Springs may function as refugia across ecological and evolutionary time scales. We follow Nekola (1999) in distinguishing between springs that have recently developed or been exposed to the atmosphere (Holocene neorefugia) versus those that have existed since the Pleistocene or longer (paleorefugia; e.g., Blinn, this book). Nekola (1999) predicted that paleorefugia were likely to exhibit high levels of endemism, unique species, and well sorted assemblages. In contrast, neorefugia were predicted to support more weedy species, with low levels of unique taxa. His studies of land snails at springs affected or not by Pleistocene ice sheets supported these predictions, and Blinn's (this volume) study of Montezuma Well in central Arizona provides additional support for the paleorefuge concept. In addition, we consider paleosprings that do not presently flow and may contain important paleoclimate, paleontological or archeological remains (e.g., Hynes, this volume).

Flow Consistency: Meinzer (1923) defined two classes of spring perenniality. Springs are considered to be perennial if they discharge continuously, or intermittent if their discharge is naturally interrupted or sporadic. It is noted that, intermittent springs may flow regularly at hourly or daily (e.g., some geysers), seasonally, annually, or inter-annually, or only on an erratic basis. Human impacts, such as groundwater extraction or well drilling, may affect discharge consistency. As with flow variability (below), multiple observations of a spring are required to determine the permanence of discharge.

Rate: Meinzer (1923) developed eight discharge classes by the magnitude of discharge from a spring at the time of measurement; however, his numeric scheme is reversed from the intuitive scale (low discharge should have a low value). However a system was proposed reversing this numeric system in a scale that accommodates the full range of springs discharges known, from seeps with near zero flow (a score of 1) to springs with a flow of >10 m3 /s (a score of 8; e.g., Ra-ElAin Spring in Syria, with a discharge of 36.3 m3 /s, Alfaro and Wallace 1994). Because the discharge of many springs varies temporally, the flow rate class will change depending on the time of measurement. Fluid flow rates are measured in different units by marine hydrogeologists. For marine cold seeps, fluid flow rates range from 10 $l/m^2/d$ (Alaska margin at 5,000 m Suess et al. 1998) up to greater than 1,700 $l/m^2/d$ on the Oregon margin (Linke et al. 1994) with intermediate values off Peru (440 $l/m^2/d$; Linke et al. 1994; 1,100 $l/m^2/d$; Olu 1996). **Variability:** Springs discharge may be variable at different temporal scales. Short-term variability may be related to loading effects, such as the syphon effect in which filling of groundwater solution channels creates periodic surging of springs discharge. Short-term hydrologic alterations may include individual storms or droughts, while longer-term flow variation may result from inter-annual climate variation, or Pleistocene-Holocene climate and hydrologic changes. Variability in springs discharge may affect the distribution of associated microhabitats. For these reasons, the classification of discharge variability should be based on repeated discharge measurements, sometimes over long time periods. Meinzer (1923) considered three levels of springs discharge variability: constant (steady), sub-variable, and variable. This classification requires multiple measurements to characterize diurnal, seasonal, annual, inter-annual, and long-term variability. Netopil (1971) and Alfaro and Wallace (1994) used flow duration statistics to calculate a discharge variability ratio (CDR): $CDR = Q10\%/Q90\%$ Eq. 1 where Q10% is the high flow exceeded 10% of the time and Q90% is the low flow exceeded 90% of the time. Of course, calculation of these flow rates requires monitoring over at least a several year period. Steady discharge results in a CDR of one (extraordinarily balanced), while wildly varying flows may produce CDR >10 (extraordinarily unbalanced; Table 4.1). Intermittent springs have an infinite CDR.

Water Quality Classification of spring water quality is often specific to an individual study, but several comprehensive approaches have been suggested. Most traditional classifications are based on water temperature and/or the dominance (concentration) of ions.

Water Temperature: Five classes for water temperature in springs have been recognized based on a comparison of spring water temperature with the mean annual air temperature (modified from Alfaro and Wallace 1994): cold, normal, warm, hot, and super-thermal springs. Cold water springs are, by convention, >12.2° C cooler than the mean annual ambient temperature. Spring waters within 12.2° C of the mean ambient temperature may be (but are not necessarily) responding to ambient atmospheric temperatures. This is to be expected in springs that emerge from shallow aquifers and these may have temperatures that vary seasonally with air temperature. Springs with warm (>12.2°C above the mean ambient air temperature, but 37.8° C) are connected to either very large aquifers with long flow paths, or to geothermal sources of heat. Superheated geothermal springs are commonly reported in tectonically active areas, such as geyser fields or marine sea floor settings. The upper temperature limit presently known for life is 121-130°C for a bacteria-like extremophile Archaea in Pacific

Ocean vents (Anonymous 2003). Variability in springs water temperature may also be important, but can only be assessed from multiple visits or by using recording thermistors. Deep submarine springs are typically characterized as cold seeps or hot vents based on their relationship to ambient ocean water temperatures. Because the temperature of seawater in the deep sea is relatively invariant (Gage and Tyler 1991), even small changes above ambient in venting waters represent a significant warming effect with major biological consequences.

Geochemistry: Numerous schemes have been developed to classify water geochemistry, primarily through the surface-water pollution literature, but few studies attempt a comprehensive classification of spring water geochemistry. Clarke (1924) classified mineral springs waters based on the dominance of seven ion groups: chloride, sulfate, carbonate, combinations of these three constituents, silica dioxide (SiO2), borate (B4O7), nitrate, phosphate, and acidity. Furtak and Langguth (1986) classified Greek springs as belonging to: 1) normal earth alkaline (hydrogen carbonatic) waters; 2) normal earth alkaline, hydrogen carbonatic sulfatic waters; or enriched alkali earth alkaline (primarily hydrogen carbonatic) waters. Dinius (1987) used an expert-based decision process to develop an index of surface-water quality to compare levels of pollution in bodies of fresh water. The twelve variables derived from that analysis include specific conductance (micromhos/cm at 25o C), pH, alkalinity (concentration of equivalent calcium carbonate), water color (platinum units), and the concentrations of chloride and nitrate (NO3), which may be relevant to springs water-quality classification, as well as several variables that may not be relevant, including dissolved oxygen concentration, biological oxygen demand, and bacterial concentration. Smith (1990) and others consider turbidity to be important to surface waters. More recent classifications have emphasized more comprehensive geochemical analyses, rare-earth element analyses (Kreamer et al. 1996), and isotopic analyses, all of which may be informative in distinguishing among springs. Also, more recent studies have emphasized more elaborate statistical analyses (e.g. principal component analysis or cluster analysis; Kreamer et al. 1996) to integrate major and minor element relationships, and such approaches will be fruitful when a large database on springs geochemistry has been developed. A comprehensive analysis of springs geochemistry awaits development of the springs database. Meanwhile, we base our selection of water-quality variables on these few spring studies and on relevant surface-water quality studies. We recommend that eight groups of geochemical variables be measured during springs inventories: major anions and cations (chloride, sulfate, carbonate, calcium, sodium, potassium), minor constituents (iron, borate, silica dioxide, carbonate/chloride, triple waters), pollution indicators (selenium, fecal coliform), useful tracers (stable isotopes, radioactive isotopes, rare-earth elements), alkalinity, total dissolved solids concentration and specific conductance, pH, and nutrient concentrations (nitrate and phosphate). Fluids associated with hydrothermal vents and cold seeps contain variable concentrations of dissolved or gaseous methane, sulfides, and hydrogen that exert a large influence on chemosynthetic biological processes. These are typically measured in submarine springs to characterize the emerging fluids.

Synoptic Climate: Synoptic climate strongly affects springs ecosystem development, processes and biodiversity. Climate variables that are often available or can be regionally modeled include air temperature (seasonality and mean monthly), precipitation (seasonality and mean monthly), and relative humidity. The seasonality index for temperature is the ratio of the mean temperature of the hottest month minus the mean temperature of the coldest month in °C. The precipitation seasonality index is the ratio of the average total precipitation for the three wettest consecutive months divided by average total precipitation for the three driest consecutive months (Bull 1991).

2.3 GEOMORPHOLOGY

Geomorphology is the study of landforms, so hydrogeomorphology is basically the study of landforms where groundwater has played a critical role in sculpting the land. On Earth the role of water is evident, particularly when Earth is compared to the heavily cratered, very ancient surfaces of the other terrestrial planets and most moons. However, even on Earth the critical role of groundwater in geomorphic processes is underappreciated, as it is conventionally judged to be inferior to effects produced by overland flow. Here again, dogma has been substituted for fundamental observation.

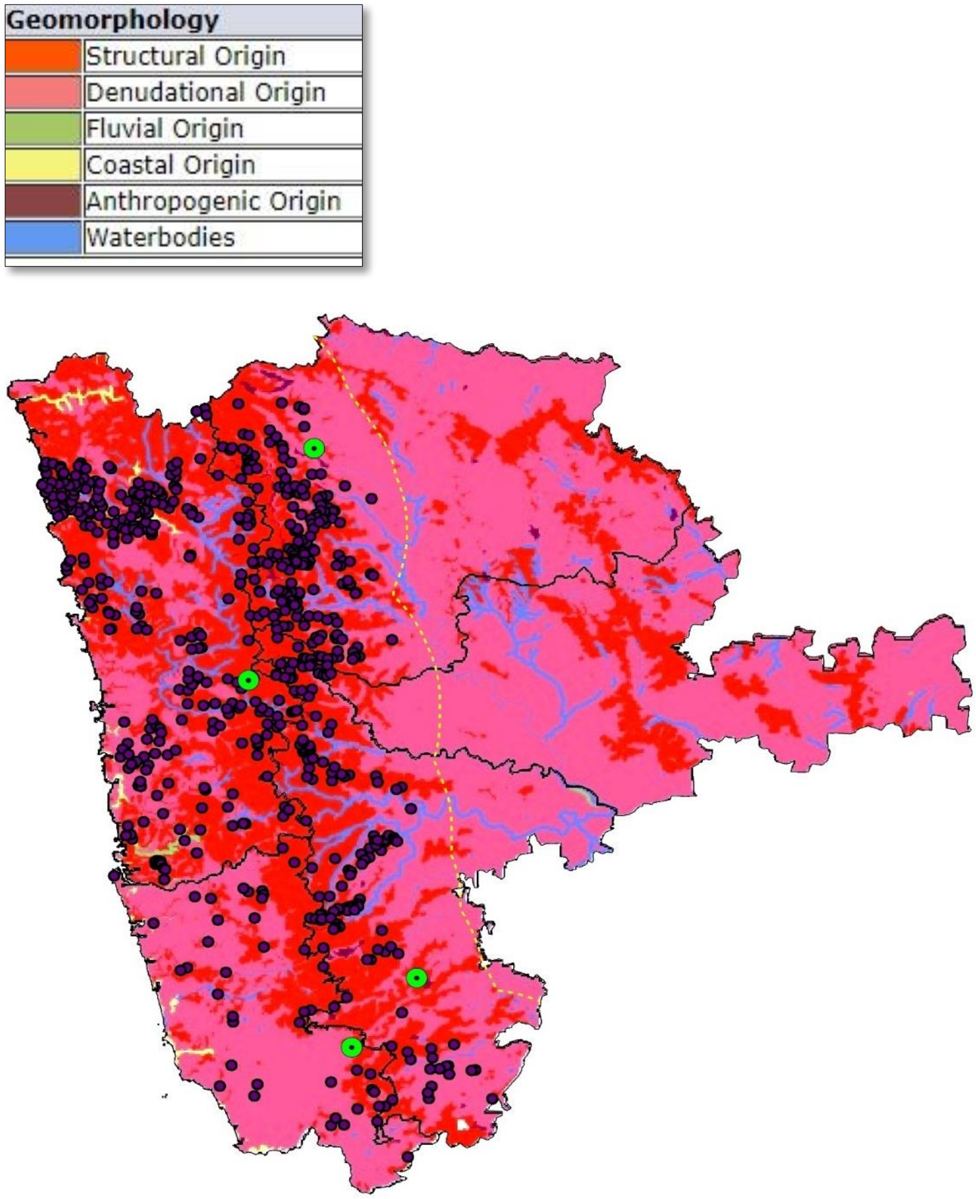


Figure 6 : Geomorphology map for the study area

The dogma is familiar enough. Fluvial systems are dominated by dendritic drainage systems, where steep, v-shaped valleys in upland areas change downstream into braided streams and ultimately to meandering rivers in broad valleys, accompanied by a progressive reduction in topographic slope. While not entirely meaningless, this viewpoint ignores the fact that most of the water in rivers and streams got there via subsurface pathways; otherwise, our rivers would become nearly dry every time a week passes without significant rain. The processes essential to hydrogeomorphology are conveniently divided into recharge and discharge.

Springs orifices occur in several specific geomorphic environments (Meinzer 1923). Groundwater may be exposed or flow from filtration settings (poorly consolidated, permeable materials), or from bedrock fracture joints, or tubular solution passages. We modify the fracture spring list to include springs that exist as groundwater exposed at the surface, but which do not flow above land surface. It also includes stratigraphic contact environments in which springs, such as hanging gardens, emerge along geologic stratigraphic boundaries. “Sphere of Discharge”: The "sphere" into which the aquifer is discharged as described by Meinzer (1923) was greatly simplified by Hynes (1970) into three different classes. According to the reports, there are 12 classes of springs,

1. springs that emerge in caves,
2. limnocrene surficial lentic pools
3. rheocrene lotic channel floors
4. mineralized mounds,
5. helocrene wet meadows,
6. hillslope springs
7. gushets
8. contact hanging gardens
9. geysers,
10. artesian fountains,
11. hypocrene buried springs.
12. paleosprings, which flowed in prehistoric times, but no longer flow (e.g., Haynes).

Both Meinzer’s (1923) original and Hynes (1970) classification schemes become complicated if multiple spheres of discharge are present, or if the spring has a highly variable discharge rate and creates multiple spheres over time. Therefore, all major spheres of discharge should be noted during each site visit, and the importance of each should be described.

2.4 SPRING DISCHARGES

The discharges from an individual or a group of springs were measured wherever possible. At or near the origin, the spring water was allowed to fall in a 20-liter bucket and the time taken to fill the bucket in each case was noted with the help of a stopwatch. In case of large discharges, a 90^o V-notch weir was used to measure spring flow. Discharge of more than 20 springs were taken and found to vary between > 1 and <500 m^3/d in the winter (December to February). The mean winter discharge of the individual springs is estimated is 62 m^3/d. All measurements were taken during non-monsoon season (October to May. During pre-monsoon seasons discharges varied between 0.54 m^3/d and 163 m^3/d. The mean pre-monsoon discharge of the individual springs is estimated to be 22 m^3/d. Spring discharges peak during the monsoon season (June to September), as reported by the local inhabitants, resulting from peaks in recharge. However, no measurement could be made during the monsoon period.

The origin of springs in the Western Ghats are dependent on the lithological character of different basaltic flow units and the terrain physiography. In the Western Ghats, springs generally issue at the contacts between (1) laterite and lithomargic clay or poorly lateritized basaltic flow, (2) vesicular basalt and non-vesicular massive basalt, (3) highly weathered massive basalt and moderately or poorly weathered massive basalt or redbole, and (4) talus deposits and hard massive basalt or laterite or lateratized basaltic flow. Springs also emerge from fractures, both horizontal and vertical, and from the intersections of fractures with different orientations.

The chemical concentrations of the spring waters are heavily dependent on the lithological compositions of the source-aquifers and the residence time of groundwaters in these aquifers. The waters are dominated by alkaline earths (Ca^{++}, Mg^{++}) and weak acids (HCO_3^-, CO_3^{--}). Chemical qualities of the spring waters are well within the BIS and WHO drinking water standards, except for that of the iron (ISI) in about 40% of the samples.

Regeneration of forests needs water throughout the year. Springs untapped for any human use may be harnessed effectively for reforestation purposes. Even if they are in use, because they flow continuously, part of their discharges could be diverted for reforestation purposes. Reforestation needs water while springs need restoration. Therefore, both forests and springs can sustain each other through Government's efforts and also through efforts by NGOs on 'give' and 'take' basis. However, it must be 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. Springs identified were grouped based on parameters such as slope, elevation and Aspects.

Out of about 672 springs which were identified during the first phase of observation, 259 springs are found between slopes 5-10%, followed by 157 numbers between 10% and 15% and the rest at higher slopes (about 145 springs at more than 15%) and 44 springs were noticed at less than 5% slopes. Discharge also showed significant variation with respect to slopes. Higher the slopes, the greater the discharge. Slope map of the study area is shown in figure below. The entire study area has been classified under seven groups based on slopes.

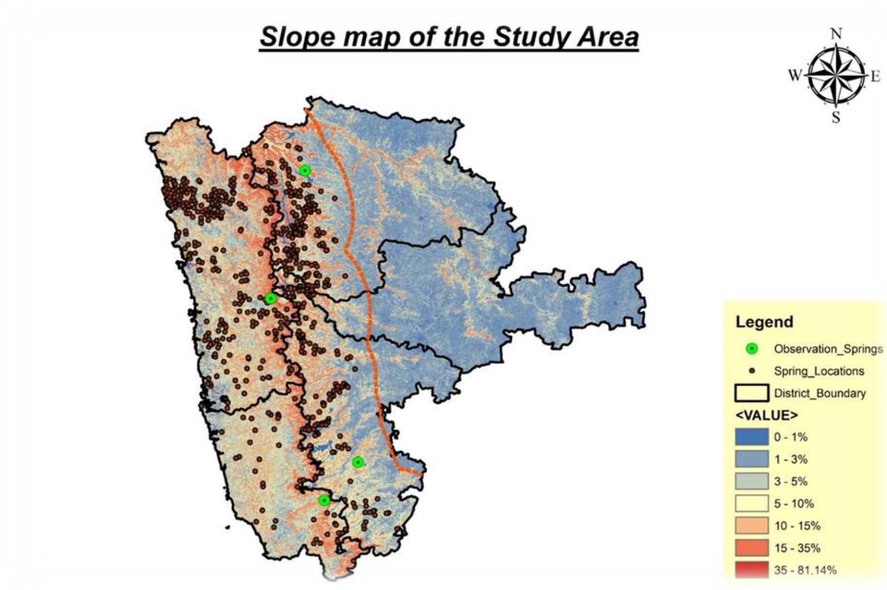


Figure 7: Slope map of Study area

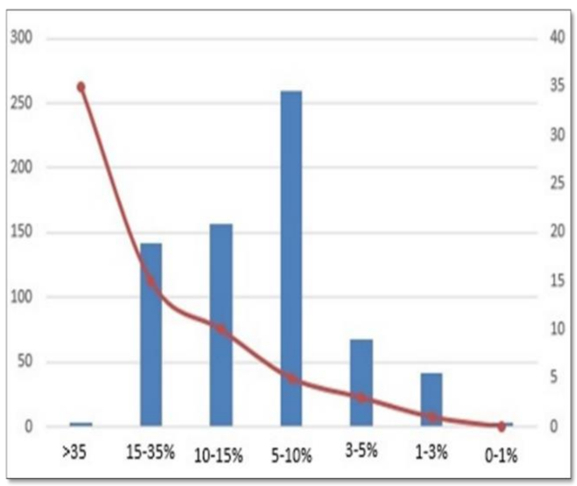


Figure 8 : Frequency of spring occurrences across different slopes of study area

Table 2 : Slope classification for the study area springs

Sl no	Slope	No of springs
1	>35%	3
2	15-35%	142
3	10-15%	157
4	5-10%	259
5	3-5%	67
6	1-3%	41
7	0-1%	3

During the present investigation, 672 springs were considered for the present analysis,which were are noticed between elevation range of 600-1300 m above MSL. The maximum number of springs (144) at elevation between 600-1100 m elevation. Springs have an occurrence frequency of one spring per square kilometer. Although rainfall and recharge areas play vital roles in the yields of these springs, their yields are largely controlled by lithological variations and hydraulic characteristics of their source aquifers. There is a marked seasonality in the spring flow domain depending on recharge. The mean discharge of the individual springs in winter is about 26 m^3/d as against a mean discharge of 11 m^3/d in the summer.

Table 3 : Frequency distribution of springs based on Aspect

Sl.No	Type	No of springs
1	Flat	1
2	North	38
3	Northeast	106
4	South	82
5	Southwest	87
6	West	80
7	Northwest	80
8	East	110
9	Southeast	88

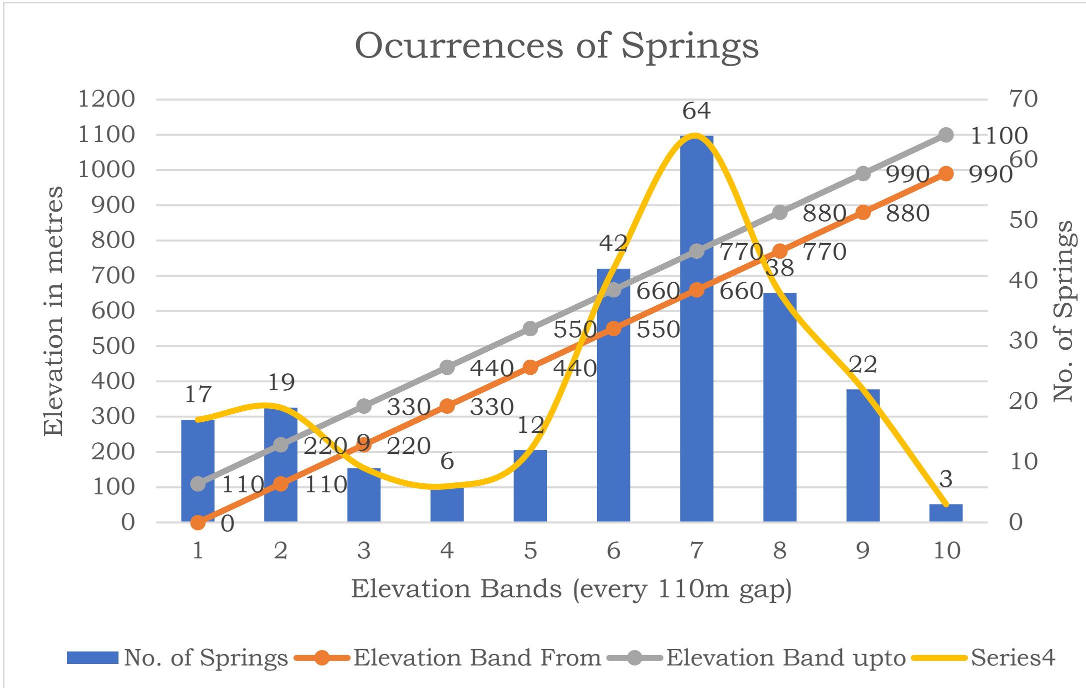


Figure 9: Distribution of Spring occurrences based on Elevation

Aspect Vs Occurrence of Springs

An attempt was made to relate the number of springs with distribution of springs. It is found that number of springs varied with the aspect of the study area. Maximum number of springs were identified in the East (110) and Northeast (106). Lowest number of springs (38) were observed in the northern part of the study area.

