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Impact of Rainfall and Soil Infiltration on Groundwater Dynamics of Yerekoppi-1 Micro-watershed, Haveri District, Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author MMV did nodal scientist and principal investigator, Reward Project (Hydrology), conceptualization, methodology, review and editing. Author NM did data collection and GIS analysis, writing original draft. Author MSB did data analysis, methodology, review and editing. Author MH did project nodal officers. Author KVB did co-principal investigator. Author SMS did project Assistant. All authors read and approved the final manuscript.

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ABSTRACT

The amount of water infiltrating the soil surface directly affects the quantity of surface runoff and erosion, and the recharge of both soil and groundwater. Groundwater recharge is an informative indicator of the water located beneath the ground surface. It has a direct impact on renewable supplies of groundwater. In the present study on Impact of rainfall and soil infiltration rate was used for effect on the groundwater level of the Yerekoppi-1 micro watershed (Manakur sub-watershed) in Haveri district of Karnataka state. Average annual rainfall is 700.7 mm and mean potential evapotranspiration is 1541.8 mm. An area of about 888 ha (94.32 %) has clay texture at the surface and 53 ha (5.68%) area has contributing settlement. In Yerekoppi-1 micro- watershed, 38 borewells are there in the vicinity of major stream of the micro- watershed. The mean depth of groundwater levels in the micro- watershed were monitored at a monthly frequency during January-2023 to March-2024. It was found that the maximum average depth of bore wells are about 17.6 mbgl and lowest average depth of borewell about 8.8 mbgl. Soil infiltration rate was measured at upper, middle and lower reaches of the watershed area in the year 2023 and 2024. The majority of the area contributed clay soil. In all the areas of micro-watershed, infiltration rate for clay soil is less than 5 mm/hr. Infiltration rates for all the areas was 1.72- 4.78 mm/hr. Soil infiltration during a rainstorm is closely related to a number of factors such as the intensity and kinetic energy of the rainfall, soil surface conditions and soil properties such as those related to aggregate stability. The groundwater recharge may be improved by growing plantation crop for increasing infiltration rate, construction of percolation tanks and farm ponds in the lower most of the agricultural land.

Keywords: Infiltration rate; drainage; groundwater level; rainfall; soil texture; soil depth.

1. INTRODUCTION

“Climate change and its possible impacts on water resources have become a focus of recent research. Water, the most precious natural resource on the globe, is also closely related to human necessities and requirements and thus bears environmental and socioeconomic values” (Li et al. 2021, Man et al. 2023). “The dynamic changes of climate and human activities have altered the natural flow of rivers and in some arid and semiarid regions, flow of many rivers continue to decrease, even appeared zero flow in dry season. For survival of vegetation, typical water deficiency and ecological river system has brought a great impact to the ecology and social development. The amount of water infiltrating into the soil surface directly affects the quantity of surface runoff and the recharge of both soil and groundwater which are the main sources of river flow. So, the river flow, especially the ecological basic flow which maintained by groundwater during periods of low or no rainfall is affected directly by rainfall infiltration. Correctly estimating the infiltration process over time is of importance in hydrologic budget determinations, watershed management and irrigation system design” (Gadeke et al. 2024, Liu et al. 2011, Wang et al. 2015). “Soil infiltration during a rainstorm is closely related to a number of factors such as the intensity and kinetic energy of the rainfall, soil surface conditions and soil properties such as those related to aggregate stability, soil texture, structure, the mineral composition and soil moisture in the soil profile” (Liu et al. 2011).

“There is a need for rainfall intensity which has effects on groundwater recharge. Recharge results from effective precipitation (ie., precipitation minus losses from evapotranspiration) which infiltrate into the subsurface from where hydraulic gradients are downward” (Taylor et al. 2013). “In many environments, natural groundwater discharge sustains base flow to rivers, lakes and wetlands during periods of low or no rainfall, so increased attention should be given to the effect of rainfall on groundwater recharge - there is a need for more detailed investigations of rainfall intensity effects on groundwater recharge. An increase in soil moisture diminishes the hydraulic gradient, thus decreasing the driving force responsible for water infiltration into the soil” (Liu et al. 2011). “The dynamics of soil water infiltration are governed by both energy and mass transport processes and initial soil moisture plays an important role in producing the mass and energy gradients. The power law functions between the infiltration capacity and the aboveground biomass increased in water-limited ecosystems, whereas vegetation biomass was not significantly related to infiltration capacity in humid regions” (Thompson et al. 2010). Thus, the aim of the research on Impact of rainfall and soil infiltration on groundwater dynamics in the Yerekoppi-1 micro-watershed, Haveri district, Karnataka. An attempt has been made to estimate the soil infiltration on groundwater studies in the Micro-watershed during 2023-24 and for understanding the influence of groundwater levels over the groundwater recharge in the study area in response of rainfall. This paper combined to estimate the effects of rainfall intensities on groundwater regime and it could provide a thought for infiltration, ecological basic flow and watershed management of the study area.

2. METHODOLOGY

2.1 Study Area

The study area of Yerekoppi-1 micro-watershed (4D4D2c08) falls under Krishna River sub-basin, upper Tungabhadra catchment of Ranebennur taluk, Haveri district, Karnataka, India, and situated between east longitudes of 75037’49”-75039’14” and north latitudes of 14032’45”-14035’37” with an area of 941.07 ha (Fig. 1). Physiographically, the area has been identified as schistose landscape. The micro-watershed area has been further divided into mounds/ridges, summits, side slopes and moderately sloping, gently sloping and very gently sloping uplands and nearly level plains based on slope and its relief features. The elevation ranges from 461-526 m MSL.

2.2 Rainfall, Infiltration, Groundwater Measurement

The micro-watershed has only few small tanks which are not able to store the water flowing during the rainy season. This is reflected in the failure of many bore wells in the villages. If the available rain water is properly harnessed by constructing tanks and recharge structures at appropriate places in the villages, then the drinking and irrigation needs of the area can be met to great extent. Rainfall data are one of the important datasets in the spatial domain, controlling the water resources budget of the region. Rainfall data for the last 08 years were collected from Karnataka State Natural Disaster Monitoring Centre, Govt of Karnataka. In order to develop the rainfall indices of the Manakur sub-watershed, data from the Ranebennur rain gauge station (TRG_ID is 581) in Ranebennur taluk of Haveri district was taken into account. The annual rainfall at Ranebennur station (Hobli H.Q.) is presented.

