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Research Article

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Hydrogeological Characteristics and Model Conceptualization of Malaprbha Catchment, Karnataka, India

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Abstract

Groundwater development in weathered and fractured hard rock aquifers is a more complex and dynamic as compared with that in unconsolidated alluvial stratum or in soluble carbonate rocks. The fact is that the aquifers classified under hard rocks are discontinuous, anisotropic and have only secondary porosity. However, in India more than 65% of the region is covered by hard rocks, particularly in the southern part of the country which is dominated by basaltic lava flows. The farmers in this part of the region are always facing conditions of hydrologic extremes due to the uncertainty in the rainfall pattern added with climatic changes. In this context, it is highly essential to develop reliable and well-conceived models for estimating the groundwater availability and to guide the society for adapting to the worst scenario of water scarcity from time to time. For sustainable development, it is necessary to take up soil and water conservation techniques in each watershed, taking a sub-basin as the unit for planning. Therefore in the present study Malaprabha sub-basin in northern region of Karnataka has been studied systematically for groundwater hydrological parameters like rate of infiltration and Hydraulic conductivity varies with respect to land use and the lithology. The rate of infiltration in the forest area is high 13% compared hard and compact rock similarly the Hydraulic conductivity varies from 0.2 cm/hr in the barren land to 5.8 cm in the Forest area. Therefore these two factors mainly affect the groundwater recharge and movement with this experimental values conceptual model has been developed and found that in the upper part of the basin the rate of infiltration is high and groundwater occurs in the unconfined aquifers and in the middle part of the basin the groundwater occurrence is low and in lower portion the groundwater occurrence is considerably higher.

Keywords: Infiltration; Groundwater; Hydraulic conductivity

Introduction

In the hard rock aquifers fractures and joints plays significant role in connecting the flow from one part of the aquifer to another. The groundwater flow through such a network of fractures is largely influenced by variations in hydraulic properties resulting from the geometry and orientation of the aquifer characteristics. The hydraulic conductivity of hard rock aquifers depends largely on the network density, size and shape of the fractures. It is presumed that the principal directions of hydraulically conductive fracture measured from electrical anisotropy are inferred from the measured electrical resistivity and geophysical properties. The coefficient of anisotropy (λ), a unique and dimensionless number, is a measure of the degree of inhomogeneity arising from fracturing, faulting, jointing and weathering in different varieties of hard rocks Kumar et al. However, number of studies carried out in the hard rock area of the world established that the hard rock aquifers are discontinuous in nature, i.e., aquifer near the surface (within the first 100 m below ground surface), due to varying degree of soil thickness and weathering characteristics exhibit wide variations in hydraulic conductivity. The classical concept of discontinuous aquifer was further strengthened based on the observations of large-scale drilling programs performed in Africa Detay et al. These water-bearing zones are thought to stem from tectonically induced open fractures [1-5]. A decrease in the occurrence of such water bearing zones with depth (within the first 100 m below the ground surface) was attributed to the “closure” of these tectonic fractures as a consequence of the increase of the lithostatic strain. These concepts influenced in the past, and still influence the methodologies used in hard rock areas. This kind of hydraulic characteristics of the aquifers are quite common in basaltic terrain of south India. Therefore, to understand the nature and variations in hydraulic properties of the aquifers, Malaprabha sub-basin in Karnataka has been selected and detailed hydrogeological investigations were carried out and a conceptual model was developed.

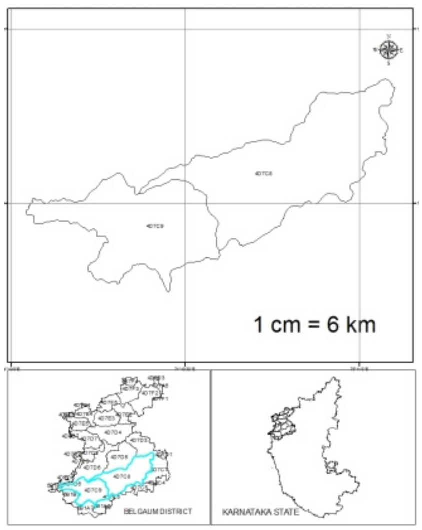

Figure 1: Location of the area.