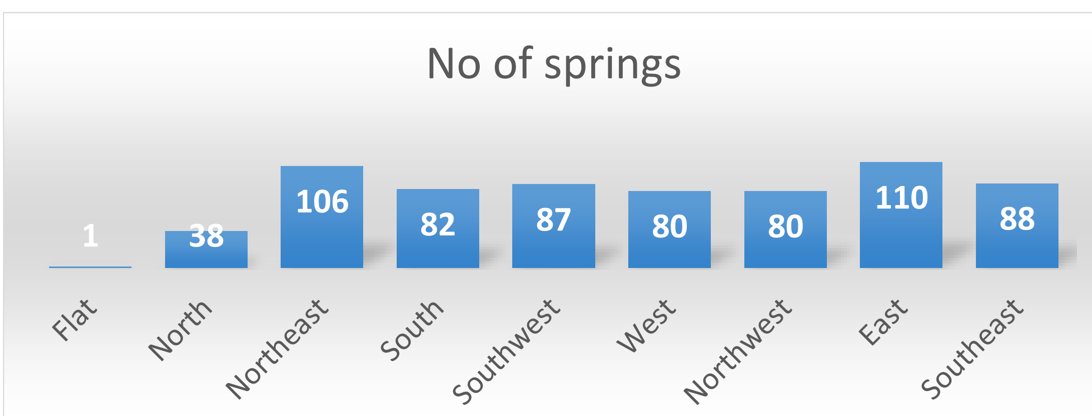


Figure 10: Frequency distribution of springs with Aspect

Figure 9 shows the distribution of the springs with reference to aspect. It is observed that majority of the springs are distributed at higher elevation.

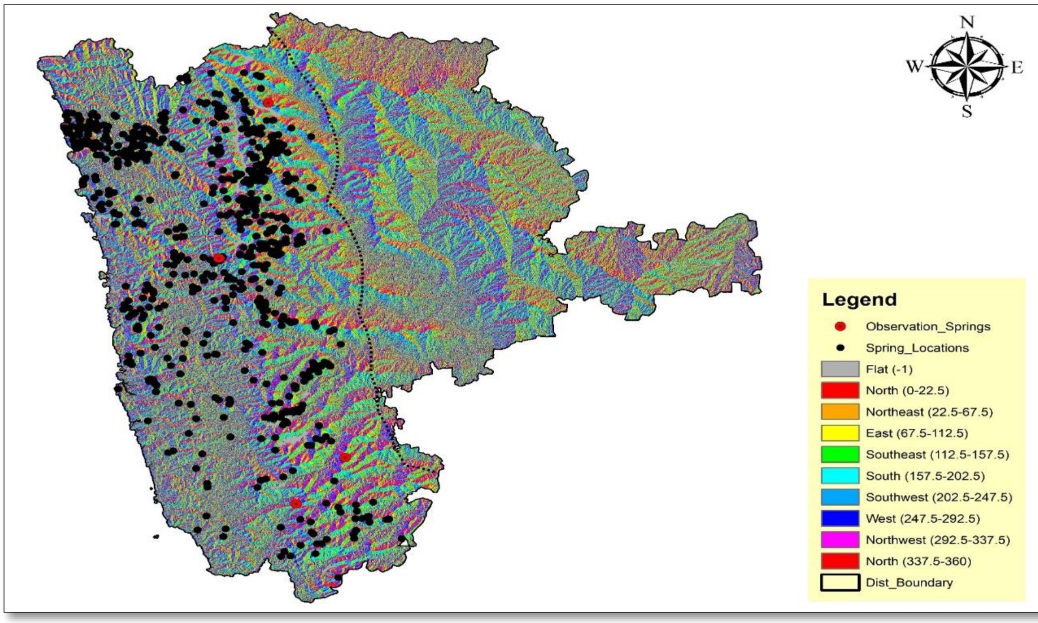


Figure 11 : Distribution of Springs with respect to Aspect

An attempt was also made to understand the occurrence of springs with structural aspect of the study area, i.e. with reference to lineament map. Interestingly it is noticed that majority of the springs distributed in close proximity with the lineament structures such as river basins. Figure 10 shows the relationship between lineament and soring occurrence.

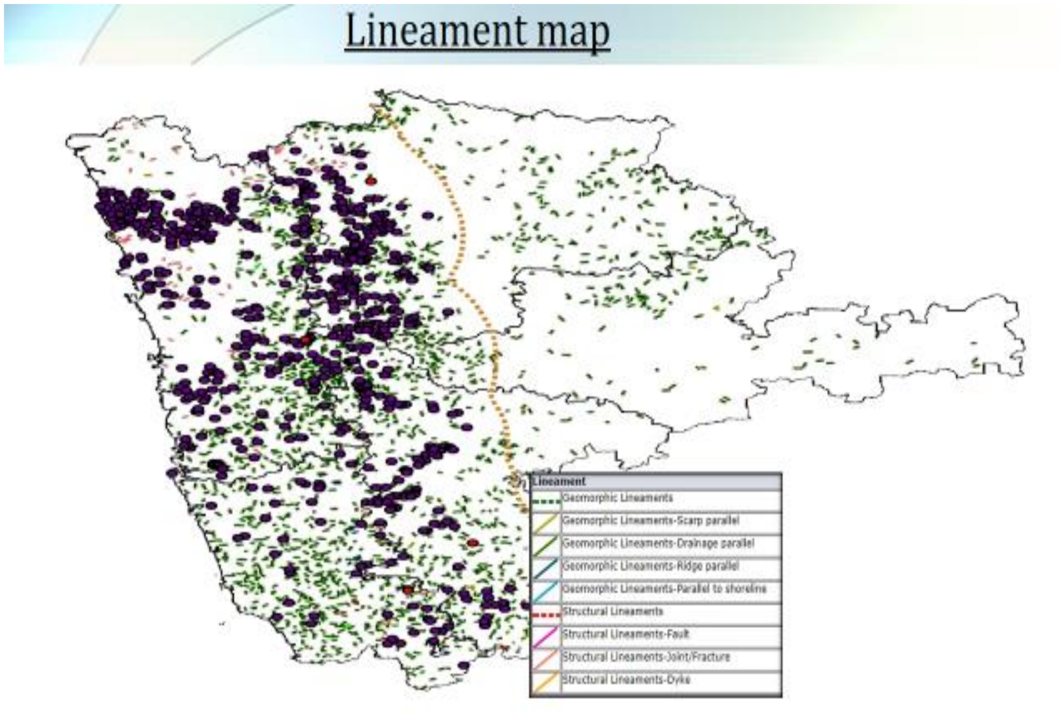


Figure 12: Lineament map of the Study area

Hydrostratigraphic Unit: Meinzer's (1923) characterization of the aquifer lithology and geologic horizon can be reduced to the rock type(s) of the hydrostratigraphic unit (igneous, metamorphic, or sedimentary). Sedimentary units can be consolidated rock, or unconsolidated sediments. Seaber (1988) defines a hydrostratigraphic unit as "a body of rock distinguished and characterized by its porosity and permeability." This classification requires that the nature and boundaries of the stratigraphic unit are mappable. As for some other spring classifications, such information may not be available without a detailed investigation of the aquifer. For instance, the spring may originate from a bedrock aquifer, but may travel through one or more other units (e.g., alluvium) before discharging to the surface. Such information may be even more difficult to obtain in deep marine and other subaqueous settings. A typical overview of the basaltic outcrops in parts of Koyna basin is shown in figure *****

Figure 13 : An overview of Rock outcrops in parts of Koyna basin

Hydrogeologically, the study area is dominated by basaltic outcrops, particularly in the upstream areas. However, in the coastal districts like Ratnagiri and Sindhudrug districts lateritic outcrops are significantly seen**.** It is observed that majority of the springs are found at the contact zone of laterite and basalts.

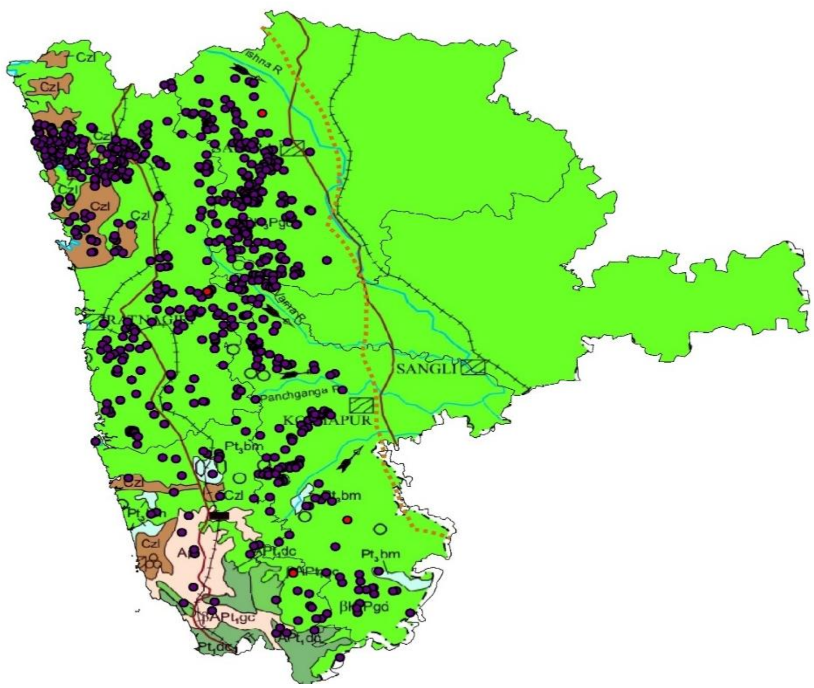


Figure 14 : Hydrogeological map of the study area (part of Western Ghat)

2.5 STABLE ISOTOPIC COMPOSITION OF RAINWATER, GROUNDWATER AND SURFACE WATER SOURCES

Water samples for stable isotope analysis were collected from different water sources in the study area, which comprises of precipitation water, various groundwater and surface water sources. Samples were collected from each category.

Table 4 : Isotope sampling points

Sl.No.	Sample ID	Type	δO18	δD
1	**WG-Chand**	OW	-1.3	-2.2
2	**WG -Chand**	OW	-1.2	-2.1
3	**WG -Satara**	OW	-2.0	-5.7
4	**WG-Satara**	OW	-1.7	-4.6
5	**Gargoti**	OW	-1.6	-3.0
6	**Ratnagiri**	OW	-0.9	0.4
7	**Sindhudurg**	OW	-1.9	-4.8
8	**Sindhudurg**	OW	-1.7	-3.4
9	**Ghataprabha**	River	-0.7	1.1
10	**Pamchganga**	River	-1.6	-2.9
11	**Krishna**	River	-0.3	3.0
12	**Chandgad**	Spring	-2.0	-4.8
13	**Chandgad**	Spring	-0.5	1.7
14	**Chandgad**	Spring	-1.6	-3.8
15	**Satara**	Spring	0.94	5.95
16	**Satara**	Spring	1.06	5.38
17	**Satara**	Spring	0.75	3.72
18	**Gargoti**	Spring	0.74	4.73
19	**Gargoti**	Spring	-1.71	-6.32
20	**Ratnagiri**	spring	-1.97	-6.50
21	**Ratnagiri**	Spring	-3.11	-14.72
22	**Sindhudurg**	Spring	-2.43	-7.36

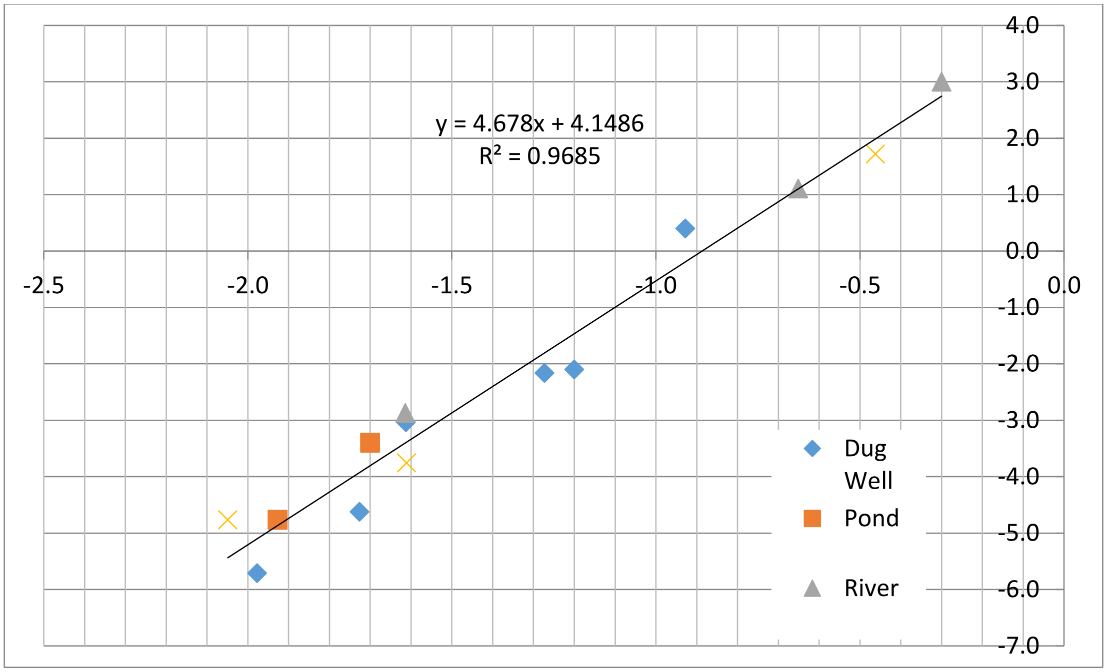


Figure 15 : Isotope plot of results

2.6 RAINFALL

IMD high spatial resolution of 0.25 x 0.25 degree daily gridded rainfall data has been collected and prepared for hydro-geological modelling of springsheds and spring-catchments. The Rainfall data has been analysed for a period of 30 years (1989-2018). The average monsoon rainfall in the study region varies from 650mm to 4200mm (Figure 16). The average annual rainfall varies between 850mm to 4881mm (Figure 17). The Eastern side of the western ghats receives comparatively less rainfall than the western side of the Western Ghats ridge.

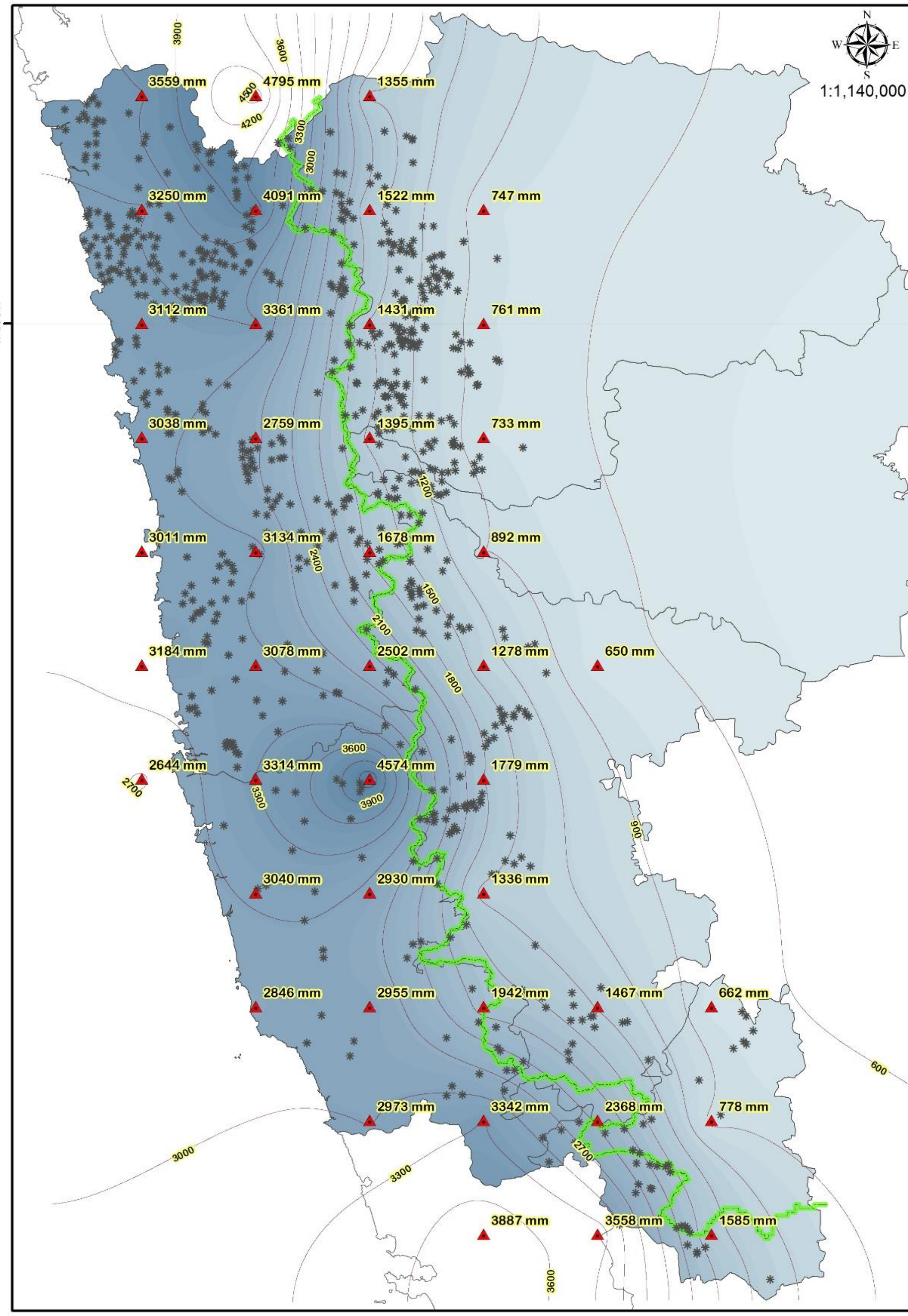


Figure 16 : Monsoon Rainfall distribution in the study region

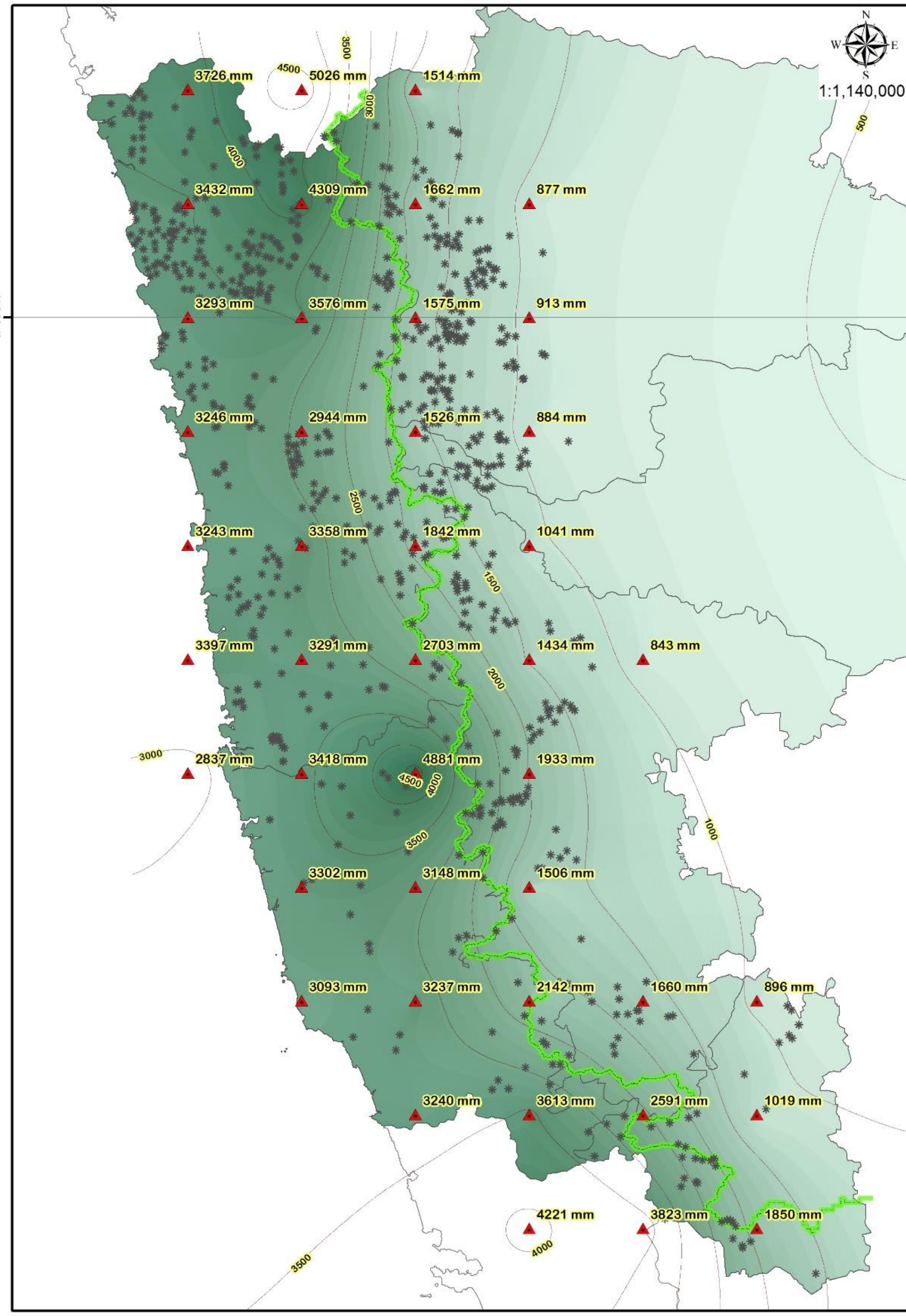


Figure 17 : Annual Rainfall distribution in the study region

3 METHODOLOGY

Modelling of Selected River Basins

In the present study, initially an attempt was made to understand the impact of various management activities on hydrological parameters, particularly with special reference to land use/land cover changes, soil and geomorphology. Accordingly, few rainfall events were selected and made measurements in selected locations in parts of Satara, Kolhapur, Ratnagiri, Sindhudurg (All Maharashtra) and Belagavi district (Karnataka). Important river basins considered for the analysis are Ghataprabha, Malaprabha, Panchaganga, Krishna (headwater catchment of Koyna reservoir) etc. Runoff was estimated using SCS method and other conventional methods. Further, water balance components were determined using SWAT model.