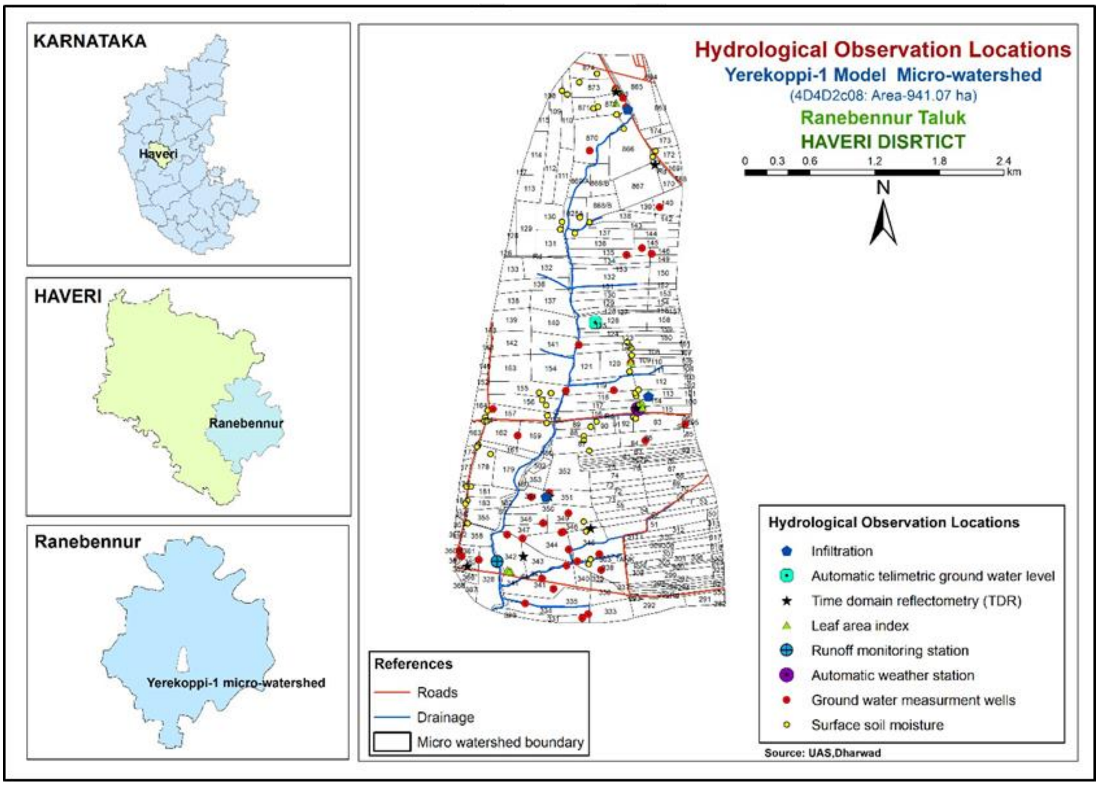

Fig. 1. Location of Yerekoppi-1 micro-watershed, Ranebennur taluk, Haveri district, Karnataka

The infiltration rate was measured at different soil phases. A double-ring infiltrometer was installed 10 cm deep in soil; care was taken to maintain the same instructed depth in all the soil phases. Out of the two cylinders, one was used to form buffer pond in order to avoid the lateral movement of water. Water level in cylinder was recorded with help of point gauge and stop watch. The point gauge was used to record the water level at the cylinder. The water level in cylinder was brought to initial level often at regular intervals of one hour. The measurements were continuous until the flow rate remained constant and the steady-state infiltration capacity was measured.

In Yerekoppi-1 micro- watershed, 38 borewells are there in the vicinity of major stream of the micro- watershed; this scenario of location of wells is due to the availability of groundwater, electricity (as electrical lines are mainly concentrated in and around this area) and geomorphologic characteristics of micro-watershed (Fig. 1). In total 38 borewells are selected for monitoring groundwater depth in the micro-watershed. The groundwater level was recorded once in a month using manual water level indicator and also station coordinates are noted using GPS. The groundwater level was recorded after 5 to 8 hours of pumping stopped.

2.3 Soil Texture and Soil Depth

Texture is an expression to indicate the coarseness or fineness of the soil as determined by the relative proportion of primary particles of sand, silt and clay. It has a direct bearing on the structure, porosity, water infiltration, adhesion and consistence. The depth of the soil determines the effective rooting depth for plants and in accordance with soil texture, mineralogy and gravel content, capacity of the soil column to hold water and nutrient availability. The Soil texture and soil depth classes used for LRI were used to classify and a surface soil texture and depth map was generated.

3. RESULTS AND DISCUSSION

3.1 Digital Elevation Model and Drainage System

“Digital Elevation Model (DEM) obtained by processing the Cartosat-1 data at a spatial resolution of 30 m is available for entire India. The DEM for the study area is shown in Fig. 2. The elevation shows a significant variation with the difference in minimum and maximum elevation being approximately 65 m. Drainage delineation analysis is an important application of DEM to demarcate the drainage basin. Elevation has a direct relation with slope and indirect relation with drainage density” (Mani 2023). “A drainage basin is the topographic region from which a stream receives runoff, through flow and groundwater flow. A number of factors like topography, soil type, bedrock nature, climate, vegetation cover, fracture pattern, etc. influence input, output and transport of sediment and water in a drainage basin. The absolute accuracy evaluation result shows in flat, hilly and mixed areas (flat and hilly), if the region of interest is on the flat region, the height accuracy is better than hilly areas. Hence it is inferred from the results that the elevations are found to be influenced by the ruggedness of the terrain” (Muralikrishnan et al. 2012).

3.2 Natural Vegetation

“The natural vegetation is sparse comprising few tree species, shrubs and herbs. The mounds, ridges and boulders occupy some area which is under thin to moderately thick forest vegetation. Still, there are some remnants of the past forest cover which can be seen in patches in some ridges and hillocks in the sub-watershed. Apart from the continuing deforestation, the presence of large population of goats, sheep and other cattle in the sub-watershed is causing vegetative degradation of whatever little vegetation left in the area. The uncontrolled grazing has left no time for the regeneration of the vegetative cover. This leads to the accelerated rate of erosion on the hill slopes, resulting in the formation of deep gullies in the foot slopes and eventually resulting in the heavy siltation of few tanks and reservoirs in the sub-watershed. There were some litters covered on soil surface, but almost no micro biotic soil crust and surface vegetation. According to the interactions between soil and vegetation in ecological succession, annual species usually grow on the soil where soil texture was loose and aeration conditions were better” (Huang et al. 2013). “The soil surface beneath shrubs or trees is protected by the canopy from raindrops, reducing the formation of soil crusts and enhancing the soil infiltration capacity. The findings suggest that land conversion improves soil water retention and hydraulic conductivity, thus attenuating the generation of surface runoff” (Yimer et al. 2018).