General Description of the Study Area

The Malaprabha River is a right bank tributary of river Krishna. It extends between 74o20’ and 75oE longitudes and 15o20’ and 15o40’ N latitude in Belgaum district of Karnataka (Figure 1). To harness the waters of the Malaprabha River, a dam has been constructed at Naviluteerth, Belgaum district to impound 1377 MCM water. There are three seasons prevailing in the catchment, the summer from March to May, the monsoon from June to November and the winter from

December to February. The Malaprabha catchment mainly experiences the southwest monsoon. The rainfall in the non-monsoon period is insignificant [6-10]. The average annual rainfall in the catchment was 800 mm. geologically, the area comprises of Sedimentary rock formations (Kaladgi group, comprising limestone, shale and Quartzites) and schistose rock formations (Dharwad Super group comprising granite, gneiss and crystalline rocks). The important soil groups found in the catchment include medium to deep black soil, mixed red and black soil (Vertisols) and red sandy loam soils (mainly Alfisols). The land use pattern of Malaprabha sub-basin shows that, 25.3% is covered by forests, 10.5% shrub, 7.8% waste land, 33.08% cropped area, 19.23% fallow land and remaining 3.97% is occupied by water bodies.

Methodology

Rate of Infiltration is obtained by conducting field studies.

Results and Discussion

Infiltration

The mean infiltration characteristics of different kinds of soil (Table 1), exhibit significant variation with respect to soil type and land use pattern. However, one of the interesting results obtained in the present study is that, the rate of infiltration is higher in the wet zone as compared to semi-arid and arid zone (soil type and texture were similar), irrespective of the land use pattern. The infiltration rate observed in the shrub of wet zone and wastelands of semi-arid and arid zone was considerably lower than other types of land covers. The major reason could be due to the thickness of soil type and thickness, runoff characteristics and the rainfall pattern occurring in three different zones. In an agriculture land, variation of hydraulic properties shows a different trend because of the impact of cropping pattern and irrigation processes adopted. In the case of barren land the infiltration is significantly lower than the agriculture land [11-15]. The infiltration characteristics of soils in an agriculture land in arid and semi-arid indicate a wide variation between the two zones. Higher infiltration capacity of arid zone soils is associated with the abundance of large pores with aggregation of clayey particles present in the command areas (arid zone). Further, being parts of command area, application of irrigation and cropping pattern would also influence the rate of infiltration. On the other hand, in parts of the semi-arid zone of the present study area, the soils are affected by salinity problems as reported by earlier researchers. Another striking feature observed is that the afforestation activities taken up in the semi-arid and arid region has improved the hydraulic properties of soil leading to higher rate of infiltration and hydraulic conductivity. It was quite higher than the rate of infiltration in shrubs and barren land. The high rate of infiltration in the forest covers of wet zone could be attributed to preferential flows taking place during the growth period. This flow occurs either when the macrospores and cracks open to the atmosphere or when the water pressure within macrospores and cracks are positive. One of the important reasons for having high rate of infiltration in tropical soil is due to the low viscosity of warm water.

Sl No.	Catchment zones	Land Use	Geology2	Soil Texture	Infiltration Final Rate cm/hr
1	Head water catchment (Kankumbi to Khanapur)	Forest	Basalts, Pink grainite	Medium Loam	13.8
2		Shrub		Medium Loam	1.8
3		Agriculture		Medium Loam	6.6
4		Barren land		Heavy Loam	3.6
5	Khanapur to up to Renukasagar dam	Plantation	Greywackes, Basalts, Quartzites,	Medium – Heavy Loam	5.4
6		Waste land with scrubs		Medium - Heavy Loam	1.2
7		Agriculture Land		Medium Loam	2.4
8		Barren Land/rocky exposures		Medium -Heavy Loam	0.8
9	Downstream of dam	Plantation	Pink Granite, Quarzite, Dolomitic limestones	Medium – Heavy loam	4.8
10		Wasteland with scrubs		Medium Heavy Loam	1.2
11		Agriculture land		Medium-Heavy Loam	5.4
12		Barren land/Rocky exposures		Medium - Heavy Loam	0.8

Table 1: Infiltration Rate in Different stretches of Malaprabha catchment.

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Hydraulic conductivity

The saturated hydraulic conductivity observed for soils in the undisturbed forest is considerably high as compared to soils in the other land types such as shrubs/scrubs, wastelands, agriculture land and barren land. The present study shows that, in all the sites, the surface hydraulic conductivity is higher than the sub-surface conductivity. There is a marked variation between sub surface hydraulic conductivity of wet zone and semi-arid to arid zone. Therefore, it is surmised that the variation in saturated and unsaturated flow depends on the basic parameter viz. hydraulic conductivity. When the soil is saturated, the hydraulic conductivity tends to be higher and if the soil is unsaturated, some of the pores become air filled and the conductivity reduces depending on the grain-size distribution. Therefore, the transition from saturated to unsaturated generally entails a steep drop in hydraulic conductivity, which may decrease by several orders of magnitude as suction increases from 0 to 1 bar. At still, higher suctions, or lower wetness values, the conductivity may be so low that very steep suction gradients, or very long times, are required for any appreciable flow to occur. Table 2 shows the Saturated soil moisture status under different hydrological regimes and saturated hydraulic conductivity at varying depths of soil (surface and below 60 cm) [16-20].