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).

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

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

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

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

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).

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.

The hydrology model is based on the 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.

Groundwater Recharge estimation methods

Chaturvedi Formula

Based on the water level fluctuation and rainfall amounts in Ganga Yamunadoab, Chaturvedi derived an empirical relationship to arrive at the recharge as a function of 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 of rainfall 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 being site 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.

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

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 RESULTS AND DISCUSSION

Application of SWAT Model

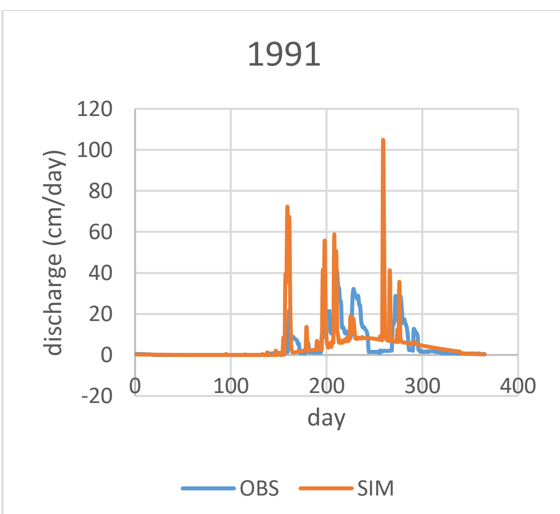
The SWAT model was set up for the Ghataprabha sub basin, following the step by step procedure outlined in the SWAT user guide (Luzio et al., 2002). The basin was divided into 3 major sub-basins and each sub-basin sub divided into smaller sub-basin based on the DEM and stream network of the study area. The 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 was 446.27 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 selected sub basins.

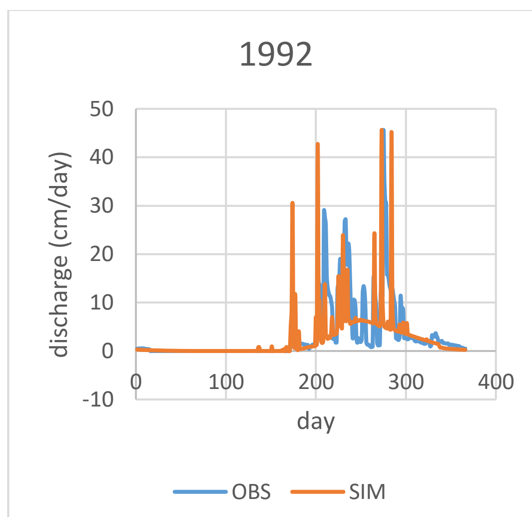
In SWAT, the first level of sub-division is the sub-basin. The number of sub-basins obtained in a watershed is determined by the minimum threshold input value for defining a drainage area. The number of sub-basins modeled in SWAT influences the number of climate stations (more importantly, the number 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 SWAT model, 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, 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.

Model Calibration

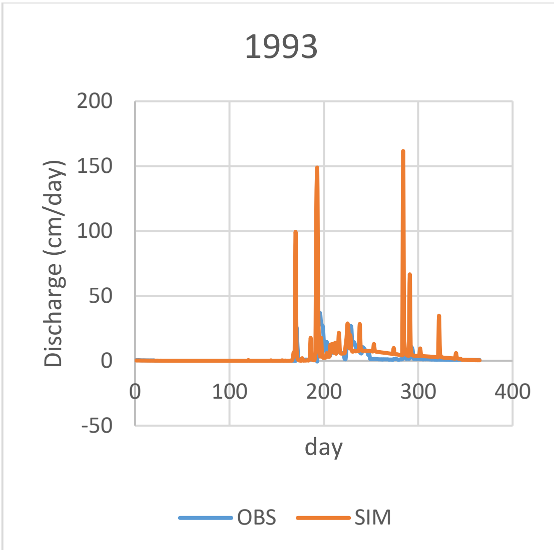
The SWAT model was calibrated with the data obtained for adjoining basin, viz. Malaprabha sub-basin at Khanapur (520 km^2). The calibration was done manually, using measured daily stream discharge data of Khanapur and following the procedure outlined in the SWAT user manual (Neitsch et al., 2002). Calibrations were done for discharge. The first step in the calibration process was the calibration for water balance and discharge for mean annual conditions in the calibration period. This was followed by monthly and daily calibrations. The calibration process focused on adjusting model-sensitive input parameters determined from the sensitivity analysis to obtain best fit between simulated and observed data. The observed and calibrated curves of daily discharge for the years 1991-1994 are shown below (figures).



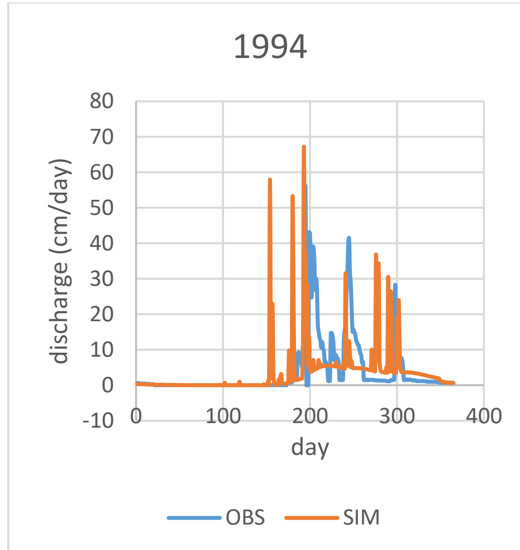
(a)



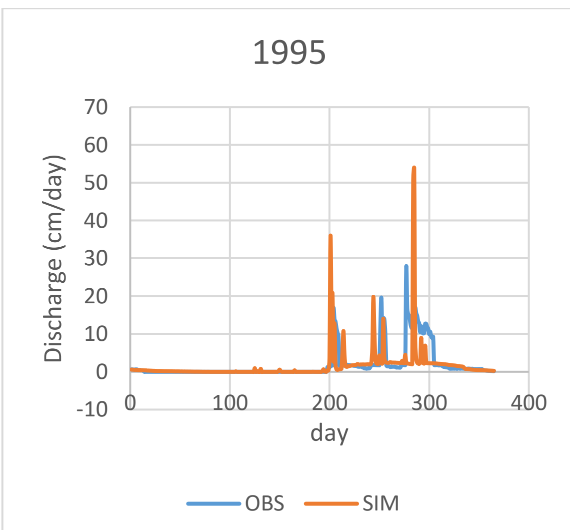
(b)


1993
Discharge (cm/day)
200
150
100
50
0
-50
0
100
200
300
400
day
OBS
SIM

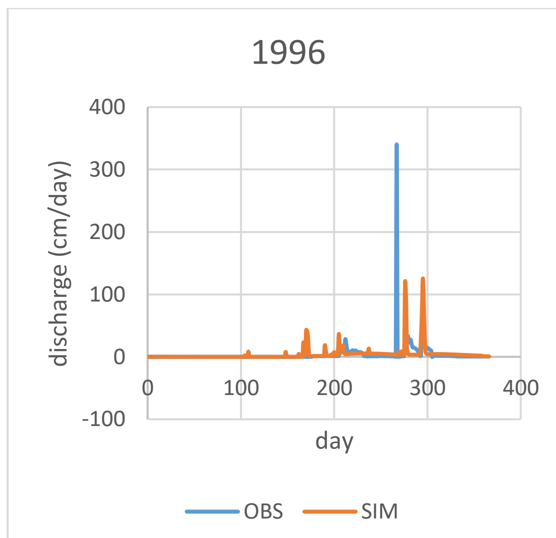
(c)


1994
discharge (cm/day)
80
70
60
50
40
30
20
10
0
-10
0
100
200
300
400
day
OBS
SIM

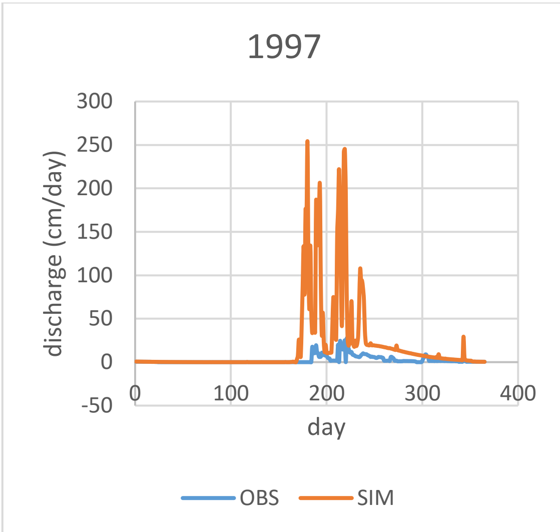
(d)


1995
Discharge (cm/day)
70
60
50
40
30
20
10
0
-10
0
100
200
300
400
day
OBS
SIM

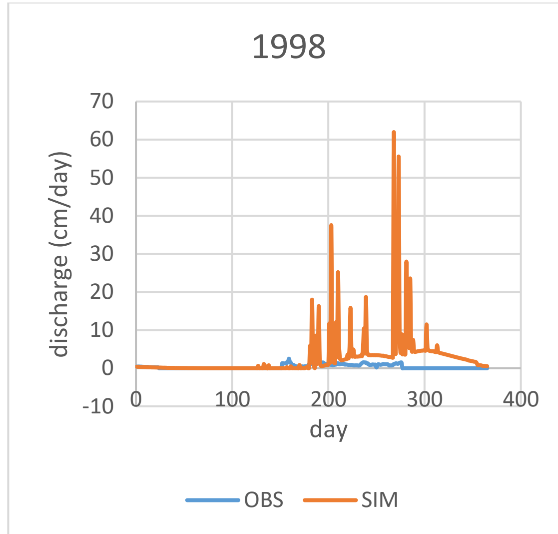
(a)


1996
discharge (cm/day)
400
300
200
100
0
-100
0
100
200
300
400
day
OBS
SIM

(b)



(c)



(d)

Figure 18 : Observed and simulated daily discharge for (a) 1995; (b) 1996; (c) 1997; (d) 1998

Calibration is the process of matching the simulated values with the observed values by iteratively changing the parameters until a good correlation is obtained. For this model, the calibrated values of the parameters are shown in the table 5:

Table 5 : Calibrated values of SWAT parameters

S. No.	Parameter_Name	Fitted_Value	Min_value	Max_value
1	R__CN2.mgt	-0.020	-0.200	0.200
2	V__ALPHA_BF.gw	0.450	0.000	1.000
3	V__GW_DELAY.gw	51.000	30.000	450.000
4	V__GWQMN.gw	0.900	0.000	2.000

Here, the parameters refer to the following:

CN2 = Initial SCS runoff curve number for moisture condition II

ALPHA_BF = Base flow alpha factor

GW_DELAY = Groundwater delay (days)

GWQMN = Threshold depth of water in the shallow aquifer for return flow to occur (mm H_2O)

Additional information about the various parameters in SWAT model can be obtained in the official SWAT documentation. It can be downloaded from www.swat.tamu.edu.

Model Validation

The SWAT model for Malaprabha catchment was validated for a period of four years (from 1995 to 1998) for daily discharge data at Khanapur gauging station. The results of the validation process are shown in figure 5.2. It is noticed that there is a considerable match between observed and simulated results.

Model Output:

The SWAT model was run for selected basins using the data range for 16 years (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. 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.

Figure 17 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.

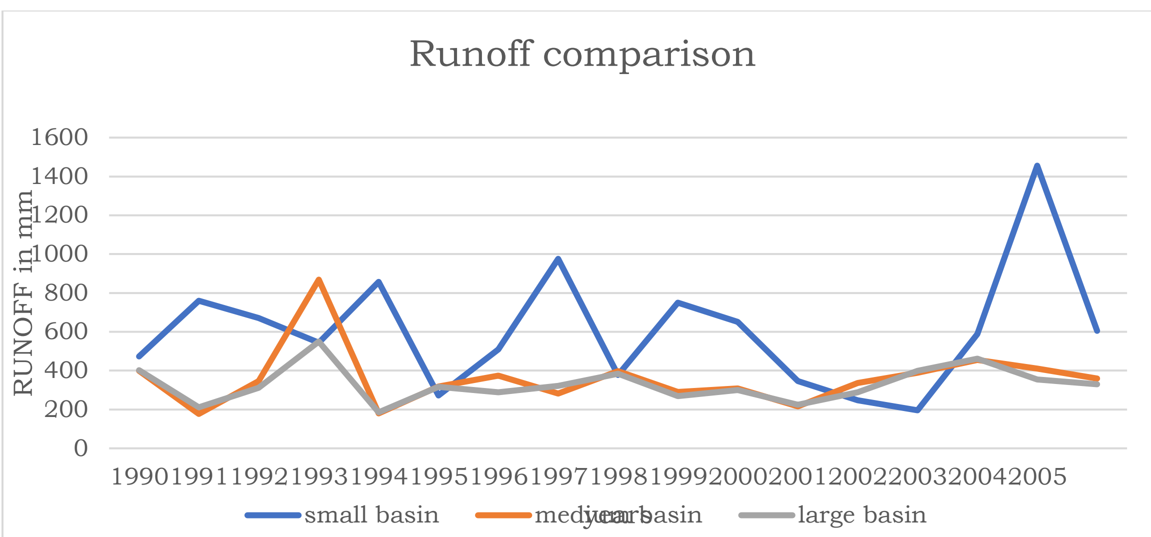


Figure 19 : Comparison of estimated runoff in three sub-basins

Table 6 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.

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 6.

Table 6 : 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 5.5

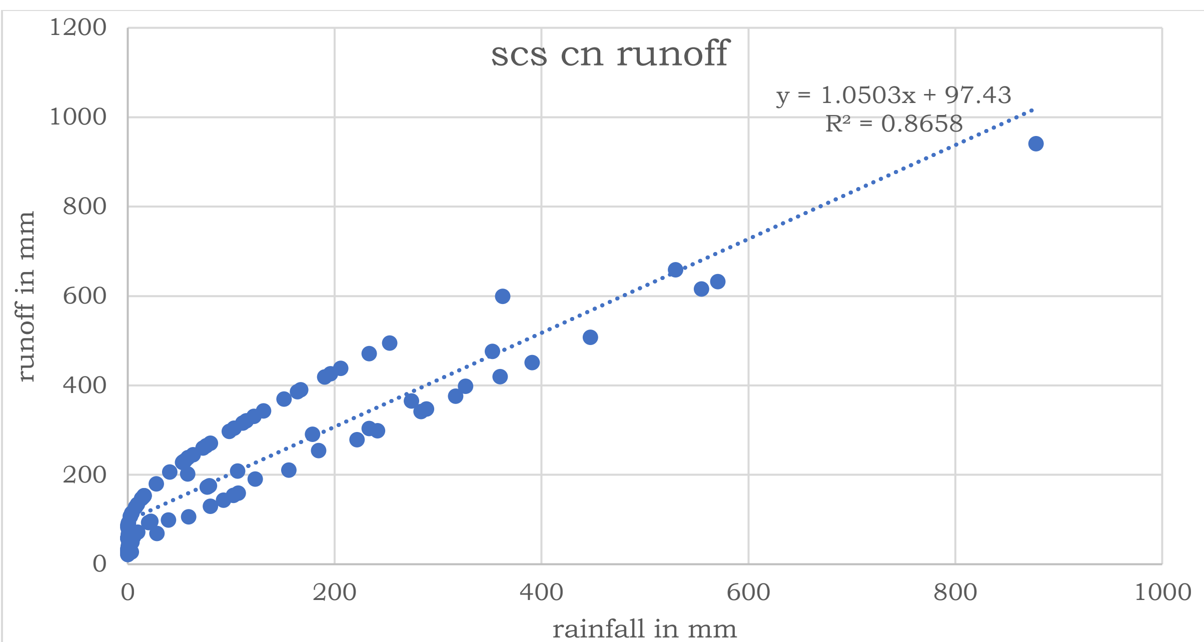


Figure 20 : Graph showing Rainfall-Runoff relation of event based.

Runoff Estimation using Conventional Methods

Table 7 shows the runoff estimated by empirical methods such as Inglis, Lacey and Khosla methods for the selected sub-basins. 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 7 : Estimated Runoff by SWAT model and Conventional methods

year	SWAT % Runoff	Inglis method % Runoff	Lacey method % Runoff	Khosla % Runoff
2001	41.92	57.98	38.64	89.79
2002	50.66	64.65	45.53	92.31
2003	51.47	61.60	42.09	91.15
2004	46.32	59.03	39.58	90.19
2005	54.01	65.76	46.92	92.73
2006	39.13	41.26	28.00	83.47
2007	45.35	57.85	38.52	89.74
2008	56.57	67.32	49.04	93.32
2009	37.50	54.71	35.96	88.55
2010	54.34	62.92	43.51	91.65
2010	49.12	62.01	42.53	91.31
2011	36.90	52.47	34.34	87.71
2012	34.00	43.16	28.90	84.19
2013	31.17	36.46	25.95	81.66
2014	44.26	62.09	42.61	91.34
2015	61.99	72.00	56.70	95.09
Avg	45.91	57.57	39.92	89.63

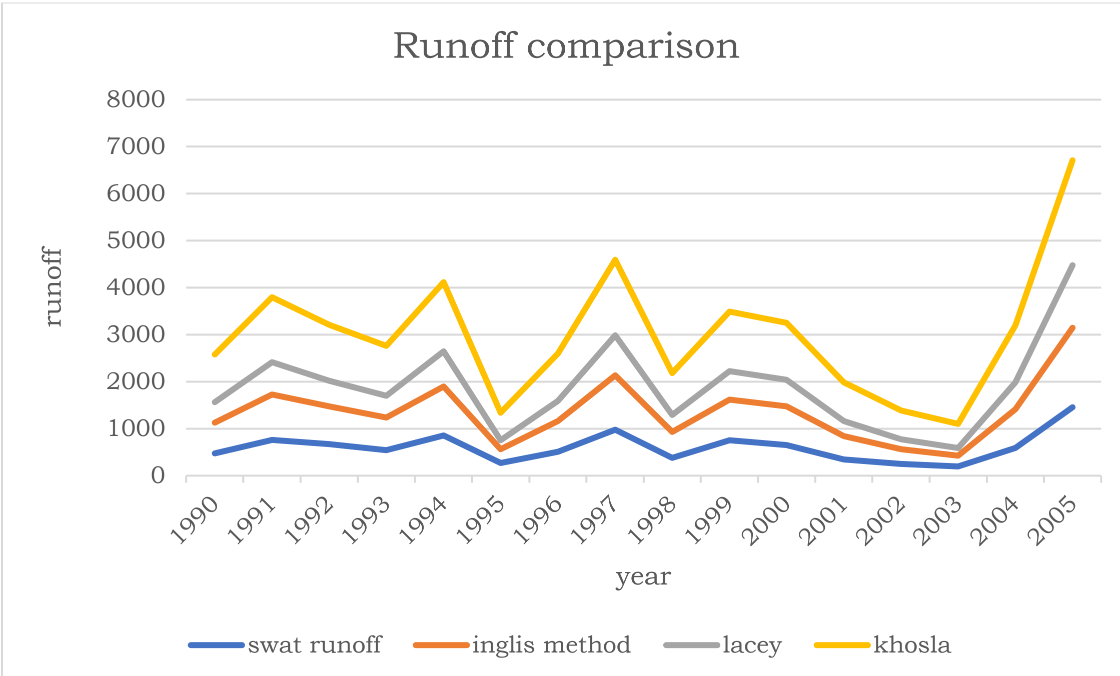


Figure 21 : . Comparison of Runoff estimated by different methods

Figures 19, 20, and 21 show the relationship between rainfall and runoff estimated by SWAT model, Inglis method, Lacey formula and Khosla's method respectively.