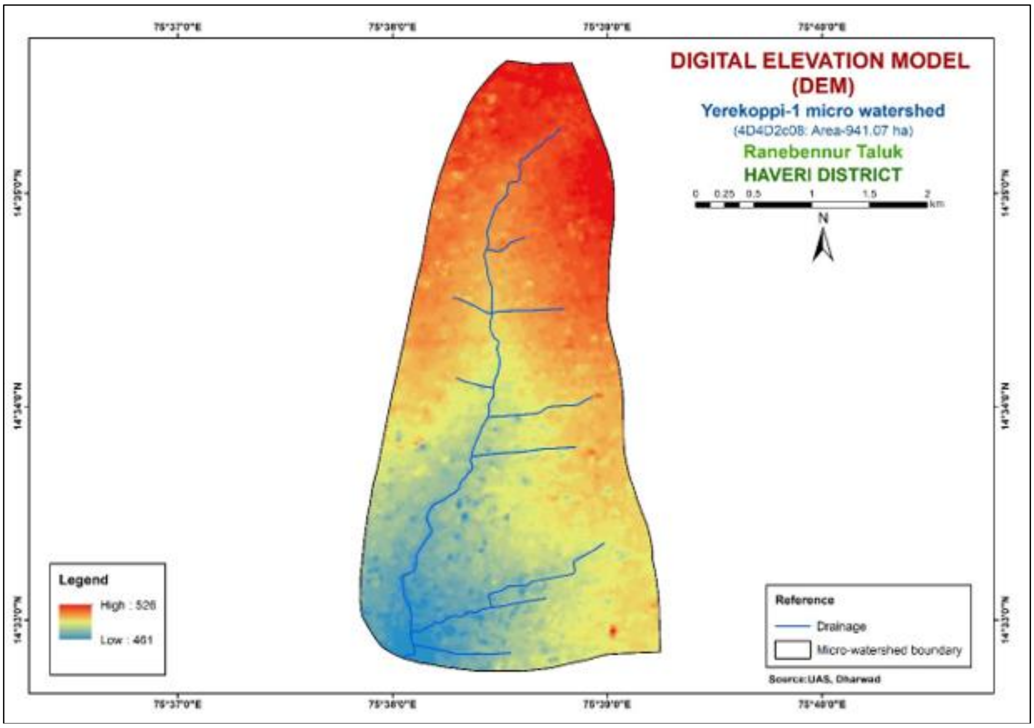

Fig. 2. Digital elevation model (DEM) of Yerekoppi-1 micro-watershed, Karnataka

Table 1. Mean monthly rainfall, Potential Evapotranspiration (PET) 0.5 PET at Ranebennur Taluk, Haveri District

Month	Rainfall (mm)	Temp Max (°C)	Temp Min (°C)	Max RH (%)	Min RH (%)	PET (mm)	0.5 PET (mm)
January	7.5	31.1	17.2	85.4	33.1	109	54.5
February	4.6	33.3	18.6	78.4	24.6	124	61.8
March	8.8	35.9	21.2	81.9	22.4	181	90.6
April	41.9	36.9	23.1	87.4	25.8	154	77.0
May	99.6	35.1	23.4	89.8	40.2	151	75.4
June	91.8	31.7	22.9	92.3	55.7	126	63.2
July	104.5	29.1	22.2	93.5	66.0	130	64.8
August	104.3	29.0	21.9	94.7	68.6	130	65.2
September	75.7	30.4	21.6	97.7	65.0	109	54.7
October	126.4	31.0	21.1	99.1	59.6	129	64.5
November	34.0	31.0	19.4	95.3	49.6	98	49.0
December	1.7	31.0	17.8	92.3	42.3	101	50.4
Total	**700.7**					**1541.8**	**770.9**

3.3 Weather and Rainfall Analysis

"The average annual rainfall (2014-2021) recorded at the Ranebennur (GP) was 700.7 mm in last 7 years (Table 1). The maximum precipitation of 376.3 mm is received during south–west monsoon period from June to September, north-east monsoon contributes about 162.1 mm and prevails from October to early December and the remaining 162.4 mm is received during the rest of the year. During the year 2015, 2016, and 2017, annual rainfall was deficient by 19.6%, 43% and 43%, respectively, during 2014, 2019 and 2021, annual rainfall was excess by 43%, 37% and 43 %, respectively as compared to average annual rainfall (Fig. 3). The data shows the clear decline in the rainfall (mm) pattern due to climate change during 2015-2017. This variability in rainfall pattern may lead to extreme hydrological incidents. Climatic patterns specific to total and average rainfall, number of rainy days, monsoon onset, and intervening prolonged dry spells are some of the important aspects that necessitate the collection of long-term data in order to develop an understanding of possible impacts of climate change on people, natural resources, Agro-ecosystems, and the economy" (Mani et al. 2023). The winter season is from December to February. During April and May, the temperatures reach up to 36.9°C and in December and January, the temperatures will go down to 17.8°C.

Rainfall distribution, Potential Evapotranspiration and 0.5 PET is shown in Fig. 4. The average monthly Potential Evapotranspiration (PET) is 128.5 mm and varies from a low of 98 mm in November to 181 mm in the month of March. The PET is higher than precipitation in all the months. Generally, length of growing period in Yerekoppi-1 micro-watershed ranged from 180 to 190 days. The length of growing period begins at 17th week (which is April 4th week) and ends at 43rd week (which is October 4th week). While 26th standard week in the growing season may be critical for moisture which means that May 4th week and partly July 1st week could be meteorologically drought period, during which precipitation is not sufficient enough to meet the minimum PET demand of the crops/ vegetation in the region. Dry spells/weeks are not found continuous and growth of crops may not be markedly affected if the recommended drought management practices for a given crop/crops are adopted. One protective or life - saving irrigation based on the critical stage of the crop would be of great advantage (Mahadevaswamy et al. 2016). Based on the observation, farmers can schedule sowing and other agronomic practices for short duration and long duration crops. The major crops in the micro watershed were maize, cotton, arecanut, soybean, onion, rabi sorghum, sunflower and chilli.