Sl. No.	Location/Agro-climatic zone	Saturated Moisture (in percent)	Residual Moisture (in percent)	Hydraulic Conductivity (Surface) cm/h	Hydraulic Conductivity (below 60 cm depth) cm/h
Head water catchment (Kankumbi to Khanapur)					
1	Forest	42	19	5.8	4.2
2	Shrub	35	17	3.74	1.8
3	Agriculture land	38	15	3.00	1.4
4	Barren land	28	3.8	3.0	1.20
Semi-Arid (Khanapur to Renukasagar dam)					
5	Plantation	33	1.1	3.8	1.55
6	Wasteland/scrubs	21	5	3.4	0.21
7	Agriculture land	27	1.2	4.7	1.10
8	Barren land/rocky exposures	18	9.0	3.6	0.58
Arid zone (Downstream of Renukasagar dam)					
9	Plantation	35	2.0	3.4	0.85
10	Wasteland/scrubs	36	1.9	2.4	0.16
11	Agriculture	21	1.1	3.9	0.17
12	Barren/Rocky exposures	30	1.6	5.5	0.38

Table 2: Saturated Hydraulic Conductivity in different stretches of Malaprabha catchment.

Hydrogeology

The study area is underlain by Basalts, Gneisses, Schist, Sandstone, Quartzite's, and Alluvium etc. of Archaean to Recent age. Ground water occurs in all weathered formations under phreatic conditions and in fractured and jointed formations under semi-confined conditions. Deccan basalts act as a multilayer aquifers having low to medium permeability. In Deccan basalts that comprise different flows, fractures and interstitial pore spaces of vesicular zones, are good repositories of ground water. Groundwater occurs under phreatic conditions in weathered zone of these basalts and under semi-confined to confined conditions in inter-trepans and also in joints and fractures at deeper levels. In the study area, it is noticed that the head water catchment is characterized by a thick layer of red soil in majority of the stretches (2 m to 10 m) followed by a weathered hard rock having thickness of about 5-6 m with The aquifers occurring within the shallow depth range of 0 to 20 m bgl are mainly weathered and fractured formations. Groundwater occurs in these formations under phreatic conditions and the average thickness of these aquifers ranges from 5 to 15m. There is a wide variation in the depth of occurrence of fractures and their thickness even in the closely spaced wells and the results show that 74% of the total fractures are encountered within the depth range of 0 – 100 m in basalts (Sivaramakrishnan. J, et al, 2014). The present observations showed that the top 30-35 m of the horizon has less dense fractures and below 50- 70 m has significantly higher density fractures as compared to the top layer. This resulted in lower yield of unsaturated zone and relatively higher yield below the unsaturated zone. As stated by Laschassagne et al (2009), the reduction in occurrence of fractures with respect to depth is due to "closure" of these fractures as a consequence of the increase of lithostatic strain. Apart from this degree of weathering and climatic conditions plays a considerable influence on the groundwater availability in the hard rock aquifers. A schematic representation of the hydrogeological conditions of the study area is shown in Figure 2.

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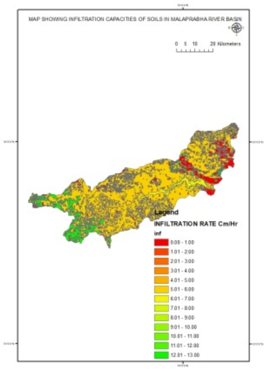

Figure 2: Map showing the rate of Infiltration.

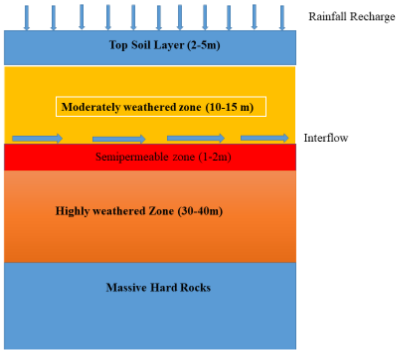

Figure 3: Conceptual Hydrogeological Profile of Malaprabha Catchment.

The storage capacity and well yield depends primarily on thickness, degree of weathering and extent of the weathered zone. The massive hard rocks found beneath 70 m are devoid of any kind of fracture for the transport of water. However, in certain pockets of the study area due to stresses occurred during different geological periods added with physical and geochemical properties of the rock and paleo-climatic conditions resulted in the development of a network of joints and fractures. Therefore, in some parts of Bailahongal and Saundatti taluks groundwater is available at greater depths below 100 m Figure 3. In the basaltic terrain, the thickness of the interflow bole bed varies widely from few centimeters to few meters and acts as an indicator to demarcate the flow occurred during different geological period Figure 4.