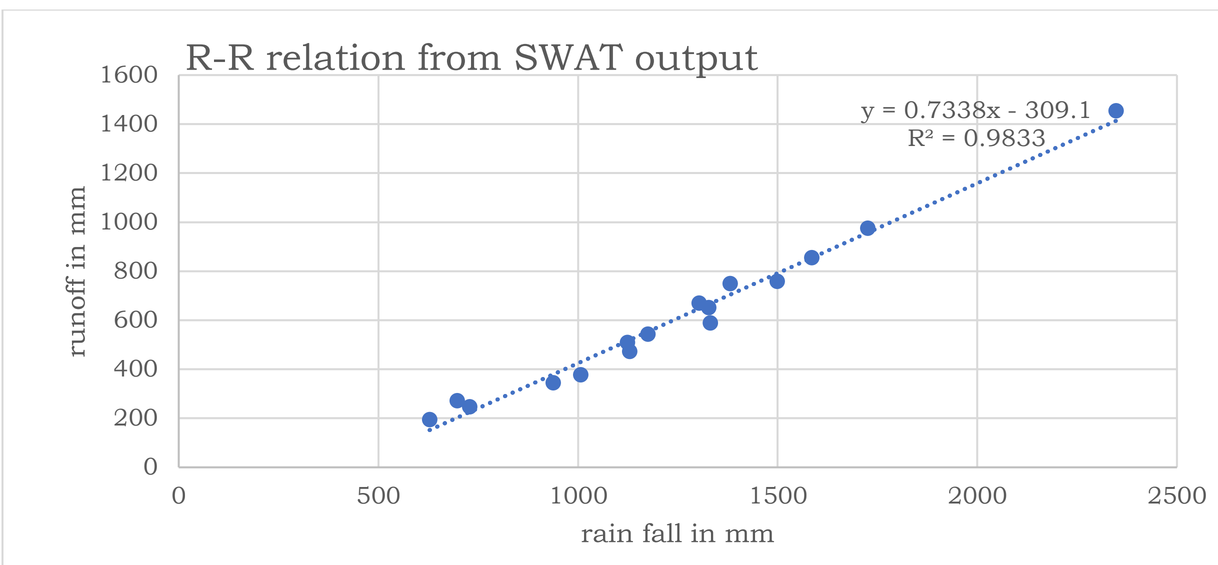


Figure 22 : Rainfall – Runoff Relation from SWAT output

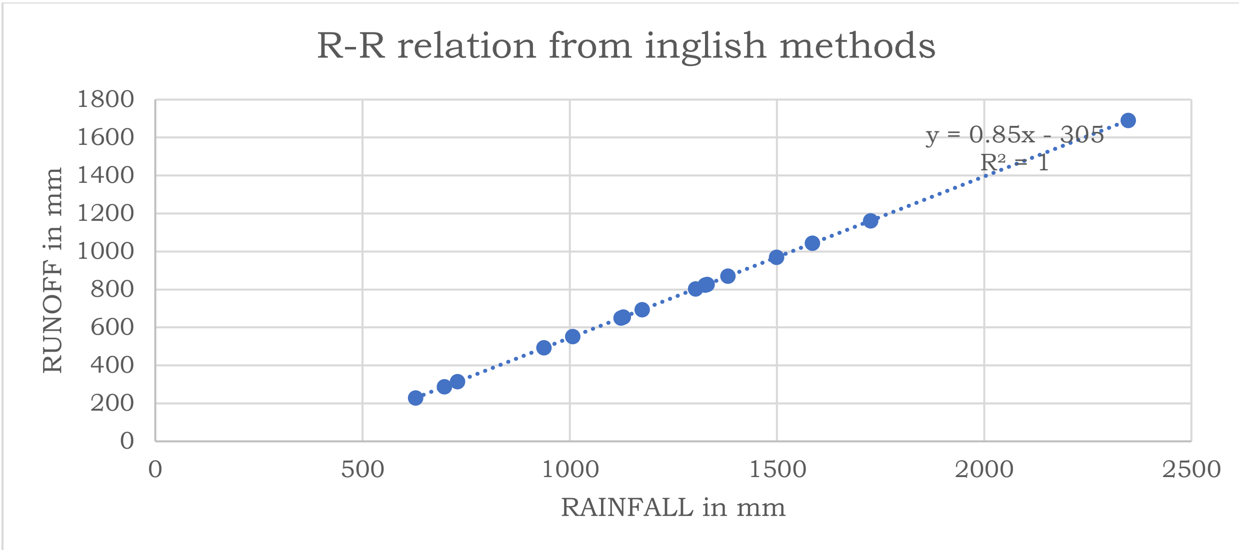


Figure 23: Rainfall Runoff Relation (Inglis method)

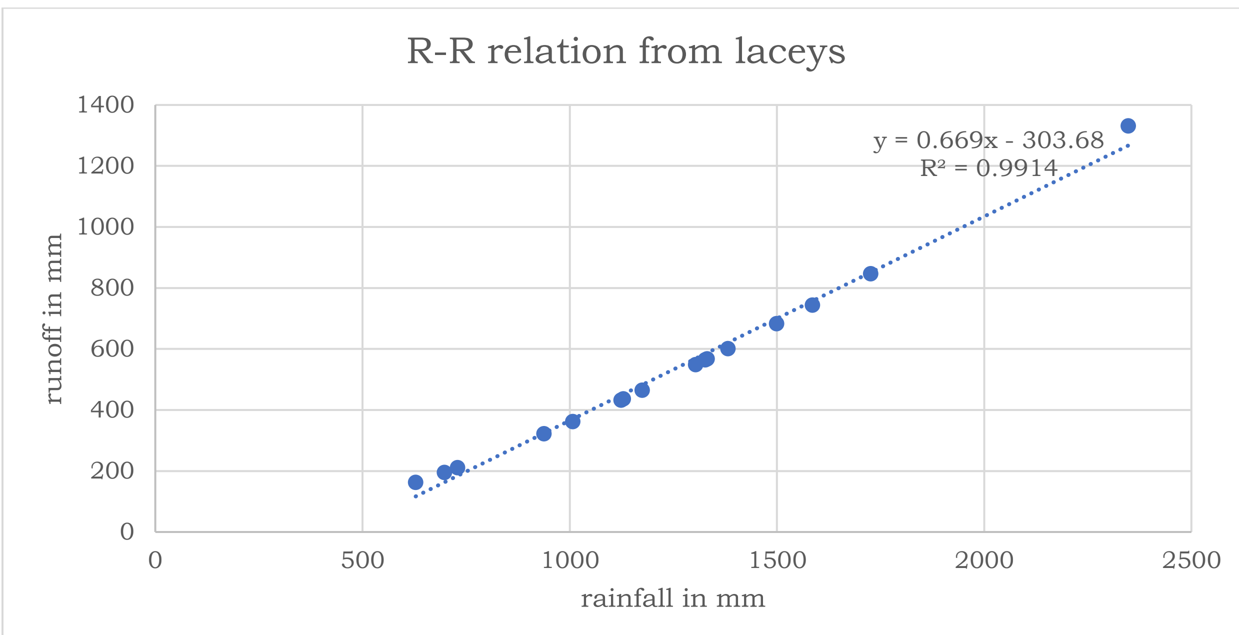


Figure 24 : Rainfall Runoff Relation (Lacey's method)

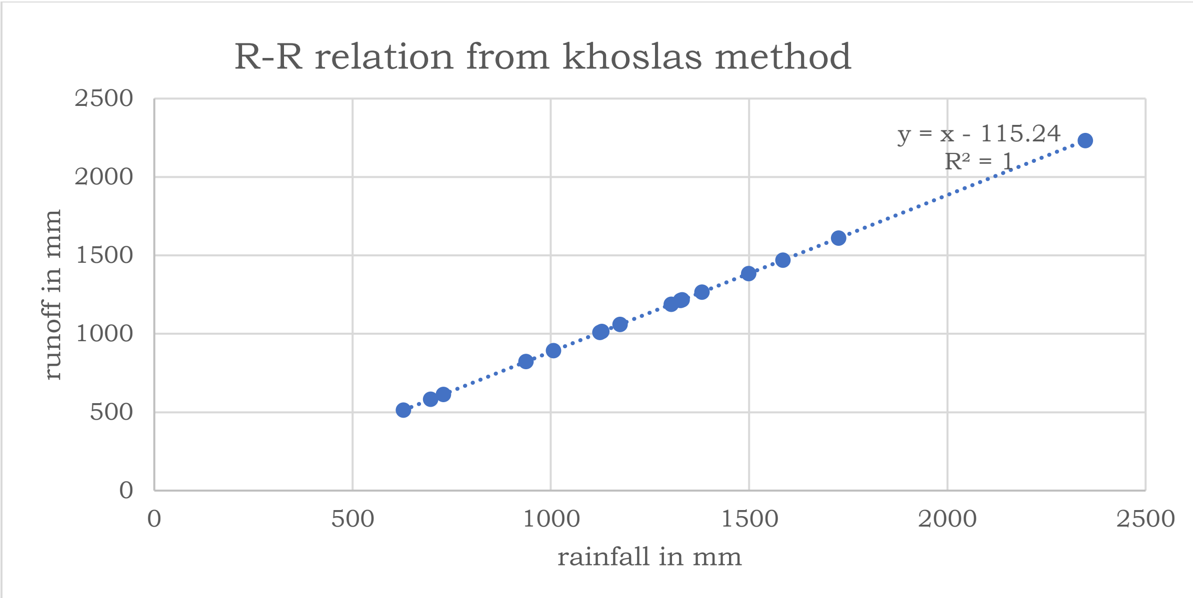


Figure 25: Rainfall Runoff Relation (Khosla's method)

5 CASE STUDIES

5.1 SATARA DISTRICT

5.1.1 Hydrogeology Methods:

Geology was mapped in the area of each spring taking transects from ridge to valley. Locations of geologic features and structures were recorded on GPS including rock type, contacts between rock formations, joints and fractures. Satellite imagery from Google Earth was also used to identify larger structures such as landscape-scale fracture systems. For each study site a geologic cross section was developed. The cross-section enabled a determination of the type of spring and provided an estimate of the extent of the potential aquifer and the likely recharge areas. These areas were visited and, based on topography or other relevant geologic features; the catchment area of the spring was delineated. These were used to inform the ecological observations of the larger ‘spring shed’, not just the spring outlet. Spring discharge was measured at the spring outlet by timed volumetric samples. Discharge was measured in the hot season (between March and May) to determine the lower bounds of water flow and to identify whether the spring was perennial or seasonal. Ecology Methods Field surveys were conducted quarterly at each study site over a one-year period between March 2017 and March 2018. Observation teams included fauna and flora experts as well as a geologist and local community members. Transect walks were conducted within the spring shed – including the spring outlet and catchment area. Surveys included inventory of flora and fauna species, identification of human pressures, impact, and land classification. Flora and Fauna.

Inventory: Observations of trees, shrubs, birds, reptiles, mammals and amphibians were conducted by the team of experts at each site. All individual species were recorded whenever possible; otherwise a large representative list was created. Special attention was given to invasive and non-native vegetation species and faunal observations at the spring outlet where biodiversity appeared high. Human Use, Impact and Land

Classification: Human pressures were recorded under direct observation and with interviews with community members. Drivers of human pressures include type and intensity of grazing, annual burning, extent and intensity of harvesting of wood, wild food or other forest/land product, extent of agriculture, construction, and groundwater pumping. Particular attention was given to the spring outlet which tended to have intensive use by domestic animals or the community in terms of infrastructure to harvest spring water. Human impacts as a result of these pressures was similarly observed: the number of domestic animals or signs of grazing, density of footpaths, extent of cut trees, signs of accelerated erosion, etc. Land use was also classified for each spring catchment using satellite imagery and field verification. Cover classes were developed after initial observations with the following definitions:

Dense Canopy – where tree spacing is less than 3m to 4m, with closed canopy and touching crowns, and multistory vegetation showing a mixed age class of trees, shrubs, herbs and climbers. This class represents the minimum human interference.

Plateau – areas with relatively flat surfaces surrounded by steep slopes. These are the characteristic plateaus of the area.

Rocky Area – areas with exposed outcrops and little soil or vegetation due to either erosion or natural means. Shrubbery – areas dominated by shrubs or small trees up to 3m height. This class could vary depending on whether the shrubs were sparse or dense.

Fields – dominated by areas under cropping or other intensive agricultural practices. Settlement – areas showing significant human activity such as any kind of infrastructure, construction, roads, houses, etc. Grassy Patches – open areas dominated by herbaceous vegetation.

Regenerating Forest – areas showing secondary growth, with smaller trees, dense undergrowth, and higher proportion of invasive species in some cases.

Results

Spring discharge ranged from 31 to 0 litres per minute in the hot season when flow is lowest. Elevations of spring outlets ranged from 1170 to 1240 meters and the size of spring catchments ranged from 6.1 to 15.8 hectares. All but one spring was determined to be a contact-type spring – meaning the spring is created when groundwater contacts a relatively impervious layer and emerges on the surface. The aquifers were generally associated with laterite rock and soils while the impervious zones were either compact basalt or lithomarge. Catchments ranged from dense, mature forests to urbanized areas, while spring outlets ranged from completely covered by springbox infrastructure to natural, open pools with diverse animal and plant life. Human pressures included annual burning, grazing, tree cutting and fuel collection, construction, and groundwater pumping. Trampling and soil compaction were also observed at many spring outlets. Specific results for each spring study location are given below, with summary information and coordinates of spring catchment centroids given below

Climate and Rainfall: The climate of the district is on the whole is agreeable. The winter season is from December to about the middle of February followed by summer season which last up to May. June to September is the south-west monsoon season, whereas October and November constitute the post-monsoon season. The mean minimum temperature is 14.40 C and mean maximum temperature is 36.8 C at Satara town in the district. The rainfall analysis for the period 1901-2005 revels that the normal annual rainfall over the district varies from 473 to about 6209 mm. In the eastern part of the district around Mhasawad (Man taluka) and Phaltan taluka it is minimum and increases toward the west and reaches maximum around Mahabaleshwar. However, probability of occurrence of normal rainfall is maximum (50 to 55%) in the south eastern part around Mhaswad (Man), Vaduj, Pusewadi and Karad. While the probability of receiving excess rainfall (i.e. 25% or more) varies from 9% to 30%. It is minimum around Mhaswad (9%) and maximum around Pusewadi (30%). The study also reveals that entire north eastern and south western part of district comprising almost entire khandala, phaltan, Khatav, Mhaswad talukas and part of Koregaon and Karad taluka which experienced drought for more than 20% of the years can be categorized as “drought area”. The average rainfall data for the period (1998-2010) are represented in table-3. The perusal of table-3 indicated that the average annual rainfall during the period ranges between 550.5 mm (Man) to 5830.3 mm (Mahabaleshwar).

5.1.2 Geology And Geomorphological Setup

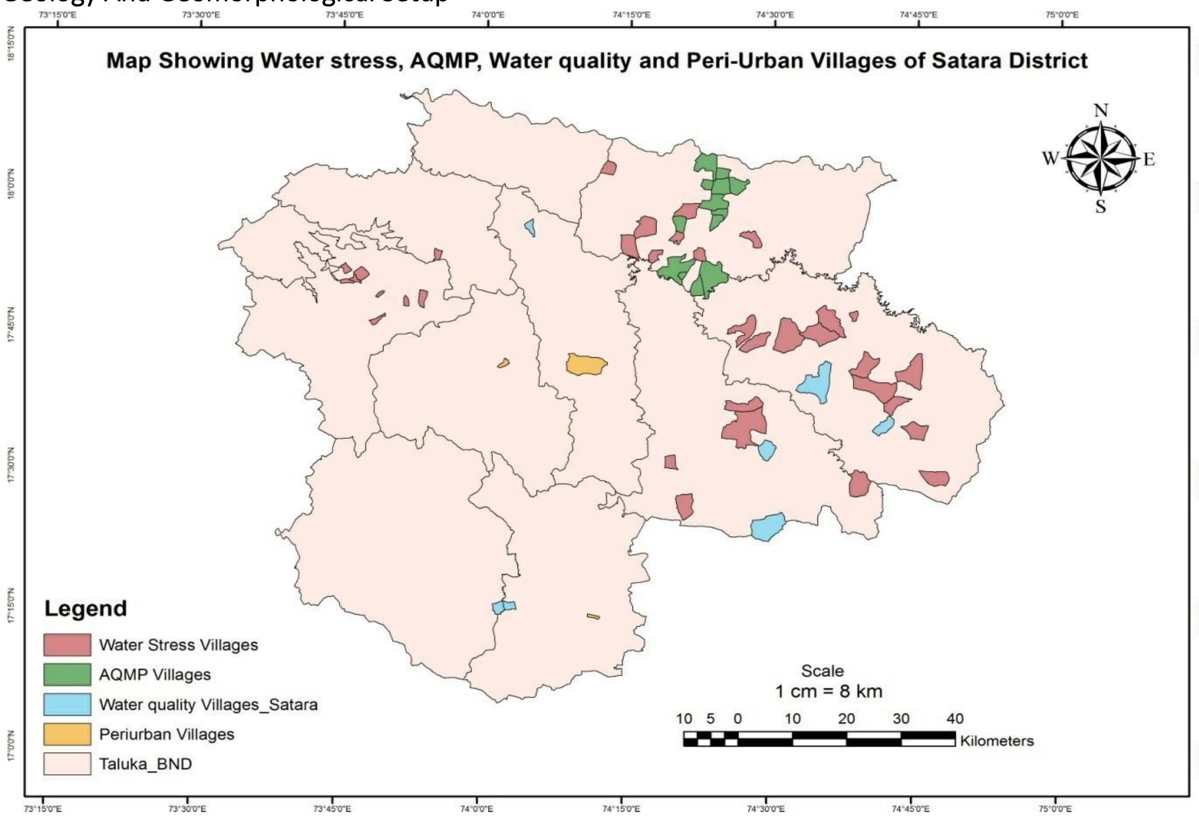


Figure 26 : : Satara District Map

The area is covered by horizontally disposed basaltic lava flows of Deccan trap formed due to fissure type volcanic eruption activity during Upper Cretaceous to Lower Eocene. During field survey work, dug well was inventoried. The surface exposures and study of road sections reveal that lower part of the basaltic lava flow is fine grained, grayish black in colour, compact and laterally as well as vertically jointed, while upper part is highly weathered.

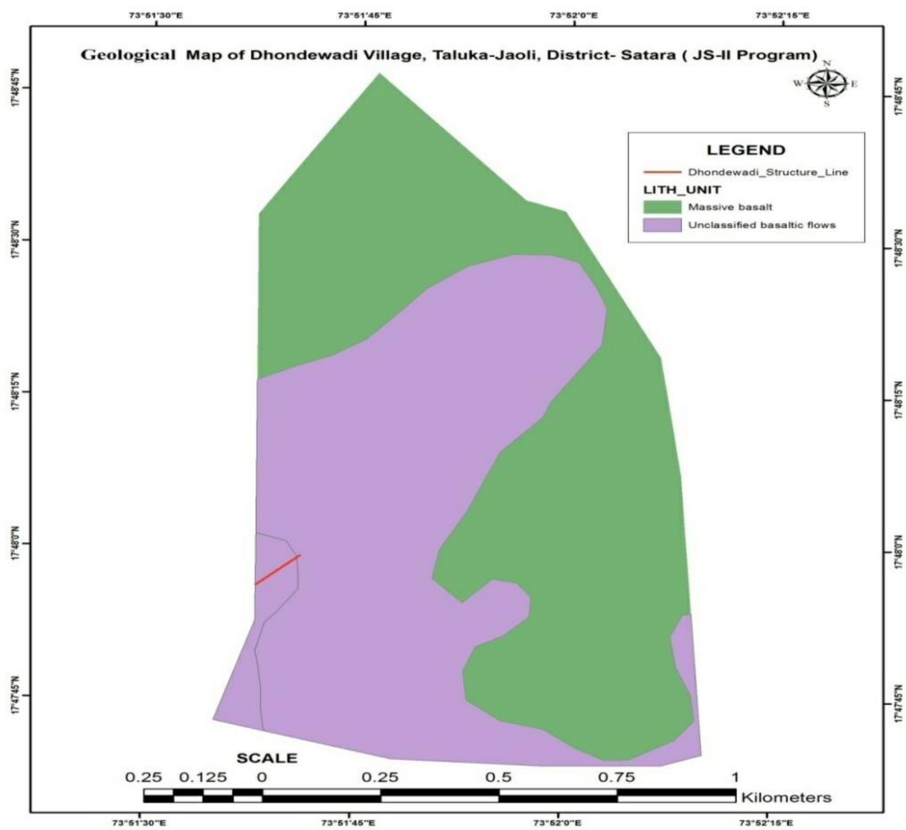


Figure 27 : Geology map of the Village study area

STRATIGRAPHY

The Study area is covered by horizontally disposed basaltic flows of Deccan Trap formed due to fissure type eruption during Upper Cretaceous to Lower Eocene about 65 (+5) million years ago. It is observed that the individual flows are varying from 3m to 35m occurs in the village. The different lava flows observed on the basis of traverses taken are indicated below: -

Table 8: Stratigraphic sequence of the study area

Sr no.	Elevation with respect to M.S.L. in mts.	Thickness in mts.	Type of flow
1	796 and above	-	Moderately weathered grey massive trap.
2	790 - 796	6	Moderately weathered, brownish, red bole encrusted vesicular zeolitic trap
3	758-790	32	Moderately weathered grey trap.
4	755-758	3	Moderately weathered light brown, vesicular zeolitic trap
5	Below 755	-	Hard sheeted grey massive trap

5.1.3 Geomorphology

In the study area, hills are the part of Mahabaleshwar plateau of Western Ghats and the village falls under highly dissected plateau. Dhondewadi is located on the foot of the hill at an altitude 830 m. above mean sea level, highest altitude in this village area is 1190 m. while lowest is 760 m. above mean sea level with an altitude difference of 430 m. The slope is steep in the south area and it becomes gentle towards North. The elevated hilly portion altitude ranges from 800m.to 1190m steeply sloping towards northern-eastern side. The western and southern boundary of Dhondewadi village is covered by hills whose altitude ranges from 850m to 1190m respectively.

5.1.4 Slope

The general slope of the Dhondewadi village is 18.2 % towards North-West. The 51% of the total geographical area shows 15-35% slope and 87% of the total geographical area shows slope more than 10% which contributes high runoff in the village.