Water consumption by crops varies substantially, reflecting differences in cropping density, crop choice, soil characteristics, irrigation availability and agricultural management as well as climatic drivers of evapotranspiration. The choice of suitable crop likely to contribute substantially towards water saving without affecting food production, where water resources are scarce (Brauman et al. 2013).

3.4 Surface Soil Texture and Soil Depth

Texture is an expression to indicate the coarseness or fineness of the soil as determined by the relative proportion of primary particles of sand, silt and clay. It has a direct bearing on the structure, porosity, water infiltration, adhesion and consistence. The surface layer of a soil to a depth of about 25 cm is the layer that is most used by crops and plants. The surface soil textural class provides a guide to understanding soil-water retention and availability, nutrient holding capacity, infiltration, workability, drainage, physical and chemical behaviour, microbial activity and crop suitability. An area of about 888 ha (94.32 %) has clay texture at the surface and 53 ha (5.68%) area has contributing settlement (Fig. 5). The most productive lands with respect to surface soil texture are clayey soils that have high potential for retention and availability of water and nutrients but, have more problems of drainage, infiltration, workability and other physical problems.

The depth of the soil determines the effective rooting depth for plants and in accordance with soil texture, mineralogy and gravel content, the capacity of the soil column to hold water and nutrient availability. Soil depth is one of the most important soil characters that are used in differentiating soils into different soil series. The soil depth classes used in identifying soils in the field are shallow (25-50 cm), moderately deep (75-100 cm), deep (100-150 cm) and very deep (>150 cm). They were used to classify the soils into different depth classes and a soil depth map was generated (Fig. 6). Shallow (25-50 cm) soils cover an area of about 26 ha (2.8 %), moderately deep soils (75-100 cm) cover an area of about 127 ha (13.51 %), deep soils (100-150 cm) cover an area of about 50 ha (5.3 %) and very deep soils (>150 cm) cover an area of about 684 ha (72.7 %). The most productive lands with deep (100-150 cm) and very deep (>150 cm) soils cover about 734 ha (78.38 %) where all climatically adopted long duration crops be grown. The maximum clay content at any depth of the profile is one of the key factors controlling the movement further down the profile and thus, the final steady rate (Parth et al. 2008).

3.5 Infiltration Rate

Soil infiltration rate was measured at upper, middle and lower part of the watershed area in the year 2023-24 and 2024-25. The majority of the watershed area is contributed by clay soil. For all the sites of the micro-watershed, the infiltration rate for clay soil is less than 5 mm/hr. Infiltration rates for all the areas were 4.78, 4.30, 4.08, 3.37 and 1.72 mm/hr and R2 for the trend line reaches the value of 0.089, 0.961, 0.603, 0.695 and 0.0481, respectively (Fig. 7). The lowest part of the area had the numeric less infiltration rate than middle and upper part of the micro watershed. The reason was likely attributed to the differences in soil pores at the different slope positions induced by the differences in soil erosion and deposition processes. Due to the flat terrain and low area for runoff concentration at the upper area, the surface runoff had transported the silt particles and organic matter. In contrast, the decomposed aggregates or clods are prone to consolidate, which decreased infiltration rate via reducing soil pores (Zhang et al. 2019, Zhu et al. 2020).