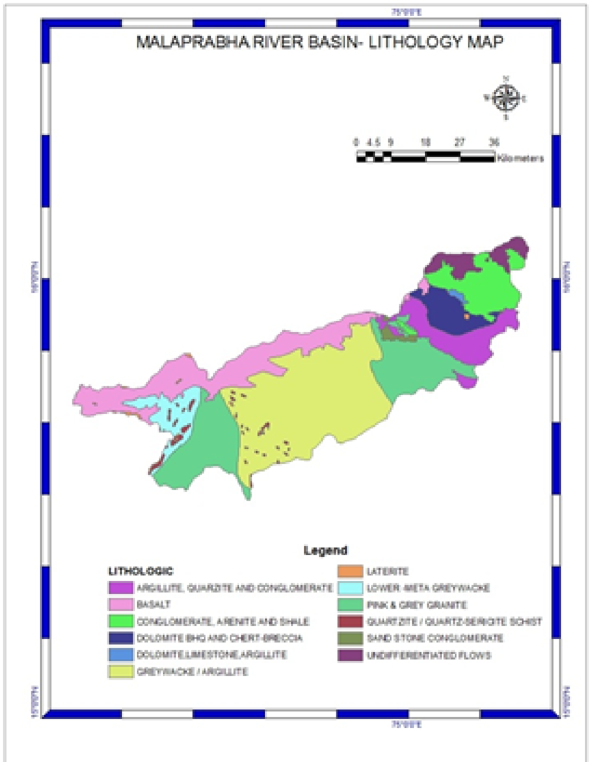

Figure 4: A Schematic view of geological map from upstream to downstream of Malaprabha catchment under study [4].

Conceptualized model

The hard rocks such as granites, basalts, metaquartzites or gneisses are of igneous or metamorphic origin with negligible primary porosity and permeability (Clark, 1985; Gustafson and Krásný, 1994). The crystalline outcrops are exposed in various locations of the study area. In order to define the groundwater flow pattern in the catchment following are the basic concepts adopted:

The study area is composed of eleven lithological units with varying hydraulic properties

The variations in hydraulic properties is significantly high spatially

Groundwater Recharge is mainly due to Rainfall

Ground water in the unsaturated zone is restricted to 6-7 m thickness.

Below the unsaturated zone there is a thin layer of semipermeable/ impermeable zone completely obstructing the ground water flow to the deeper aquifer

The groundwater in the deeper aquifer is only through fracture and joints.

An overlying regolith (unconsolidated material derived from prolonged in-situ decomposition of bedrock.), with a thickness from negligible to a couple of tens of meters.

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Weathering is more rapid in the semi-arid zone whereas in the arid areas and higher elevations the rate of weathering is low in comparison with that of erosion.

The regolith usually has a high porosity and a low permeability (due to clay-rich material)

The porosity of the weathered profile generally decreases with depth, along with clay content, until fresh rock is reached.

Conceptual representation of the Hydrogeological profile is shown in Figure 5.

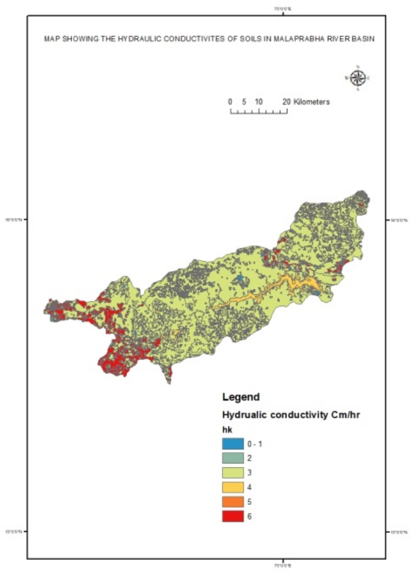

Figure 5: Map showing the Hydraulic conductivity in the area.

Conclusion

The present study showed that the groundwater availability in major of the catchment is restricted to the top 30-40 m out of which only 7-10 m is productive zone. Due to the presence of a thin semipermeable/impermeable zone below the unsaturated zone very high quantity of infiltrated water escape as interflow thereby reducing the groundwater recharge. However, in the downstream areas where there is an influence of Renukasagar dam, in spite of low rainfall and relatively high temperature conditions there are numbers of fracture zones which are identified during the present investigation thereby influencing the deep groundwater occurrence.

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