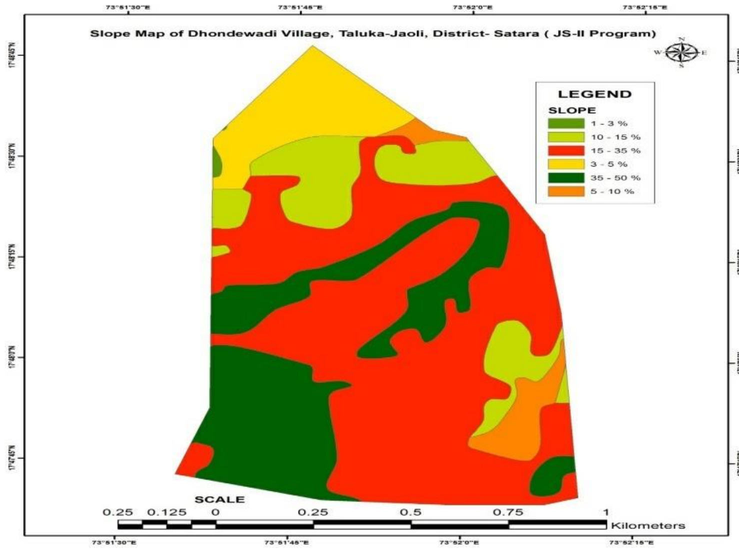


Figure 28 : Slope map of the study area

Table 9 : Slope percentage of the village

SN	Slope	Area%
1	0-1%	0.00
2	1-3%	0.19
3	3-5%	9.05
4	5-10%	3.76
5	10-15%	12.64
6	15-35%	50.99
7	35-50%	23.36

Land Use and Land Cover

The GIS map of LU/LC was analyzed. Land use is directly related to the physiography, geology, rainfall and soil cover in the area. The total area of the Dhondewadi village is 117.95 Ha. Out of the total geographical area of 117.95 Ha, Notified Forest covers 10%, un-notified forest covers 48%, Agricultural land covers 40%, built-up area covers 1%.

Drainage Pattern

The village is drained by local streams which flow in the North-East direction. All the streams are seasonal. The entire drainage is of a dendritic type. The drainage density in the village is low i.e. 5.41(km-1). All the local streams originate in the western and southern portion of the hillocks within the village area and ultimately join the Kudali River. There are eleven 1st order streams, three 2nd order streams and one 3rd order stream in the village. The bifurcation ratio of 1st order streams is 3.7 and that of 2nd order streams is 3. This shows that village has undulating terrain with high run-off percentage.

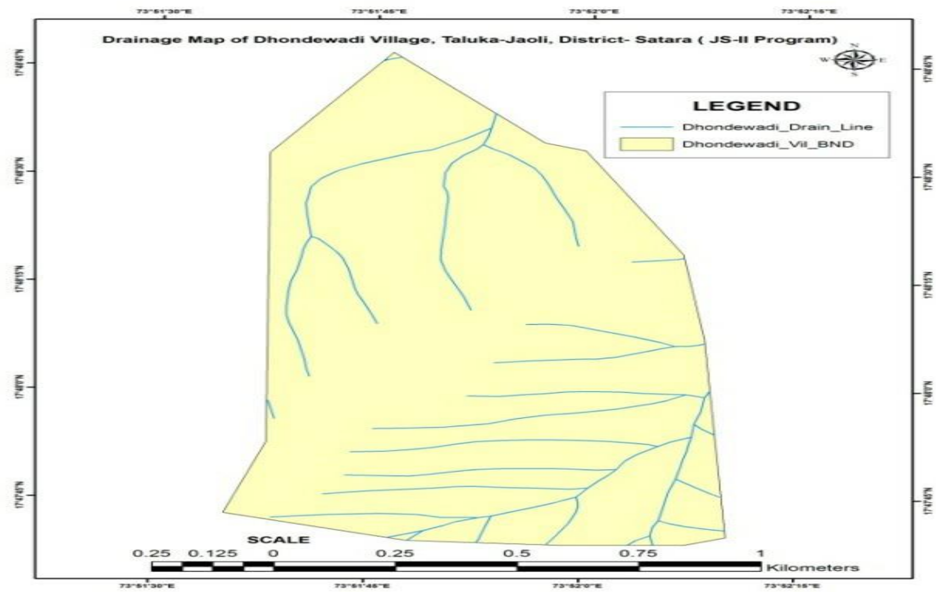


Figure 29 : Drainage map of the village

Table 10: Morphometric analysis

Stream Order	Total number of Streams	Bifurcation ratio	Stream Length (Km)	Area of Village (sq.km)	Drainage Density (Km^{-1})
First Order	11	3.7	4.8	1.18	5.41
Second Order	3	3	1.2		
Third order	1		0.4		
TOTAL	15		6.4		

5.1.5 Soils

The soils in the southern part of the village are moderately deep, well dressed, loamy soils on moderately sloping spurs with severe erosion and moderate stoniness; associated with moderately deep, well dressed, clayey soils on moderately steeply sloping spurs with severe erosion and moderate stoniness. While soils in the northern part of village are shallow, well dressed, clayey soils on gently sloping lands with moderate erosion and slight stoniness; associated with deep, well dressed, fine soils with moderate erosion and slight stoniness.

Hydrogeological Set-up

In Deccan basalt, the primary porosity is due to presence of interconnected vesicles when not filled with secondary minerals, while secondary porosity is developed due to the weathering, and due the development of joint and fractures within a rock. The ground water potential depends upon the extend of interconnection within different sets of fractures joints and weaker planes while in case of vesicular basalts, a ground water potential increases rapidly when the empty vesicles are interconnected.

In the village area, the ground water occurs under unconfined aquifer conditions. The weathered and jointed zones in the massive units form the main unconfined aquifer. The topography, the nature and extend of weathering, a jointing pattern, the thickness and the depth of occurrence of weathered basalt are important factors which govern the occurrence and movement of ground water. A general ground water occurrence is low as the local aquifer is not continuous.

In the Dhondewadi village, 8 Dug wells and 2 Bore wells were recorded. The Dug wells as well as Bore wells remains dry during summer. The aquifer is shallow and it is only observed in some parts of Dhondewadi. The aquifer remains dry during summer.

Akhegani Spring

This spring is located within the village of Akhegani in Jaoli Block, Satara District. The spring outlet and catchment area are several kilometers away from habitations, with the water being gravity-fed to the community via pipes (see Figure 3). The geological survey suggested that groundwater is being recharged through fractures on the plateau above, and through the deep lateritic soil and talus of the adjacent slopes. Percolation occurs through the soil-talus complex until an impervious lithomarge is reached. The spring outlet emerges along roughly 10 meters of the horizontal contact of the lithomarge making this a contact spring. However, other springs in the area occur not along the contour of the lithomarge but along the slope-line of nallas indicating fracture springs. As per the data available from Buono et al., (2015). Spring discharge was measured as

15 liters per minute on April 14, 2014. Land cover classes showed that 92% of the area is covered by regenerating forests. The area of both the spring outlet and catchment were similar - forested with a closed deciduous canopy of moderate density and a stratified structure showing some shrubs, climbers and the presence of regenerating species. The dominant tree species included Tambat (Flacourtia indica), Jambhul (Syzygium cuminii), and Pisa (Actinodaphne hookeri). The dominant shrubs found were Phapat (Pavetta crassicaulis), Toran (Ziziphus rugosa), Alu (Meyna laxiflora) and climbers like Ambulki (Elaegnus latifolia). In terms of fauna, birds like Red vented Bulbul, Red whiskered Bulbul, Common flora, Grey Jungle Fowl, Coppersmith Barbet, White cheeked Barbet were heard and seen. Amphibians like Indirana spp. were observed inside the spring box. It should be noted that all springs in the area were modified with a spring box. These are generally plastered brick boxes built at the spring outlet to collect water for community use – see Figure 6 for an example. Human pressures in the area include moderate encroachment on the forest in the springshed, particularly from clearing for construction and wells. Grazing, fire and tree cutting are present but limited as much of the springshed is on Forest Department land. In the more pressured areas, where the canopy has been opened from tree loss, the Forest Department has undertaken restoration and recharge practices such as infiltration basins, tree plantings and farm ponds.

Godavalli Spring:

The Godavalli village is located on the south slope of Panchgani Tableland. Panchgani town, a popular tourist destination, borders the village. Therefore, recent growth has been rapid and the village's character is changing from a rural farming community to a more urban centre with hotels, schools and weekend homes. The geological survey indicated that recharge of groundwater occurs on the laterite plateau and the adjoining slopes which are comprised of vesicular basalt. The spring emerges at the lowest point in the village, along the contact with compact basalt. A fracture zone runs approximately NW-SE through the village that appears to help carry water from the plateau to the spring. According to community members, the temple in the village was built around the spring generations ago. However, over the last few years, the spring is no longer perennial and goes dry by March. The spring was not flowing during our spring survey;

thus no discharge was recorded. In this case only 9% of the area is covered by Dense canopy and more than 40% occupied by grassy patches.

The village shows presence of large, old trees. The dominant species found were Mango (Mangifera indica) and Jackfruit (Artrocarpus heterophyllus). However, little of the historic vegetation remains as most of the trees were planted domestically. Several invasive and nonnative species were observed. Birds observed were Common Kestrel, Golden Oriole, Red vented Bulbul, Common Myna, Jungle Crow, House Sparrow, Red whiskered Bulbul, Coppersmith Barbet. Overall, however, biodiversity was low due to the proximity of urbanized area. There is intensive and continual pressure from grazing, agriculture, fuel wood collection, construction, groundwater pumping, tourism and annual burning.

Kirunde Spring: Located near the village of Kirunde, the spring is in a sparsely populated area. The catchment is on a high elevation lateritic plateau with deep soils and dense forest. The geological survey indicated that groundwater recharge occurs in the deep soils on top of the plateau and passes through laterite and vesicular basalt via a fracture system. The spring emerges just above the contact with the compact basalt. Discharge is very high (31 liters per minute in the dry season) and the flow is perennial. The catchment area on the plateau is dominated by dense forest canopy with stratified layers. Species included mature Jambhul (Syzygium cuminii) trees and a few specialized trees like Narkya (Nothapodytes nimmoniana) and Garcinia spp were also observed. The shrubs principally included Alu (Meyna laxiflora) and Karwand (Carissa congesta). Numerous animals were observed such as langur, wild pig, barking deer, and reptiles such as Brook's gecko, Pit Vipers, Rat snake, and Keelback. Leopard tracks were observed during one survey and sightings by community members confirmed their presence. Land cover classes were observed and found that dense canopy is the largest land group (71%) followed by regenerating forest of 9%. The only impact seems to be some trampling by domestic animals that use it as a water source.

Taighat Spring:

The Taighat Spring sits above Taighat village bordering the hill station of Panchgani. The geological survey found that the spring emerges from a fracture in the lower section of the laterite rock and talus complex at 1195 meters in elevation. There are several similar fractures in the area. All are vertically oriented and trend north-south as can be seen in Figure 7. Many of these fractures are associated with springs. The springs would therefore be defined as fracture springs, but occur near the contact with the compact basalt. Spring discharge was very low and seasonal, going dry in April or May. Therefore, no discharge was measured in the hot season. The spring catchments were sparsely vegetated with some stands of Gulmohor and Nilgiri trees with a much smaller number of indigenous species like Mango (Mangifera indica), Bakul (Mimusops elengi) and Sonchapha (Magnolia champaca). Vegetation at the springs outlets consisted of open, sparse grasses and shrubs with occasional trees such as Bombax ceiba (Kate Sawar). The faunal activity observed was mainly of common city based bird species like Common Myna, Red vented Bulbul and Land cover class was observed with dense canopy of 39% and grassy patches 52%.

Human pressure was high with intensive land use including roads, construction, residential and commercial (tourism) structures, wells and a number of latrines just upslope from the spring outlets. According to community members, the latrines, placed roughly 30 meters upslope of the spring outlet, have contaminated the water. This spring, as well as all of the others in the area, are no longer used for drinking and are now solely for domestic livestock, small-scale irrigation of tree plantations and car washing. There are a series of spring boxes built to harvest water, including a separate small tank below the outlet for domestic animal use.

Umbri Spring: Located in Umbri Village, the geological survey for this spring suggests that groundwater is recharged via a rocky laterite plateau and the slopes above the spring. The spring outlet occurs near the contour of the contact between the laterite and the compact basalt, indicating a contact spring. Discharge was measured as 5.5 liters per minute in April 2014. The catchment is a mixture of grasslands, rocky outcrops and small patches of moderately dense shrubs. In grassland patches the catchment shows dominance of Themeda spp. with few herbs like Sonaki (Senecio bombayensis), Leucas aspera and Pogostemon decccanensis. The dense patches included presence of Pisa (Actinodaphne hookeri), Jambhul (Syzygium cuminii), Hirda (Terminalia chebula). The area surrounding the spring outlet is open with occasional tall trees and shrubs including Walunj (Salix tetrasperma), Karwanda (Carissa congesta), Toran (Ziziphus rugosa) and Phapat (Pavetta crassicaulis). The bird species mainly included Red vented Bulbul and Common fIora. Little other fauna was observed. Human pressure included intensive grazing, annual fires and fuel wood collection in the catchment, as well as intensive domestic animal presence at the spring outlet. The spring outlet sits above the village and is used to gravity-feed drinking water to the community centre. A springbox is built on the spring outlet, and connected nearby is an open tank for domestic animals to drink. Discussion Hydrogeology Spring discharge across the springs studied averaged 10.3 liters per minute in the hot season. The aquifers were mainly composed of laterite with some vesicular basalt. All were considered contact-type springs that emerged at the lithomarge at the base of the laterite or at the contact with the compact basalt, except for the fracture-type spring at Taighat. Elevations were generally around the 1200-meter mark which marks the lower margin of the laterite plateaus in the area. Although only a small number of springs were selected for this study, these characteristics are consistent with the only detailed spring survey conducted in the area, by Naik et. al. (2002). The only difference we observed was the presence and impact of fracture zones. Naik et. al. (2002) found only 12% of springs could be classified as fracture springs, and attributed little effect to fractures on the springs. This study, however, found that the majority of springs investigated were associated with fractures, even if they could not be specifically defined as fracture-type springs. Fracture zones have been proven to serve as conduits for groundwater infiltration and transmission in the Northern Western Ghats (Krishnamurthy et. al. 2004; Lie and Gudmundsson 2002; Peshwa et. al. 1987). They are therefore very likely to play a significant role in spring formation. Fractures were also found to connect different parts of the landscape with outlets and catchment areas often geographically distant. The fractures tend to be vertically oriented and can extend from the surface down through mountains passing through all rock types, essentially connecting porous rock formations and allowing water to percolate through impervious formations. Therefore, a spring in a valley bottom may be recharged from a catchment on a mountaintop hundreds of meters above (Deolankar et. al. 1980; Kale and Kulkarni 1992; Kulkarni et. al. 1995; Peshwa and Deolankar 1990). Fracture zones were evident at Taighat, Kirunde and Godavalli. Although not part of this study, adjacent spring sites at Kirunde were also fracture-type. These fractures tended to span rock formations including the laterite plateaus at the top of the watersheds. In the case of Kirunde and Taighat, they possibly spanned the ridgeline which would extend the catchment across the watershed boundary. Figure 10 illustrates the typical groundwater flow paths including contact springs emerging at the base of the laterite along the contact with the compact basalt, as well as along fractures crossing numerous rock formations. Ecology Vegetation and animal surveys showed a large variation between springs. The Kirunde spring catchment was dominated by dense-canopy, mature forest and exhibited diversity of native plants and animals. The spring outlet was in a natural state and provided habitat to numerous species including an area leopard. In contrast, Godavalli catchment was dominated by human oriented land use.

5.1.6 Drinking Water Source Dependability

All families i.e. 29 families of the Dhangarwasti, Dhondewadi village use PWS from `natural spring in the southern side of village. There is one common water supply stand locally known as Kondale. For 29 families the common stand is nearby. During summer i.e. March-June, the natural spring does not yield up to the norms, and required drinking water is supplied by means of tanker.

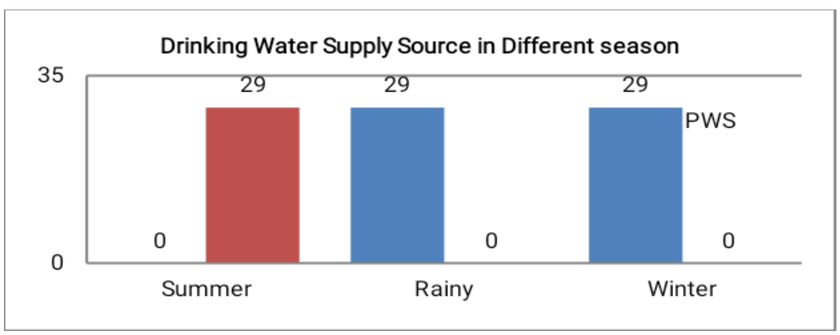


Figure 30: Bar diagram showing drinking water supply source of Dhangarwasti

Yield of the Source

The natural spring in southern side of village is the only drinking water source in the Dhangarwasti. According to measured and reported readings calculations were made. The calculation indicates that natural, yield up to the norms in the months of July to November (i.e.35KLPD) and it yields very poor in the months of March to May (0.5KLPD). During scarcity period, drinking water is supplied by tanker.

Table 11: Yield of open well with respect to time

Month	Head (inch)	Angle	Discharge coefficient	Head correction factor(inch)	m3/day	Lit/day	Total month
Jun	0.3	90	0.5779049	0.034830202	0.787	787	23610
Jul	1.5	90	0.5779049	0.034830202	71.652	71652	2221200
Aug	1.5	90	0.5779049	0.034830202	71.652	71652	2221200
Sep	1.5	90	0.5779049	0.034830202	71.652	71652	2149548
Oct	1.5	90	0.5779049	0.034830202	71.652	71652	2221200
Nov	1.0	90	0.5779049	0.034830202	35.404	35404	1062130
Dec	0.7	90	0.5779049	0.034830202	5.615	5615	174074
Jan	0.5	90	0.5779049	0.034830202	2.538	2538	78670
Feb	0.4	90	0.5779049	0.034830202	1.513	1513	42351
Mar	0.3	90	0.5779049	0.034830202	0.787	787	24397
Apr	0.3	90	0.5779049	0.034830202	0.787	787	23610
May	0.2	90	0.5779049	0.034830202	0.324	324	10050

5.1.7 Chemical Quality Analysis

It is observed that ground water is used for drinking, considering these aspects the water sample from natural spring near storage tank, Dhangarwasti was collected and analyzed in SDL, Somardi, Jaoli to find its suitability for different uses. The samples were analyzed for pH, conductivity, TDS, iron, nitrate and fluoride. It is observed that pH is 8.3. The water is suitable for drinking as TDS level is 319 mg/l and Fluoride level is 0.66 mg/l which are well below the standard permissible limit.

Table 12 : Chemical analysis of the Spring water

Sample Collected	Nitrate (mg/L)	Fluoride (mg/ L)	Iron (mg/ L)	TDS (mg/L)	Alkalinity (mg/L)	pH	Chloride (mg/L)	TH (mg/L)
Post-monsoon season	1.125	0.66	0.051	319	136	8.3	32	200

5.1.8 Water Balance

The water requirement for domestic use is 2.36 ham, for agricultural use is 2.4 ham and available water for utilization is 3.98 ham. Thus, water balance of the Dhondewadi village is -0.77 ham. Due to its geological and geomorphological setup, the village faces water scarcity during summer. After rainy season, in the month of October and November groundwater drains out as a base flow through streams.

Table 13: Water balance of the Dhondewadi village

Village Name - Dhondewadi			Population		576	
1	Total Geographical area				117.95	Ha
2	Average rainfall	1515	mm		1.515	m
3	Total available water from rainfall (area *rainfall)	179	ham		2	MCM
Forms of water available						
3a	Recharge	7.97	ham	4.46%	0.1	MCM
3aa	Base flow	3.98	ham	50%	0.0	MCM
3b	Soil Moisture Retention	6.36	ham	3.56%	0.1	MCM
3c	Surface Run off	151.89	ham	85%	1.5	MCM
3d	Evapotranspiration	12.47	ham	6.98%	0.1	MCM
4	Net Water available for Utilization	3.98	ham	(Recharge - Base flow)	0.04	MCM
5	Water requirement					
5a	Water Requirement for Domestic use					
	population *60*365	1.26	ham		0.01	MCM
	Cattles*60*365 (100)	1.10	ham		0.01	MCM
5b	Crop Water requirement					

	Crops	Area (ha)	Water Requirement (per ha)	Water Use (ham)	Water Use (mm3)	
	Jowar	4	0.6	2.4	0.00	MCM
	Total	4		2.4	0.02	MCM
6	Total Requirement of Agriculture purpose	2.4	ham		0.02	MCM
7	Total water Requirement for Village (Domestic + Agriculture)	4.76	ham		0.05	MCM

5.1.9 Drinking Water Problem

The Dhangarwasti faces drinking water problem during summer season. The Dhangarwasti has one natural spring. It is reported that water is available for drinking up to the norms (i.e.40 liters) in months of July to November as natural spring yields good water. But spring yield declines below norm from months of January to June. During the scarcity period water is supplied by tanker. There is a pipe water supply scheme based on natural spring for Dhangarwasti. There are two storage tanks with capacity of 12,500 liters each, of which one is damaged. The requirement of water during water stress period is 8,39,553 liters. Thus water scarcity is observed in village during months of February to June. During scarcity period water supply is provided by means of tanker supply.

Table 14: Drinking water balance in the Dhangarwasti

Month	Monthly available	Monthly require	Monthly Balance
Jun	45376	175200	-129824
Jul	2221200	181040	2040160
Aug	2221200	181040	2040160
Sep	2149548	175200	1974348
Oct	2221200	181040	2040160

Nov	1062130	175200	886930.2
Dec	174074.4	181040	-6965.63
Jan	78669.64	181040	-102370
Feb	42350.93	163520	-121169
Mar	24396.58	181040	-156643
Apr	23609.59	175200	-151590
May	10049.68	181040	-170990

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 उन्हाळयात 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.