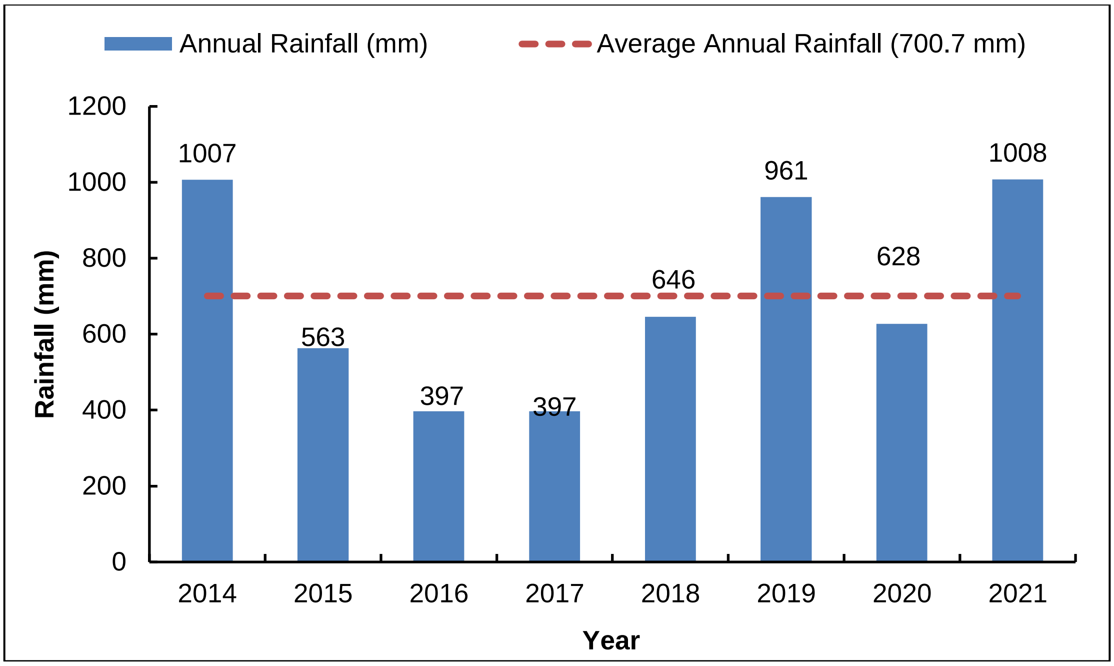

Fig. 3. Average annual rainfall of Ranebennur Taluk, Haveri District

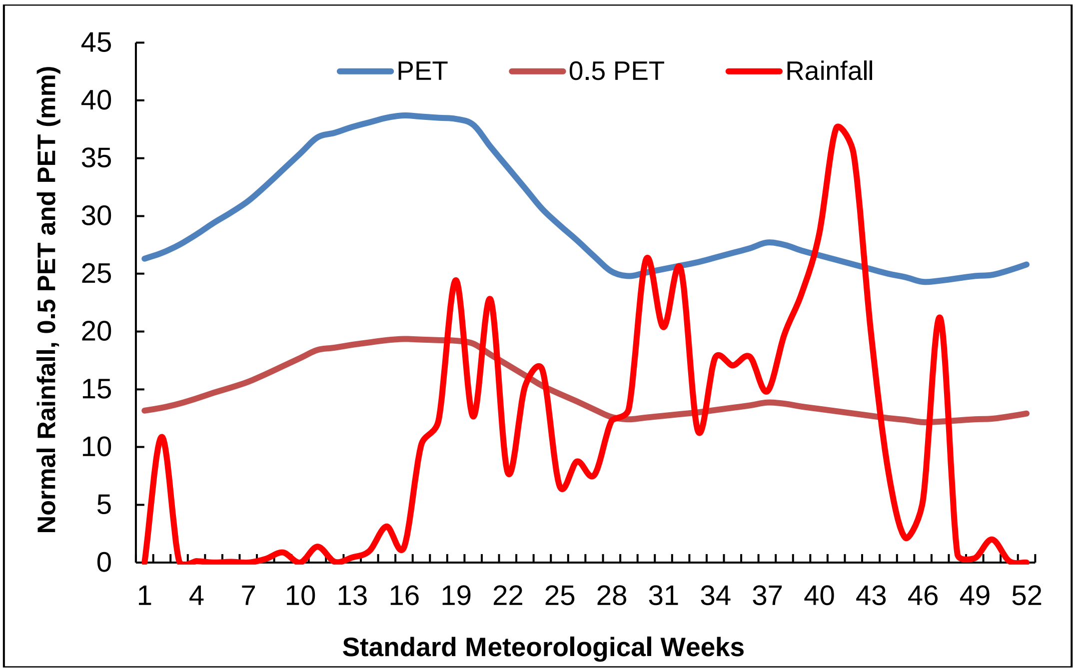

Fig. 4. Mean weekly rainfall, PET and 0.5 PET at Ranebennur Taluk, Haveri District

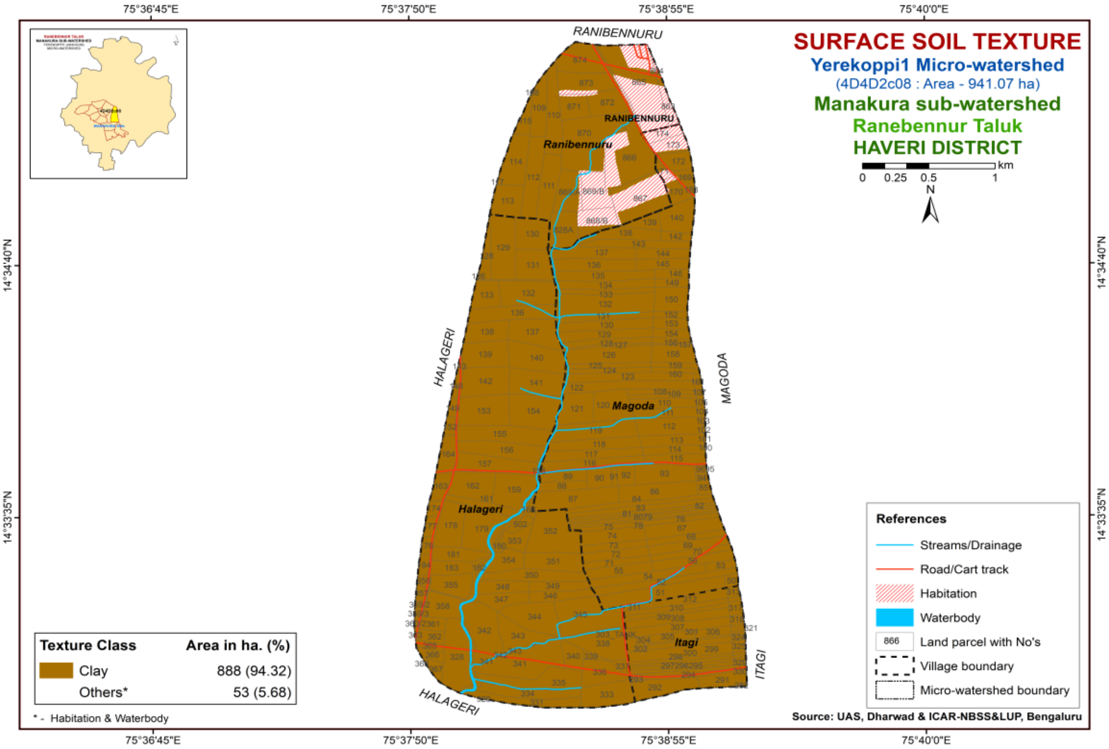

Fig. 5. Surface Soil texture of Yerekoppi-1 micro-watershed, Ranebennur Taluk, Haveri District