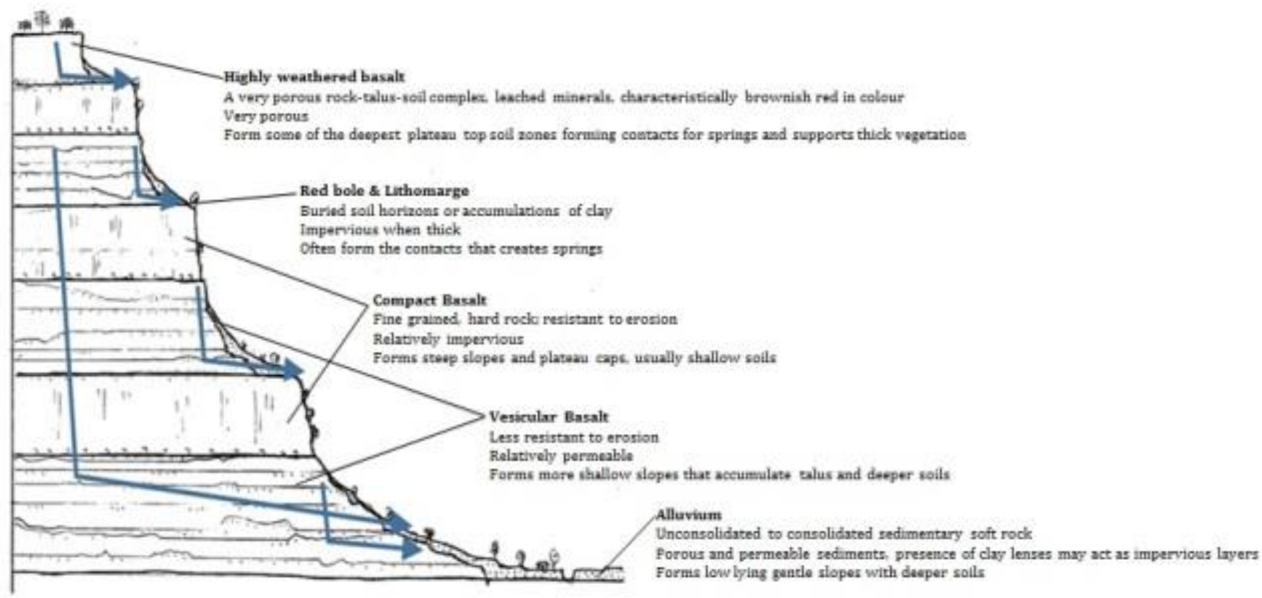


Figure 31 : Typical framework of Hydrogeological units with genderalised groundwater flow paths (modified and adapted from Buono et al. 2015)

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.

0.16	0.51	0.0016	1.739	91.752

Where θs and θr are the saturated and residual moisture and α and n are the van-Genutchen parameters, and

$$m = 1 - 1/n$$

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

Groundwater Recharge

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 15 : Estimated GWR using SWAT model and Conventional methods

Year	GW R in mm	% Recharge	Chaturvedi (mm)	% Recharge	Krishna Rao (mm)	% Recharge
1990	218.7	19.37	205.2	18.17	204.14	18.07
1991	274.1	18.28	236.4	15.76	292.92	19.53
1992	227.9	17.48	224.7	17.24	257.422	19.74
1993	217.9	18.55	225.8	19.22	258.57	22.01
1994	305.7	19.28	252.7	15.94	346.71	21.86
1995	94.56	13.55	162	23.22	110.915	15.90

1996	225.0	20.02	223.2	19.86	252.46	22.46
1997	283.7	16.43	256.0	14.83	358.15	20.75
1998	195.3	19.39	197.1	19.57	184.132	18.28
1999	271.5	19.65	242.8	17.57	312.94	22.65
2000	230.1	17.34	224.4	16.90	255.795	19.27
2001	178.9	19.07	182.8	19.50	151.66	16.17
2002	130.2	17.86	162.0	22.22	110.83	15.20
2003	84.79	13.49	143	22.75	79.87	12.71
2004	289.5	21.75	221.4	16.63	247.56	18.59
2005	451.5	19.23	299.2	12.74	672.455	28.64
Avg	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 29, 30, and 31 show the relationship between rainfall and groundwater recharge.

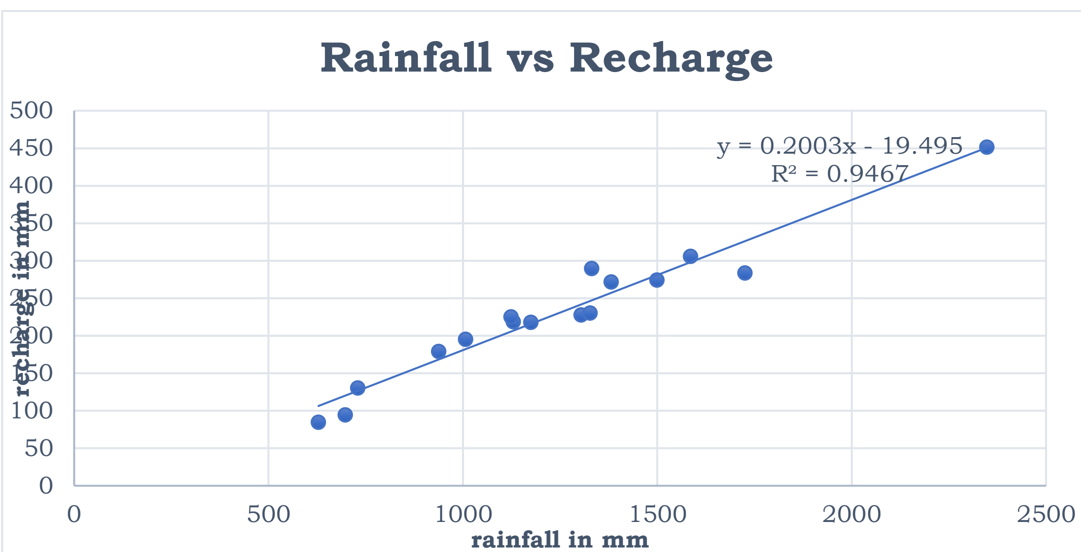


Figure 32 : Rainfall-Recharge Relation (SWAT output)

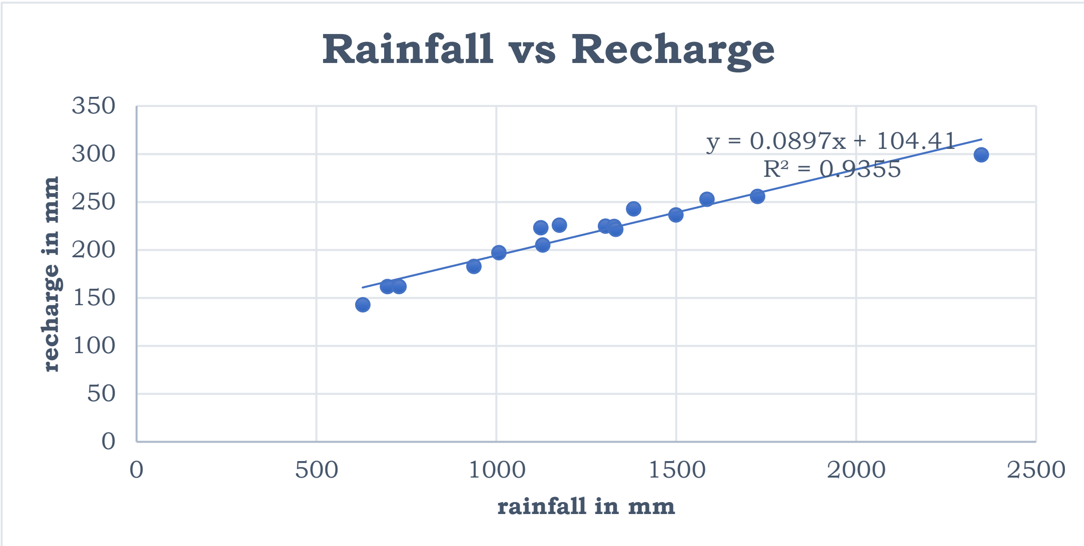


Figure 33 : Relationship between Rainfall and Recharge using Chaturvedi method

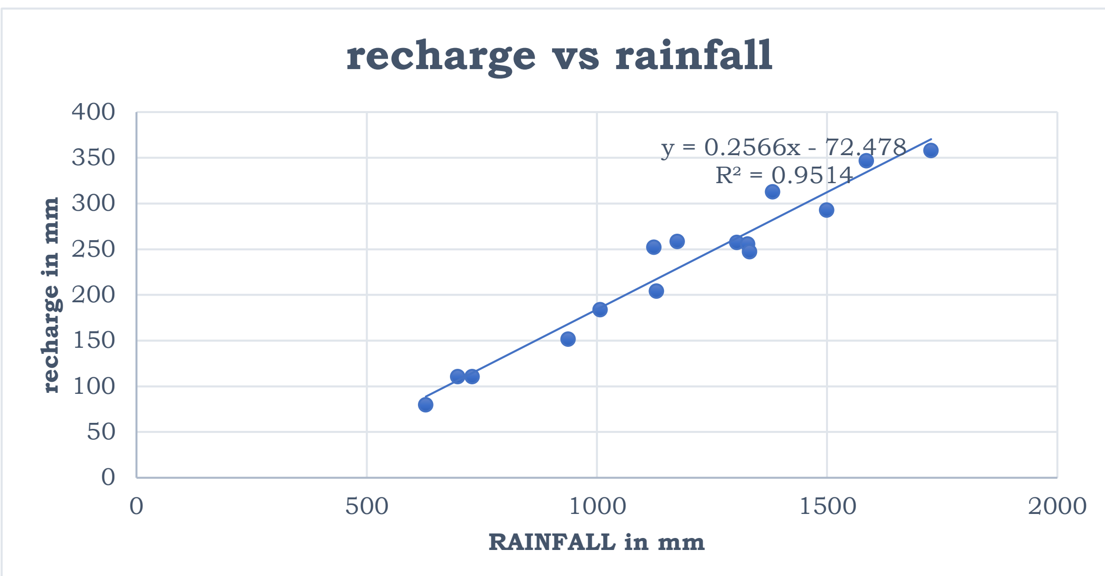


Figure 34 : Rainfall Recharge Relation. (Krishna Rao's method)

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.

Table 16 : Comparison of SWAT output of sub-basins with varying slope conditions

Hydrological Components	Slope greater than 30%	Slope between 15%to 30%	Slope less than 15%
Surface runoff %	68.90	63.81	54.84
ET%	16.21	18.75	21.11
Lateral soil flow %	0.97	2.14	7.68
GW(shallow AQ) %	11.70%	12.99%	13.44%
Deep AQ recharge %	0.06%	0.067%	2.20%
Total AQ recharge	11.76	16.66	18.64

5.1.10 Water Quality of Water Supply Springs

The following are the important sites where springs are distributed and used for water supply.

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 17 : Values of the Concentrations (mg/l) obtained by analysis

Samples	**Chlorides**	**Alkalinity**	**Acidity**	**Hardness**
Bore well 1	11.91	180(HCO^{3-})	0	76
Bore well 2	37.72	308(HCO^{3-})	16	32

Bore well 3	13.92	200(HCO^{3-})	24	124
Bore well 4	13.9	332(HCO^{3-})	12	96
Spring water 1	9.92	40(CO^{3-})	2	40
Spring water 2	9.92	20(HCO^{3-})	2	0
Spring water 3	0	30(OH^{-})	2	90
Spring water 4	0	20(HCO^{3-})	12	0
Spring water 5	9.92	30(HCO^{3-})	2	40
Spring water 6	9.92	30(HCO^{3-})	12	30

Table 18: Different Parameters for samples collected.

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

5.2 Impact of Landscape Dynamics on Hydrological Parameters and Springshed Development of Kanbargi Area In Belgaum

5.2.1 Introduction

Mountain springs emanating naturally from unconfined aquifers are the primary source of water for the rural households dominantly in parts of Western ghats and also in patches of the hard rock aquifers distributed in Peninsular India. With impacts of climate change, manifested in the form of rising temperatures, rise in rainfall intensity, reduction in its temporal spread with a marked rise or fall in rainfall pattern and increased human intervention, the problem of dying springs is being increasingly felt across this region. Therefore, it is the need of the hour to look for various sources of water bodies with a specified focus on rejuvenation of springs and adjoining watershed for the sustainable water supply and also for other human needs which includes both agriculture and recreational purposes.

In this context, a detailed analysis of a springshed located on the hills of Belagavi city (Kanbargi hills). The major challenges faced in springshed development were identifying recharge areas accurately, developing local capacity, incentivizing rainwater harvesting in farmer's fields and sourcing public financing. The mean discharge of the springs was found to peak at 136 litres per minute during the post monsoon (Oct-Dec) and then diminish to less than 68 litres per minute during spring (Mar-May). The lean period (mar-may) discharge is perceived to have declined by nearly 50% in drought prone areas and 35% in other areas over the last decade.

The springshed development approach to revive these springs using rainwater harvesting and geohydrology techniques showed encouraging results, with the lean period discharge increasing substantially. Accordingly, to initiate an action plan as a part of the smart city program, detailed hydrogeological investigations have been carried out using remote sensing data products and discharge variations based on stress conditions. Simulation studies of the springshed was carried out to understand the impact of LULC changes on groundwater recharge using SWAT model. Based on the model results rainwater harvesting and conservation measures have been adopted to enhance the recharge using simple recharge structures and also to revive the existing spring to sustain the unforeseen drought condition and at times of excess rainfall/recharge the water may be used for the revival of lake water bodies present in the downstream part of the springshed. The said study is under implementation as a part of the Belagavi Smart City program for both revival of lakes (3 numbers in the downstream) which will be used for recreation purpose of publics in the region.

5.2.2 Study area

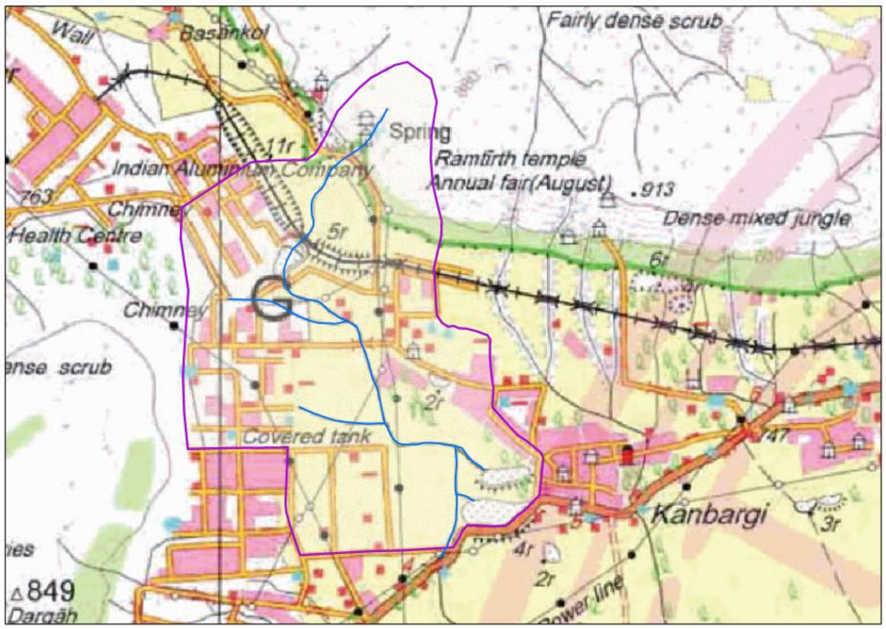


Figure 35 : Index map of Kanbargi Springshed

Figure 36 : Google earth imagery of Kanbargi Springshed

5.2.3 Thematic layers

Geomorphology and Groundwater prospects: The Springshed has highly dissected plateau on the uppermost reaches of the Springshed. This zone is characterized by high recharge rate. This is followed by an outer fringe of upper plateau where the slope drastically starts increasing. The features of the plateau zones are essentially formed over horizontally layered rocks marked by extensive flat top and steep slopes. Since, plateau is highly dissected, there are good to moderate groundwater flows along fractures/ joints/ lineaments especially at intersections. This zone has the origin of many springs in the Kanbargi Springshed. The downstream of springs is composed of Lateritic plain shallow geomorphology. The groundwater prospects in this area is moderate.

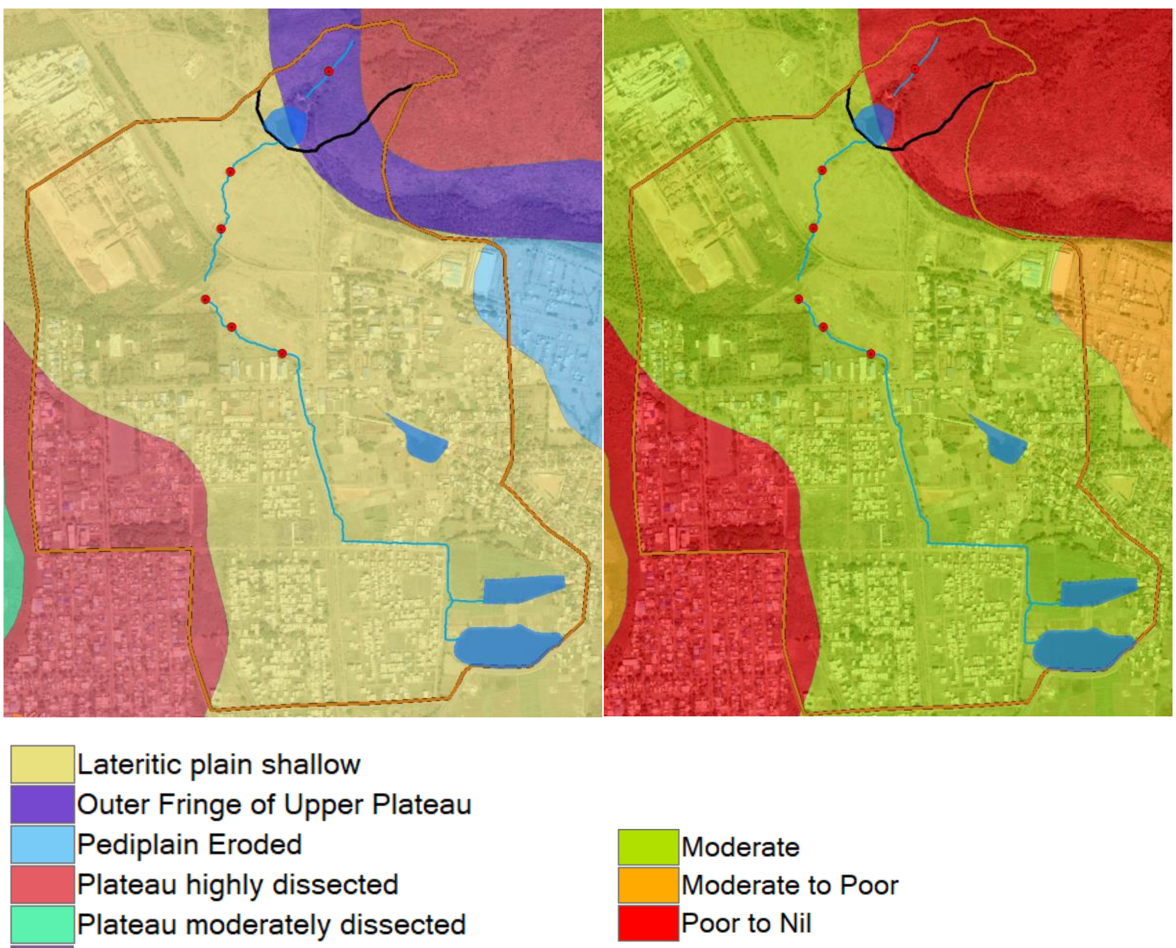


Figure 37 : Geomorphology and groundwater prospects map of Karnbargi Springshed area

Slope: The slope analysis of 1:50k scale indicates that the terrain is characterized by gentle slopes in the uppermost part of the Springshed followed by sudden strong and very steep slopes. The springs are originating at the transition point of slope from 3-5% to 10-15% and 35-50%. This is followed by gradual change from moderate slopes to nearly level topography.

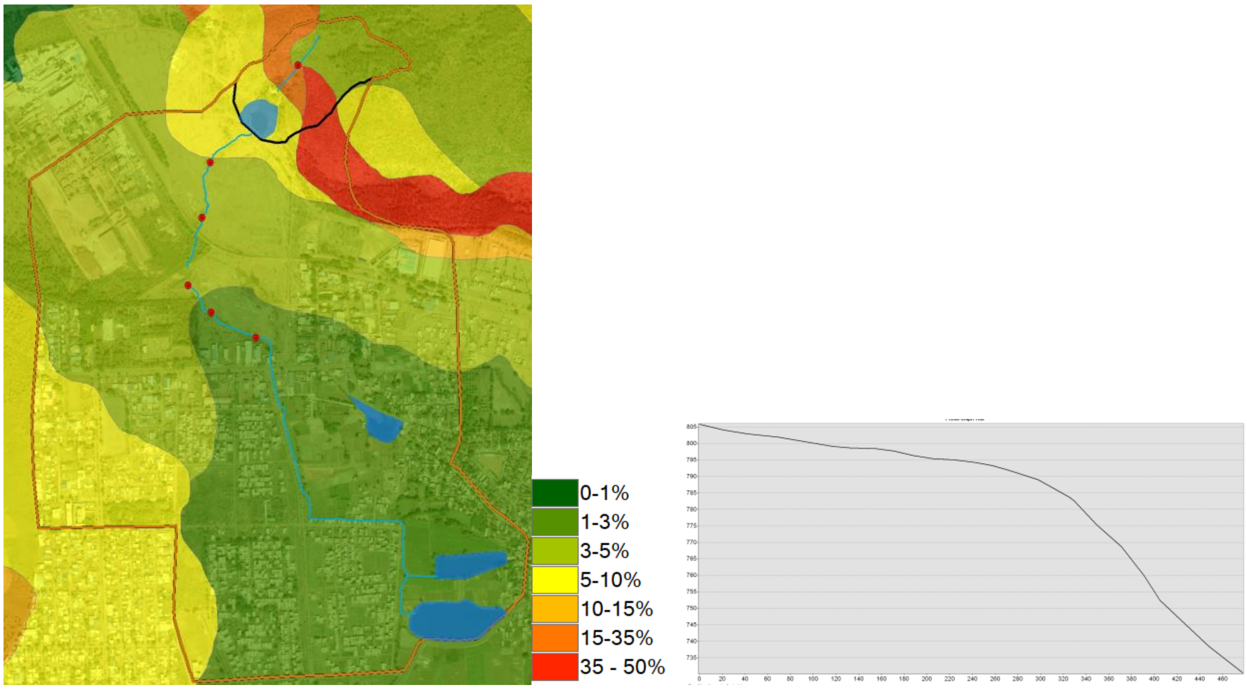


Figure 38 : Slope map of Karnbargi Springshed area

Soil: The upper reaches of the Springshed is loamy soils followed by loamy skeletal type of soils. The infiltration rates of these soils are moderate in the range of 10-20mm/hr. The average infiltration rate of 4.7 cm/hr can be usually observed in forest & loamy skeletal soil. Further downstream of the Springshed, Clayey soil are observed which has low infiltration rates. In this area, 3 lakes are existing and the surrounding area is habituated and surviving on open wells.

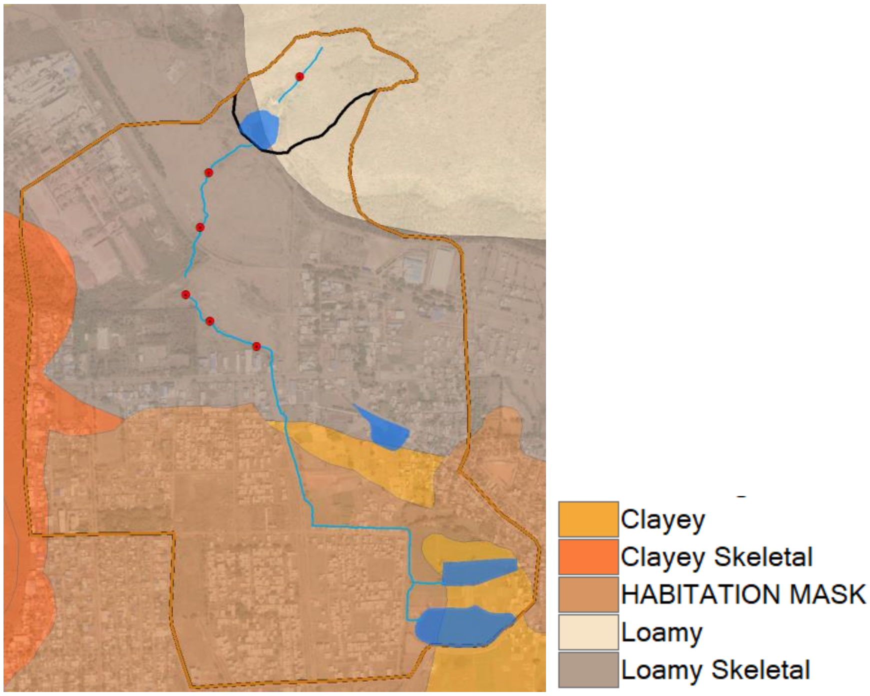


Figure 39 : Soil map of Karnbargi Springshed area

5.2.4 Water quality analysis

The water quality analysis was carried out for different seasons. The water quality analysis indicates the suitability for drinking water for the surrounding population.

Sl.no	Parameters	Result	Desired Limit
1	pH	6.61	(6.5 to 8.5)
2	Electrical Conductivity	434 µmhos/cm	-
3	Total Dissolved Salts	193 mg/l	(<500)
4	Carbonate	NIL	-
5	Bicarbonate	136 mg/l	-
6	Total Alkalinity	136 mg/l	(<200)
7	Chloride	64 mg/l	(<250)
8	Total Hardness	132 mg/l	(<200)
9	Calcium	120 mg/l	(<75)
10	Magnesium	12 mg/l	(<30)
11	Acidity	6 mg/l	-

Hydro-geological modelling:

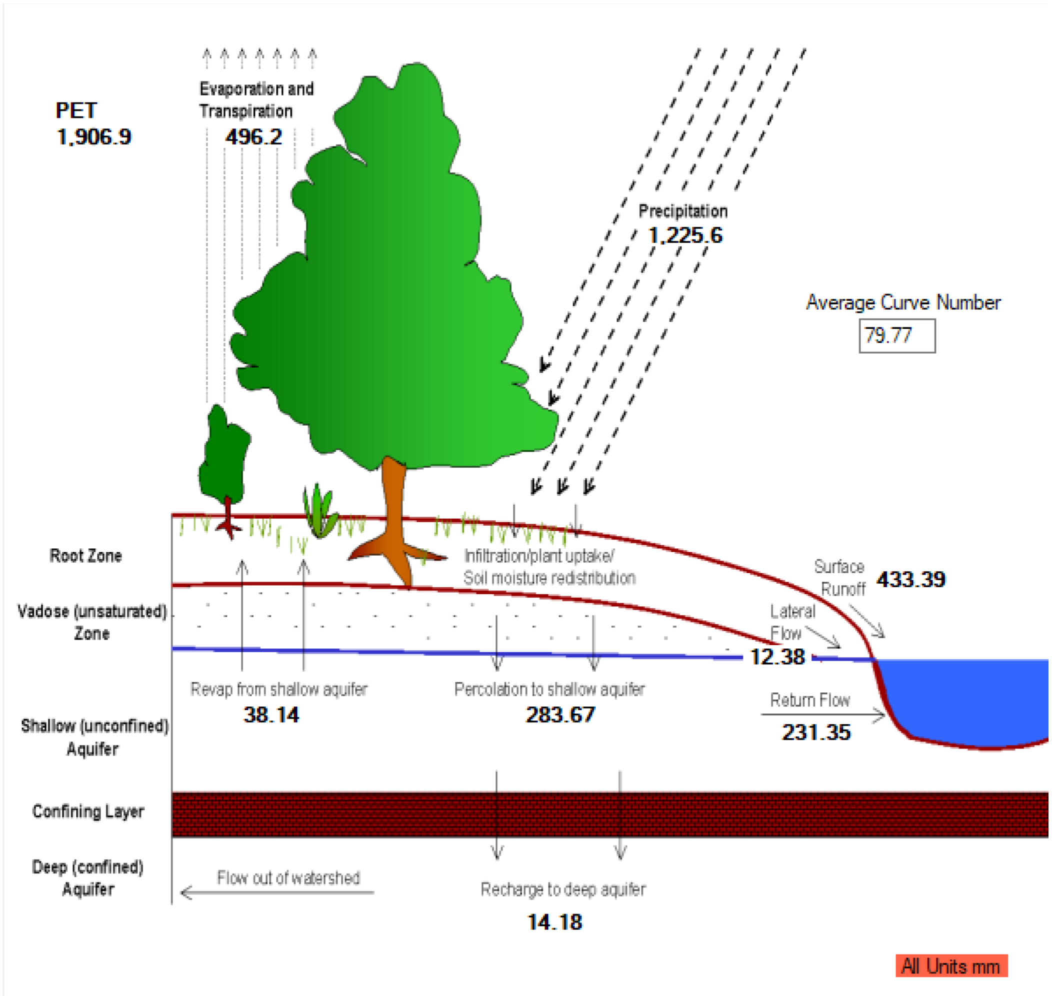


Figure 40 : Water balance chart for Kanbargi Springshed

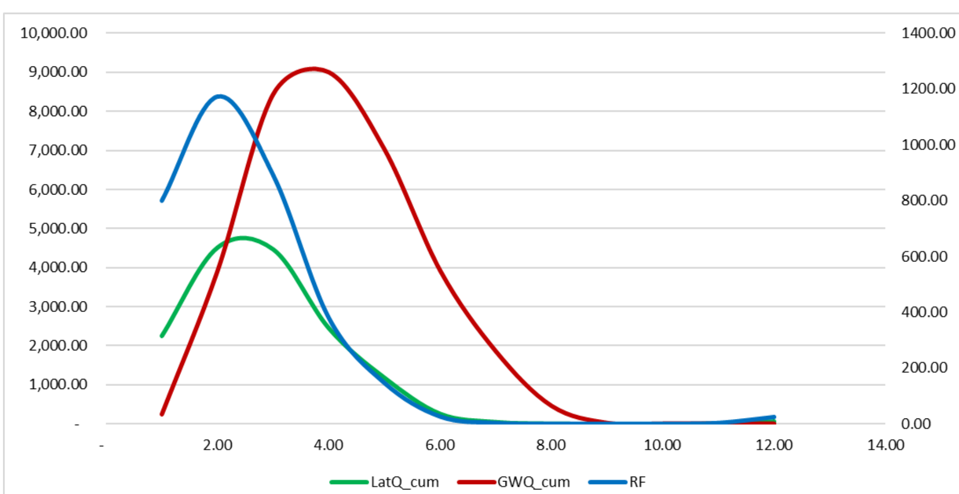


Figure 41 : Hydrographs of Lateral flows, Groundwater Flow and Rainfall.

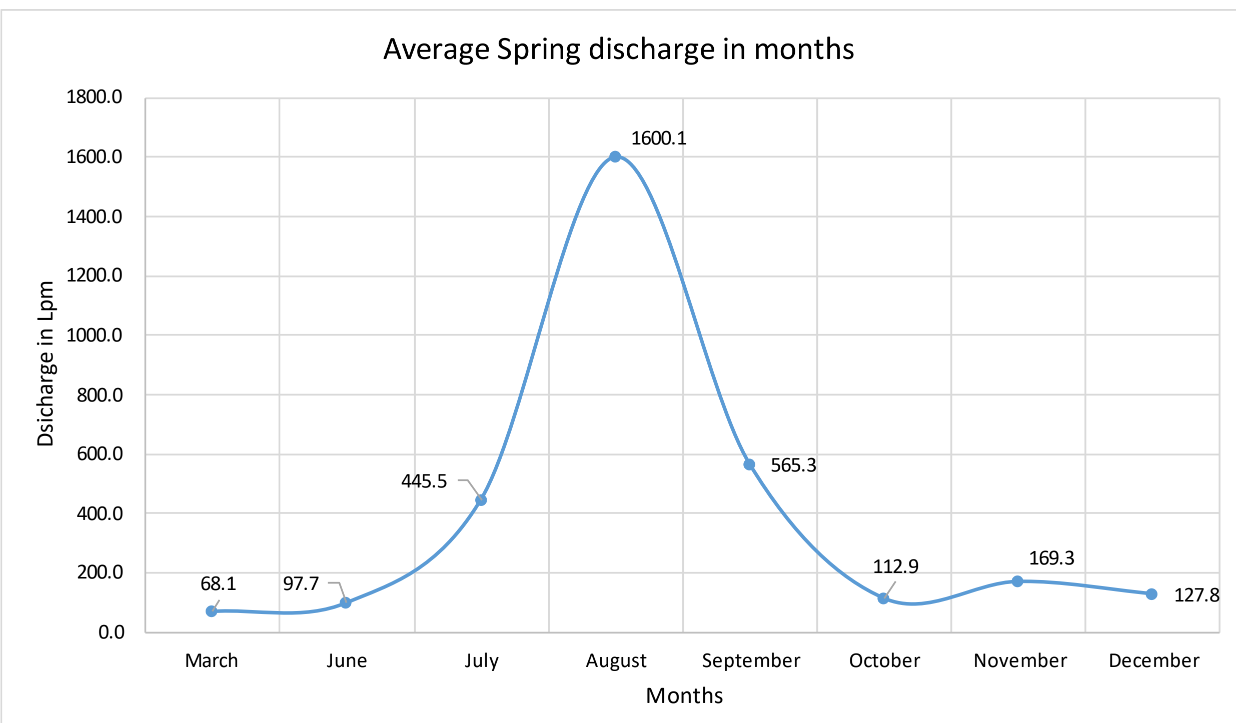
It can be observed that in this type of Springshed setup as briefed in the previous sections there is a groundwater delayed discharge from the spring aquifers (Figure 41). This also indicates a storage capacity of the spring aquifer which is assessed through hydro-geological modelling and field observations especially during lean periods.

The recharge component from the model is found to be 231.35 mm in the shallow aquifer of the Springshed. The average monsoon rainfall in this region is 950.7mm and non-monsoon rainfall is 274.9mm. The Springshed potential from percolated water in shallow aquifer are found to be 18% of the average annual rainfall. The recharge component is on the higher side because of the Landcover is forested in the Springshed.

The shallow groundwater recharge component can be estimated as

231.35 mm x 15 ha = 34,702.5 cum

Hydrograph: Continuous Field observations were carried out to assess the spring discharges during different seasons of the year and also rainfall event based. The peak discharge from Springshed is found to be 1600 lpm and an average of 136lpm during post-monsoon season and less than 68 lpm during pre-monsoon season. The average water potential of the Springshed considering lean season is 5064 cum per month.



Population: Socio-economic survey was carried out in the watershed of springs and collateral data was also collected from local authorities for population details. There are nearly 210 households surveyed and identified as potential beneficiaries of spring water. The water demand was calculated to be 113.4 cum/day at the rate of 135lpcd and 75.6 cum/day at the rate of 90 lpcd. The annual water demand of the downstream habitation is 27,745.2 cum at 90 lpcd. Hence, the drinking water demand for this layout can be met within the water potential from the Springshed.

Action Plan: An action plan was prepared to harvest rainwater and boost the recharge component in the catchment of springs so as to aid the downstream lakes and rejuvenate the streams. Suitable location for boulder checks, recharge wells and infiltration trenches were located based on field investigations.

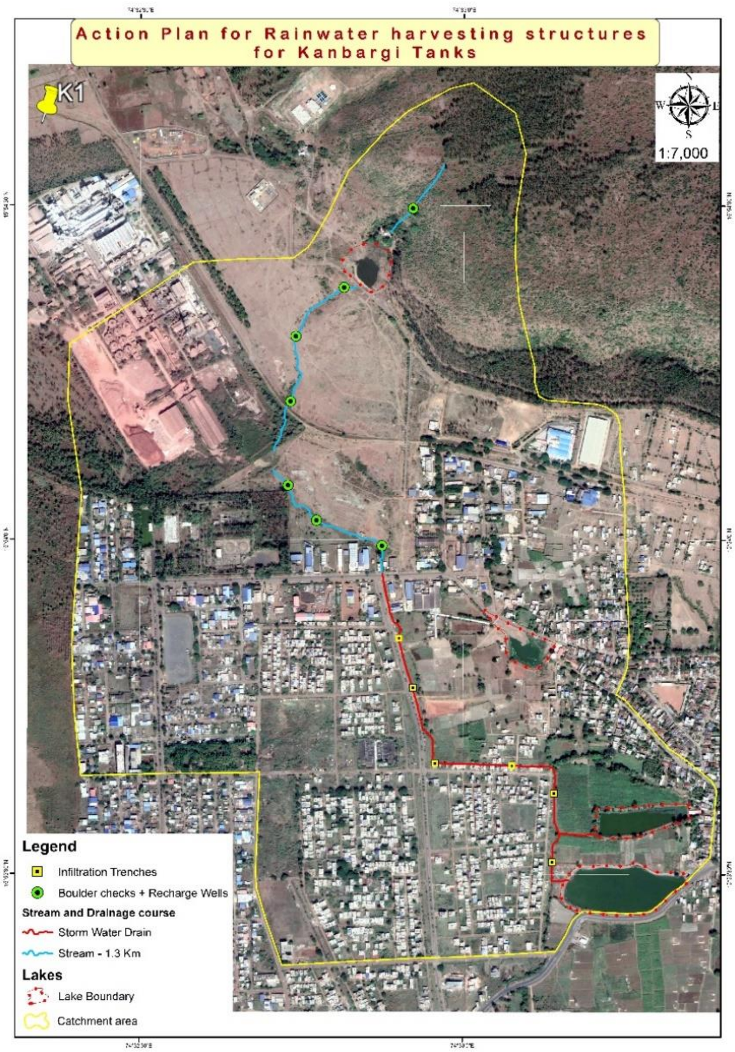


Figure 42 : Action plan for Kanbargi Springshed catchment

6 WEB-BASED SPRINGS INFORMATION SYSTEM

6.1 INTRODUCTION

The Government of India, Ministry of Jal Shakti, Department of Drinking Water and Sanitation has introduced schemes such as National Rural Drinking Water Programme (NRDWP) and Jal Jeevan Mission (JJM) with a motive to provide portable drinking water to every house hold by 2024. The centre takes up the implementation of these schemes through state departments by providing necessary technical and financial assistance. The works taken up are with a major goal of having a sustainable In-village water supply system which can provide reliable drinking water to the rural population of India. It is assisted by exploration of reliable drinking water sources, augmentation of existing resources and their development and rejuvenation activities.

UNESCO has recognized Western Ghats as one of the world's eight 'hottest hotspots' of biological diversity because it represents geomorphic features of immense importance with unique biophysical and ecological processes[1]. The Western Ghats is not only a home to the rich biodiversity but also supports a population of approximately 50 million[2]. It is a challenging task to fulfil government schemes to the villagers of Western Ghats as well as to regulate developmental activities in such Ecological Sensitive Zones (SEZ). In such cases, sustainable and scientific ways of planning and managing water resources plays a key role in balancing supply and demand of water to the rural population of Western Ghats.

One of the technological element developed in this study which immensely supports planning and management of In-village water supply system is by locating and analysing the nearest spring water resource by use of the Springs Information System (SIS). The study involves comprehensive data preparation of various thematic layers of Western Ghats study area which impacts the springs' water potential, observational studies, Hydro-geological modelling, water quality analysis, possible average forecast of spring discharges and an action plan for rejuvenation and sustainable existence and use of spring resources. The outcome of the research is extracted to visual interface of SIS for

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[1] Western Ghats - UNESCO World Heritage Centre

[2] Population density may have hit Western Ghats ecosystem: Government - The Economic Times (indiatimes.com)

the stake holders to use it to the full potential. The components of SIS is explained in detail in the subsequent sections of this chapter.

6.2 WEB INFORMATION SYSTEM AND GIS

A web information system is an online information system that uses internet web technologies to deliver information and services to end users using an application. The conventional standalone GIS had limitations on the application capability on the Internet. However, with the advancement in technologies and software, WebGIS has emerged as a strong tool to retrieve and analyse spatial data through the web sources. A WebGIS is the integrated product of geographic information system (GIS) and internet-based information system. In this system the internet technologies are made use along with GIS in order to take advantage of their superior capabilities such as interactive tools, visualization options, ease of use by graphical user interface, existing published background maps and related services for end users. The WebGIS applications can be accessed through desktop use, web browsers as well as mobile applications across the globe.

6.2.1 Stake Holders

In this research study, a prototype web-based application was developed and programmed which would serve the purpose for the following end users

- Government agencies primarily GSDA (Groundwater Surveys and Development Agency), Rural drinking water supply and Sanitation department, Govt. of Maharashtra, Smart City department, Govt. of Karnataka
- End users (public in remote areas of Western Ghats, environmentalists, active researchers, academicians and student community)
- Decision takers, Policy makers, bureaucrats
- Central government agencies (NIH, CGWB, National Rural Drinking Water Mission (NRDWM), Har Ghar JAL schemes) to providing technical and scientific solutions to regional drinking water issues in isolated pockets of Western Ghats. State and Central Water resources information centres. National level information centres.

6.3 SPATIAL AND NON-SPATIAL DATA FOR SIS

In a Geographic information system, several types of data are integrated and analysed with reference to spatial location and resources. Many organizations are using GIS to make maps that communicate, perform analysis, share information. The current research involves preparing of following thematic layers for a scientific investigation on Occurrences of springs in parts of Western Ghats. The findings of the research are finally attributed in springs information system and geo-tagged to the spatial data.

The following data are compiled to create attributes for each spring in the study area.

Field Data	**GIS Thematic layers**	**Non-spatial data**
1. Status of Spring	1.Geology	1. Demographics
2. Discharge data	2. Lineaments	2. Historical data
3. Socio-economic	3. Elevation (DEM)	3. Photographs
4. Water samples	4. Slope	4. Dimensions Measurements
5. Soil sampling	5. Aspect	5. Water balance charts
6. Stream flow Measurements	6. Landuse / Landcover	6. Hydrographs
	7. Soil	7. Rainfall
	8. Geomorphology	8. Temperature
	9. Watersheds	
	10. Springsheds	
	11. Basemaps	

The detailed specifications for the data products, sources from which it is attained for SIS is as detailed in Table 1.