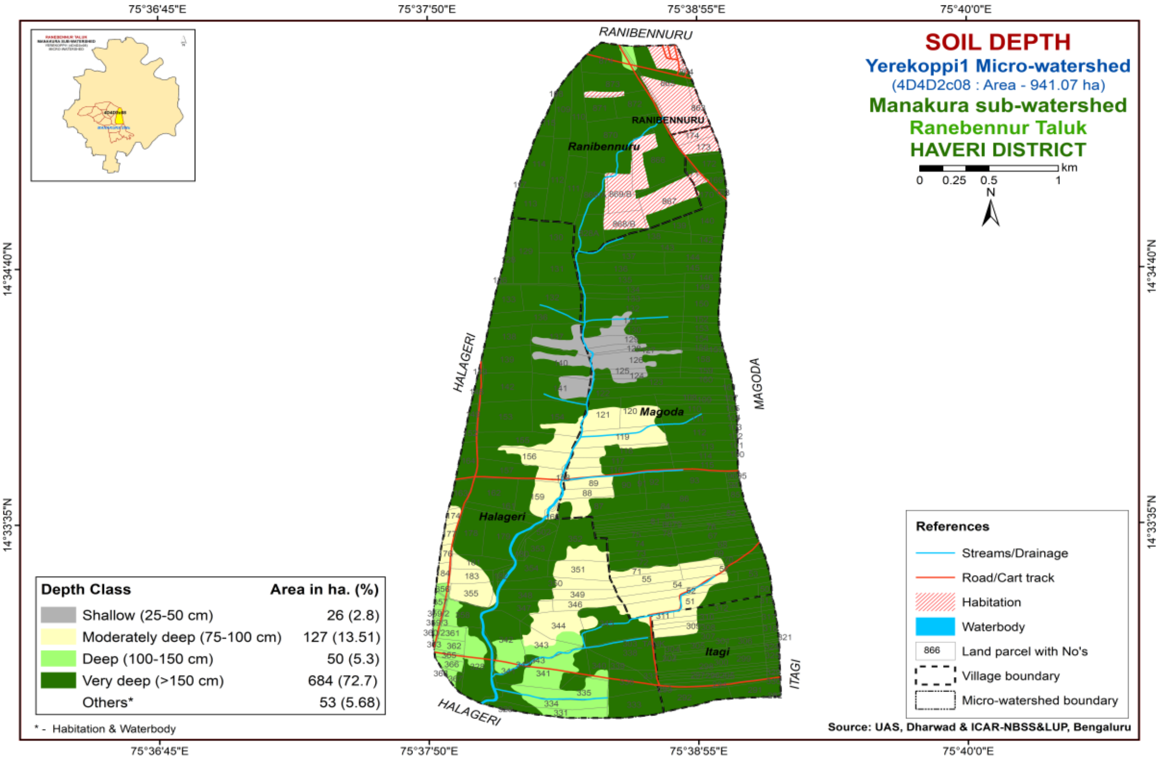

Fig. 6. Soil depth of Yerekoppi-1 micro-watershed, Ranebennur Taluk, Haveri District

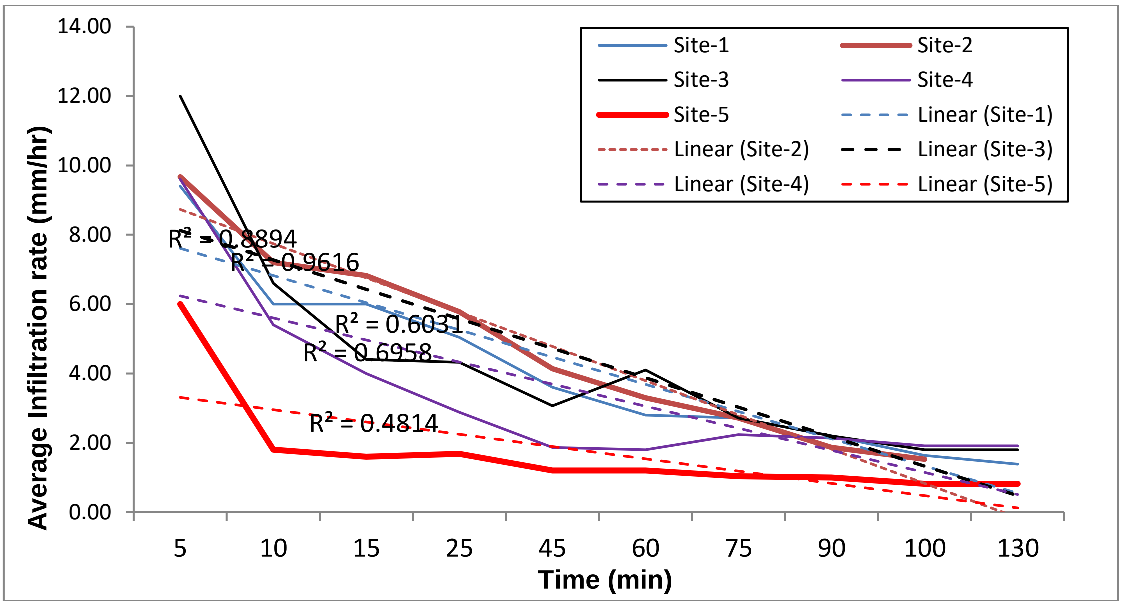

Fig. 7. Infiltration rate at different sites of Yerekoppi-1 micro watershed, Karnataka (2023-24)

Infiltration rates decrease linearly at R2 =0.481 with the increase in soil strength. This indicates that the soil layer with high resistance to penetration controls the movement of infiltrated water to lower the infiltration rate. This condition is due where the topsoil consists of compacted due to the machinery in logging operations leads to soil compaction (De Armond et al. 2023), which leads to less void space between space particles and reduces the availability of macro pores, which is an important pathway in the process of infiltration of water into the soil (Cleophas et al. 2022). The infiltration of water is mainly governed by geology, land use practice and elevation of the terrain (Bharathkumar et al. 2018). The surface soil textural class provides a guide to understanding soil-water retention and availability, nutrient holding capacity, infiltration, workability, drainage, physical and chemical behavior, microbial activity and crop suitability (Christelle Basset et al. 2023, Nawaz et al. 2013). Soil textural classes are pivotal in determining the volume of water that can infiltrate into subsurface formations, thereby influencing groundwater recharge. When evaluating infiltration rates, soil texture and hydraulic properties are important considerations (Huang et al. 2020).

3.6 Groundwater Depth

Groundwater levels fluctuate naturally in response to a sequence of climatic events and to constraints imposed by hydrogeologic and topographic characteristics. The groundwater level influenced by borewell recharge, discharge, topography of land, soil texture etc. Trend analysis of water table depths indicates marked spatial variations of groundwater levels in Yerekoppi-1 micro-watershed of the study area. The depth to water table was recorded from April, 2023. The deeper water table (17.6 mbgl) was recorded during March,2024 and the shallow water table depth of 8.8 mbgl was recorded during October, 2023 (Fig. 8). There was falling trend of depth to water table in the watershed, as these months were lower rainfall and indicates utilization of groundwater to buffer the lower rainfall moths. The long-term data of depth to Water level is analysed to interpret the behaviour of groundwater over period of time. The groundwater level is observed to show an increasing trend (Manjunatha et al. 2024).

“These data indicated marked spatial variability in the distribution of wells with distinct rates of change across the different geomorphic units visible” (Suneel et al. 2021). “Groundwater resource of a region is one of the building blocks for balanced economic development of the area. The water table represents the groundwater reservoir and changes in its level represent the changes in groundwater storage” (Raghavendra et al. 2013).