Table 19: Data products for Springs Information System

Sl.no.	Thematic Data	Specification and description
1.	Topographical maps	1:50,000 scale published by Survey of India
2.	Satellite imageries	LISS III image archives with 24 metre spatial resolution and a swath of 141 km, Collaterally Google earth imageries, LANDSAT with 30m resolution and a swath of 141 km Specific purpose: Landuse / Landcover data preparation
3.	Demographic details	The demographic details of the population dependent of water resources in parts of Western Ghats study area. Specific purpose: To assess water demand Source: Census of India
4.	Hydro-meteorological data	1. Nationally available high spatial resolution (0.25X0.25 degree) Long Period (1901-2018) daily gridded Rainfall data and 1x1 degree gridded daily temperature data (1951-2018). Source: IMD- India Meteorological Department 2. Daily observed rainfall data from • Hydrology Project Division of Maharashtra. • Water Resources Development Organization (WRDO), Karnataka.
5.	Digital Elevation Model (DEM)	National DEM developed by the Indian Space Research Organization (ISRO) called The Cartosat-1 Digital Elevation Model (CartoDEM) of 30m resolution prepared from Cartosat-1 stereo payload, is used in this study. Elevation details are extracted from DEM.
6.	Slope	The Slope maps are prepared based on AIS&LUS: Soil Survey Manual, IARI 1971 followed in IMSD guidelines ISRO for thematic maps generation
7.	Aspect	Using DEM Aspect maps are prepared using geo-processing techniques.
8.	Geomorphology	The Geomorphological maps are derived from a three-level classification system based on the origin of landforms which was used in creating

9..	Lineaments	geomorphology and lineament database on 1:50,000 scale by NRSC.
10.	Geology	The Geological thematic layer was prepared from Geological and Mineral map of Maharashtra published by Geological Survey of India of 1 in 2M scale.
11.	Soil	The soil layer is prepared from Soil state atlas of Maharashtra published by National Atlas & Thematic mapping organization[3].
12.	Landuse / Landcover	The Landuse / Landcover is prepared at a finer scale for springsheds and at least to 1:50,000 scale for Hydro-geological modelling of catchments.
13.	Water Quality	The Water quality has been tested to required standards in WQ testing laboratory at NIH-RC Belgaum and Isotopic analysis is carried out at Headquarters NIH-Roorkee.
14.	Spring discharges	The Spring discharges were measured on field for the representative spring categories.
15.	Observed Stream flows	Stream flow observations were made periodically in pre-monsoon and post-monsoon seasons at selected points in downstream of springshed catchments. Additionally, Hydro-observation (HO) consisting of flow measurements from WRIS time series data is also collected.

[3] National Atlas & Thematic Mapping Organisation (natmo.gov.in)

6.4 USER INTERFACE MANUAL AND ACCESS

The Springs Information System under this PDS is made accessible through a web-based application for wider use of stake holders. One of the popular platforms providing the required tools to develop the SIS is ArcGIS software packages. A model Springs information system application are developed on a non-commercial temporary educational and research license and used for trial runs in the current PDS. It has been updated with value additions experienced from trial users and also open to be upgraded as and when required. The concept of major components of a SIS that are vital in defining the characteristics of springs of Western Ghats is given in the following sections.

Link to download and view SIS

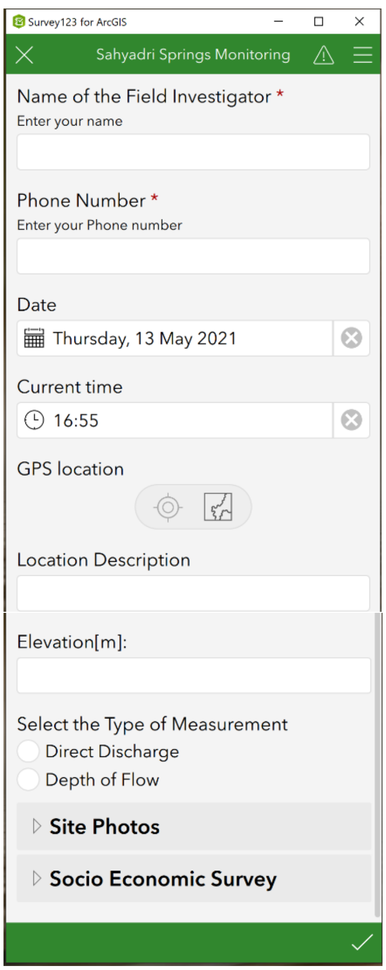
- Springs monitoring system by use of Survey123 by ArcGIS Geo-app spatial smart form named as "*Sahyadri springs monitoring*"

Scan the above QR code to access

- Springs information system through Web-application link and ArcGIS explorer Mobile app access named as "*Sahyadri Springs Information System - Beta version*" is downloadable and viewable from the below link
  https://arcg.is/00bi1H

Components of springs monitoring system: "*Sahyadri springs monitoring*"

The following are the typical components necessary to record spring characteristics at site. The inputs fed in the springs monitoring system app directly updates the springs database in real-time to the server and is readily accessible as spreadsheet or spatial format such as shapefile. The inputs are fed into a geo-spatial smart form by clicking on Collect. The data collected in the mobile application is stored within Inbox until there is network connectivity or WiFi to upload and operates with or without mobile network even in remote areas of Western Ghats. The field data is finally accessed at office for further analysis, inferences and updated in SIS to respective springs categories.

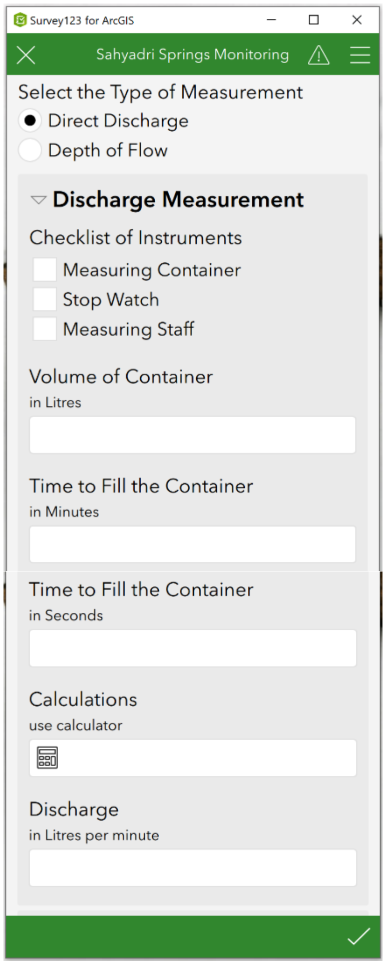


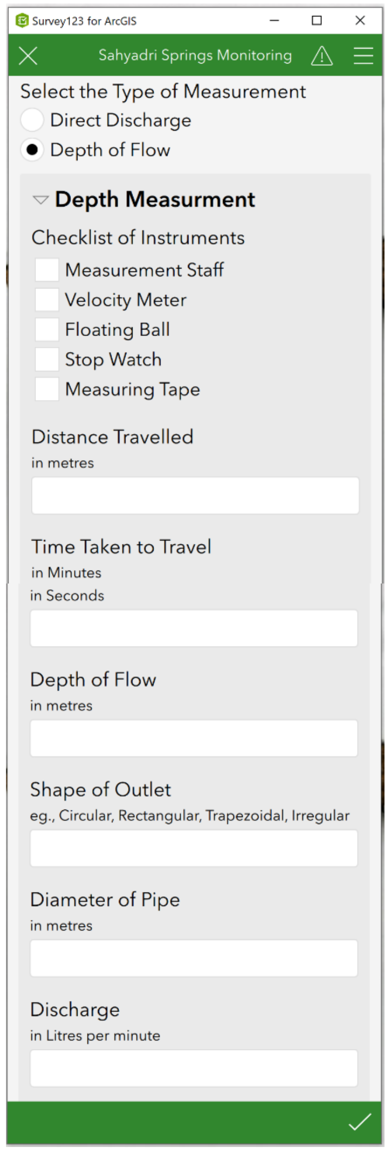
The typical interface for springs monitoring system by a mobile app with spatial smart form developed and named as "Sahyadri Springs Monitoring" is as indicated in figure. The typical components are explained as follows,

- **Name of the Field investigator**
- **Phone number of the Field investigator**:
  The above two information acts as a database to correct human errors if any
- **Date and Time of the survey**
- **GPS location and description**: The mobile app directly records the GPS location with its Latitude and Longitude with an accuracy of ±10m threshold. An option is also provided to note the description of the GPS reading for further field identification for re-visits.
- **Elevation in metres**
- **Selecting the Type of measurement:** spring and flow discharges can be commonly measured based on the type of site conditions in two ways:
  1) Direct discharge measurement using volumetric containers.
  2) Measuring dimensions of outlet, Depth of flow and Velocity of flow.
- **Site Photos**
- **Socio Economic Survey**

Selecting Type of measurements

The type of measurements should display the following sub-components for the field surveyor to record the observed discharge readings based on the site conditions.





A drop down inputs appear upon selecting the type of measurement and is shown in the figure.

- **Checklist of Instruments** A checklist of instruments to be indicated to the field surveyor so that no observational measurement instruments are missed out in proper recording of data.

- **Discharge measurement** process is carried out by filling respective readings as per the type of measurement.

1) **Direct Discharge measurement**

In case of the Volume of the container is known. The time taken to fill the container volume is recorded with a stopwatch.

If the volume of the container is not known the measuring jar will measure the volume of the water filled in defined time interval. The volume filled is then measured using measuring jar.

A calculator option is embedded within the app for on-spot calculations.

$$Q = \frac{V}{t}$$

The discharge is calculated by dividing volume of water by time taken to fill the specific volume. This gives the discharge in litre per minute.

2) Discharge measurement by depth of flow

This mode of recording discharge can be used for both spring discharges as well as stream discharges in the springsheds and watersheds of springs.

The discharge is measured by measuring depth of flow using equation

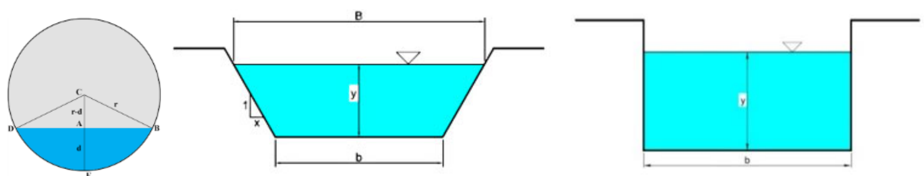
$$Q = A \times v$$

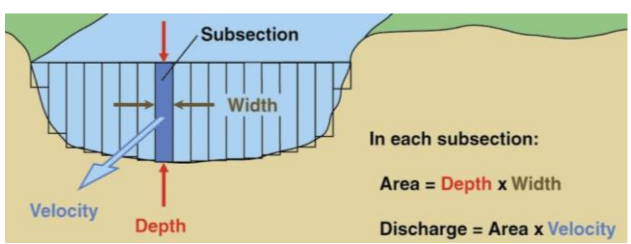
A is the cross-sectional area of flow channel …sqm

v is the velocity of flow …m/s

Q is the discharge … cum (conversion factor is 1cum/m = 1000lpm)

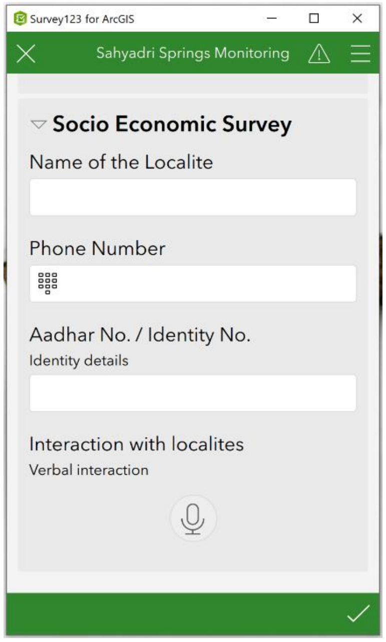
The depth of flow is commonly used to calculate the wetted area of flow. The shape of outlet is noted for further computations of A. The Depth of flow is measured using measuring staff. The necessary dimensions for each choice of outlet is also recorded in the application. Hence, A is calculated in different ways for different type of outlets as shown in the figures below,





v is calculated by recording distance travelled and time taken for the Floating ball to travel specific distance in the flow channel.

Socio economic Survey



The Socio-economic survey is carried out in the field by interacting with the localites and collecting necessary information to the questionnaire.

The name and phone number of the interacting villager along with an identity card and the voice note of the complete interaction would act as a sufficient documentation for future references.

The field photographs are attached by taking pictures directly from the mobile applications or selecting photos from the gallery. This is automatically geo-tagged to the respective spring shapefile feature.

It is preferred to capture the photos of Springs origin, outlets, harvesting structures, landscape and any other necessary feature at the discretion of the field investigator.

Components of Springs Information System: *"Sahyadri Springs Information System"*

The major components of Springs information system developed in this study and customized for springs in hard rock regions of Western Ghats is as shown in Figure 2. The necessary attributes are displayed as a result of geo-tagging process.

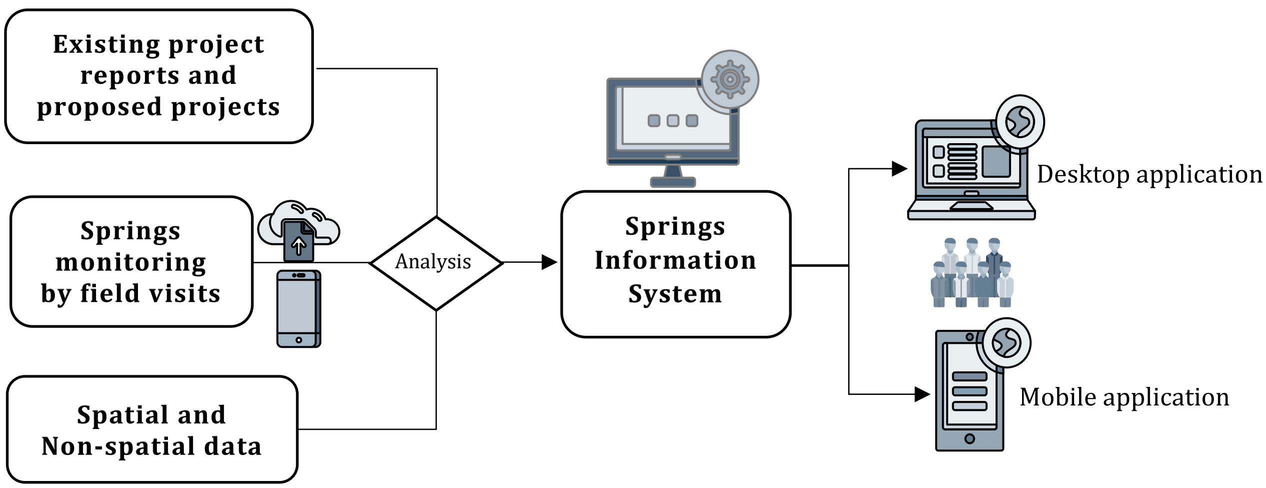


Figure 43: Components of Springs Information System.

The Core of the Springs information system is a geo-spatial database which houses the information received from analysis and inferences of this research. Existing project reports, proposed projects, literatures act as a base data for analysis. The important observational details are obtained from field investigations through springs monitoring mobile app which updates the database for analysis. The spatial and non-spatial data is prepared using GIS and remote sensing techniques. All the above information is pooled on a common platform to prepare data input for hydro-geological modelling and analysis. The results are then interpreted case by case basis and categorized widely on geo-hydrological occurrences. The springs characteristics from analysis are compared and validated using the observational springs in each of the study districts. The important attributes associated to springs are geo-tagged to respective locations. The Geo-tagged attributes are explained in the following section.

6.5 GEO-TAGGED ATTRIBUTES

Springs Information system pops-up the following essential information upon clicking on any springs in the study area using SIS applications. It consists of the following information to the users,

Details		
1.	Spring ID	
2.	Spring Name	
3.	Latitude	
4.	Longitude	
5.	State	
6.	District	
7.	Gram Panchayat	
8.	Village Name	
9.	Area of Village	Ha
10.	No. of Households	
11.	Total Population	
12.	Origin side	
13.	Elevation	m above MSL
14.	Slope	%
15.	Aspect value	
16.	Aspect	
17.	Geomorphology	
18.	Geology	
19.	Soil	
20.	Water Quality	
21.	WQ_pH	
22.	WQ_TDS	
23.	WQ_EC	
24.	WQ_Acidity	
25.	WQ_Alkalinity	
26.	WQ_TH	
27.	WQ_CaH	
28.	WQ_MgH	
29.	WQ_Cl	
30.	WQ_Na	
31.	WQ_K	
32.	WQ_Turbidity	
33.	Watershed code	
34.	Catchment area	Ha
35.	Average Monsoon Rainfall	mm
36.	Discharge	Lpm
37.	Purpose	
38.	Occurrence	
Media		

39.	Field Photographs	
40.	Water Balance Chart	
41.	Hydrographs	

6.6 Summary

The web-based geo-applications namely *Sahyadri Springs monitoring* system and *Sahyadri Springs information system* are strong tools for assessing occurrences of springs in parts of Western Ghats. The information system consists of a comprehensive database on nearly 800 springs in western ghats and their characteristics which is accessible in both web portal and mobile applications. The tool offers wide options for the users to plan and harvest locally available spring water resources for In-village water supply schemes based on the current research findings. The web-applications give the planners an idea on spring water potential and sustenance estimate. The geo-tagged attributes provide necessary design parameters for feasibility studies on framing drinking water supply to remote areas of Western Ghats.

7 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 about40% 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.

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 LULCC 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.

In formerly forested regions in the humid tropics, notably in the more densely populated regions of south and south–east Asia such as the Western Ghats of India, major land-cover changes have occurred at a century time scale. The latter have included permanent deforestation and conversion to a variety of agro-forestry and agro-ecosystems, regrowth as well as reforestation. Consequently, there is a particular need for decision makers and policy makers to have information from hydrological studies that address the fundamental processes associated with such land cover changes. Over 100 million people depend on surface water sources in streams and rivers that emanate from the Western Ghats. Further this region is a major repository of carbon in its forests and soils (Seen et al., 2010) and is a global biodiversity hotspot (Das et al., 2006). In an era where various ecosystem services are being recognized and valued, it is essential for ecological economists, policy and decision makers to be aware of the synergies and trade-offs between various regulatory and provisioning services (Elmqvist et al., 2010). Thus an investigation of the hydrological effects of specific land-cover changes is a high priority (DeFries and Eshleman, 2004).

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 farmers 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. 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 the hydrological and socio-economic studies.

The catchments in the study area are on the back slopes of the Western Ghats, deeply dissected, and the geology is dominated by Greywackes. The soils in both the Coastal and Malnaad basins are deeply weathered. Soils are red and lateritic similar to the description of Putty and Prasad (2000a). In the absence of any deep drilling in the basins, however no detailedsoil descriptions down to bed rock exist. Exposures in hills and stream banks do suggest that soils extend well beyond 2 min depth.

The main aquifers in the study area are the weathered and fracturedzones of metavolcanics, meta-sedimentary rocks, granites andgneisses, laterites, along with the alluvial patches found alongthe major stream courses. Significantly there is no primary porosity in the hard rocks. It is the secondary structures like joints, fissures and faults present in these formations up to 185 m belowground level (mbgl) which act as a fractured rock aquifer with an effective porosity of 1.0 – 3.0% and contain groundwater. The transmissivity of aquifer material are in the general range from 2.09 to 24.41 m^2/day (CGWB, 2008). Spot surveys undertaken by State and central government in May (pre-monsoon) and November (post-monsoon) 2006 and using a network of 30 of the national hydrograph stations, showed that pre-monsoon water levels vary between 5 and 10 mbgl. These observations were typical over large parts of Uttara Kannada. In the post-monsoon, the prevailing depths within the Coastal and Malnaad areas were respectively 2–5 and 5–10 mbgl (CGWB, 2008).In the absence of any deep drilling in the basins, however no detailed soil descriptions down to bed rock exist. Exposures in hills and stream banks do suggest that soils extend well beyond 2 m in depth. Further no detailed mapping of soil pipe occurrence (Putty and Prasad, 2000a,b) was undertaken, although we have observed soil pipes in the forested catchments in the region and there was evidence of vertical macro-pore flow in soil exposures.

7.1 Impacts Of LULC:

7.1.1 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. [9]

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.

7.1.2 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. [11]

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]

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. 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:

(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 catchment.
(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?
(5) Springs are greatly threatened by human impacts and rarely have these productive, biologically diverse ecosystems been managed for long-term, ecological sustainability. Development of the classification system and lexicon proposed here may help clarify the distribution, condition, and conservation of springs ecosystem. Existing classifications of springs have thus far been concerned with water to point of discharge. The physical classifications of Bryan (1919) and Meinzer (1923) require modification because of changes in geologic and hydrologic theory. Biological classification criteria of springs are proposed, with emphasis on the refugial and biogeographic status, ecoregional setting, and steepness of ecological gradients with respect to surrounding upland environments. Management authority and cultural uses of springs are recognized as important variables for status and conservation 16 analyses, although additional understanding of traditional cultural knowledge, history and uses of springs is often needed. Development of a well-managed information management will require rigorous quality control protocols. We recommend the use of the above classification system to develop this global database. Analyses of a large, well-managed springs database will provide fruitful future research

into springs ecology, and is essential for the conservation and sustainability of these ecosystems.

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9 FIELD INVESTIGATIONS PHOTOS

Village : Gotvewadi

District : Sindhudurg

Date of Visit : 19-12-2018





Village : Amboli

District : Sindhudurg

Date of Visit : 19-12-2018

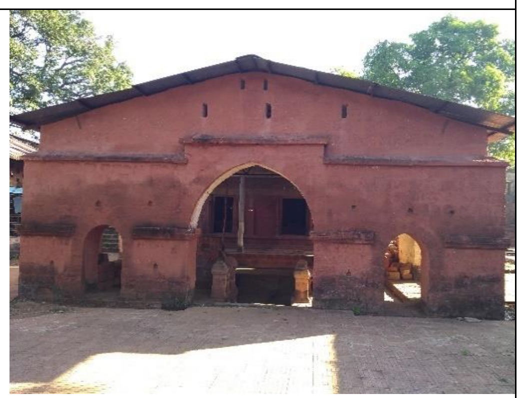
	
	

Village : Kundi

District : Ratnagiri

Date of Visit : 20-12-2018


Village : Kundi
District : Ratnagiri
Date of Visit : 20-12-2018

Village : Ratnagiri
District : Ratnagiri
Date of Visit : 20-12-2018

Village : Meda
District : Satara
Date of Visit : 19-12-2018

	
	
Place : Alewadi **District : Satara**	**Rock Outcrops**
	
Place : Dandewadi **District : Satara**	

	
Place : Ambegar **District : Satara**	**Natural Spring observed in a hilly track of Pune –Satara Road**
	
	

	
Springs of Gargoti, Kolhapur District	

Field investigation photos to be updated

A map of photo locations