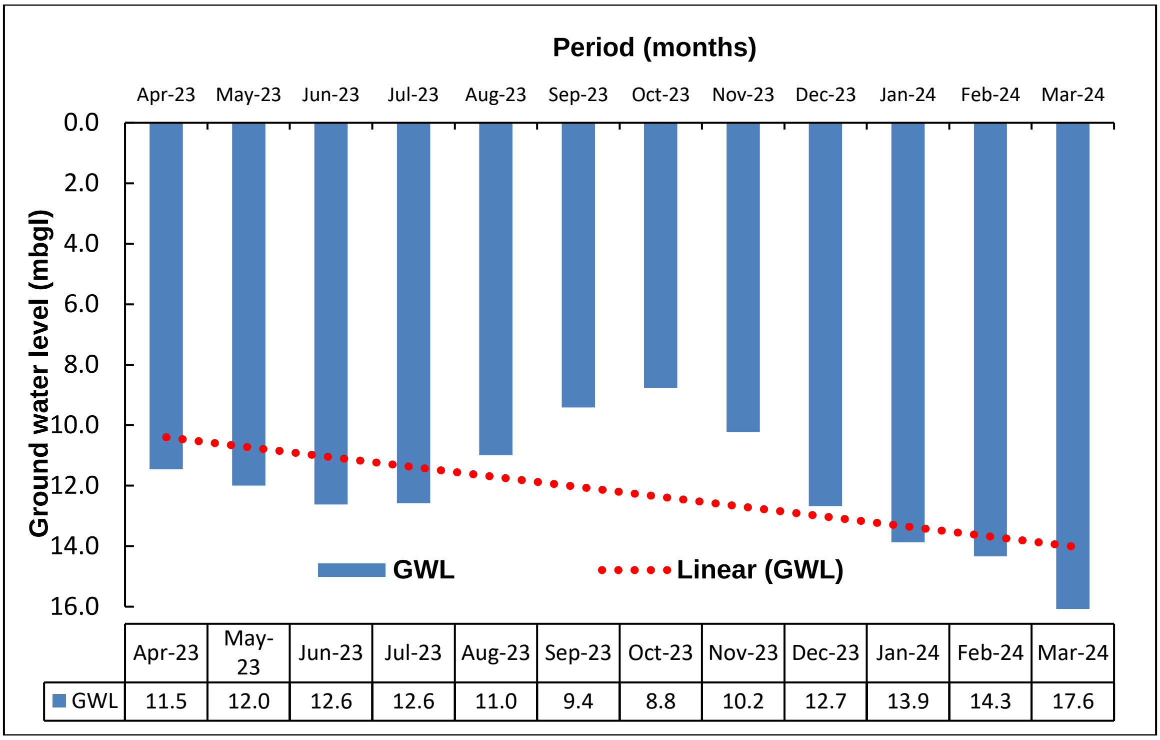

Fig. 8. Groundwater depth of Yerekoppi-1 micro-watershed, Karnataka

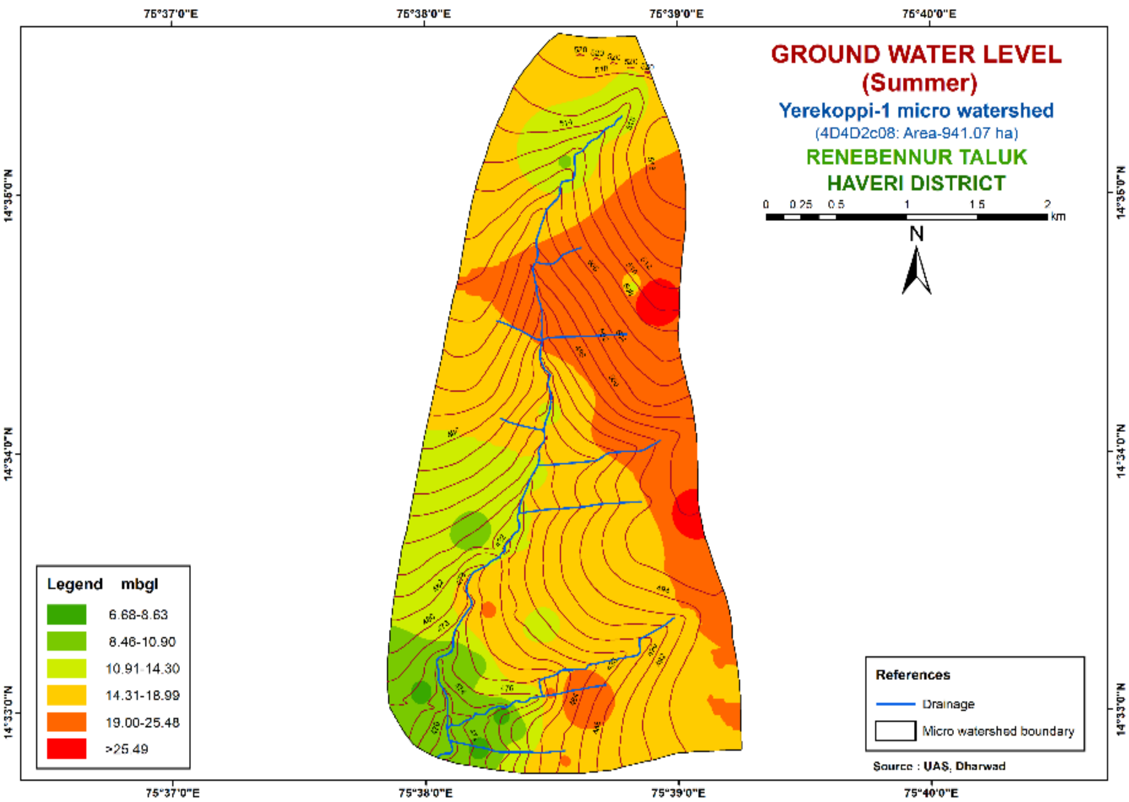

Fig. 9a. Groundwater depth at Yerekoppi-1 micro-watershed during summer

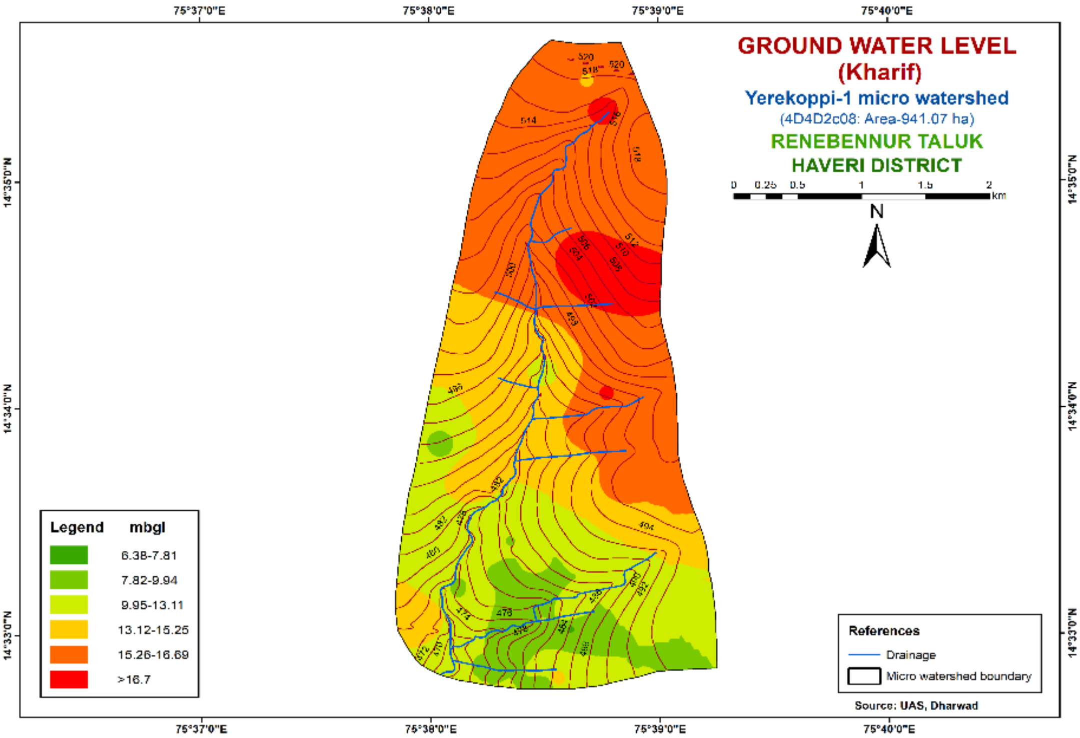

Fig. 9b. Ground water depth at Yerekoppi-1 micro-watershed during kharif

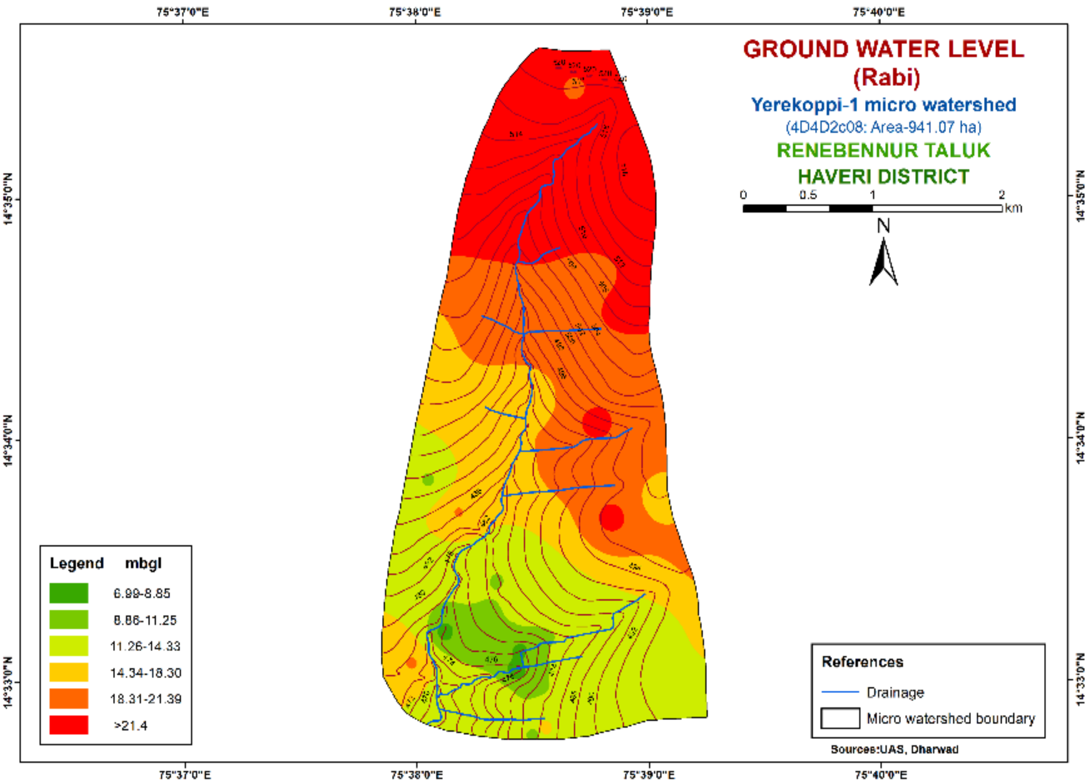

Fig. 9c. Ground water depth at Yerekoppi-1 micro-watershed during Rabi

The groundwater levels during the summer, Kharif and Rabi for the year 2023 observed at 38 wells located in Yerekoppi-1 micro-watershed has been used to create point maps in GIS. The groundwater table in the Yerekoppi-1 micro-watershed has been recorded between 6.68 to > 25.49 mbgl during summer, 6.38 to > 16.7 mbgl during kharif and 6.99 to > 21.40 mbgl during Rabi season (Figs. 9 a,b,c). During summer season, most of the watershed area has deeper water table and during rabi season has a medium groundwater table in the year 2023 (Figs. 9 a,b,c). The highest groundwater elevation occurred in north-eastern part to north of the study area and the lowest groundwater elevation obtained in the south-eastern to south parts of the study area. The groundwater elevation gradients are higher in northern part and gradually decrease towards the southern parts and the general flow occurs from north to south (Nikroo et al. 2010).

The groundwater table is deep on the upstream side and shallow on the mid and valley side. This is possibly due to the flux that the water drains down slope to bring the soil moisture to the field capacity (Addisie et al. 2022). In addition, the soil depth on the upslope is shallow, which means it dries out faster than the deep soils due to evaporation; therefore, the quantity of water flowing toward the well is declining faster as compared with well in the deep soil (Cholo et al. 2023).

4. CONCLUSION

The total geographical area of the Yerekoppi-1 micro watershed is 941.07 ha. Average annual rainfall is 700.7 mm and mean potential evapotranspiration is 1541.8 mm. An area of about 888 ha (94.32 %) has clay texture at the surface and 53 ha (5.68%) area has contributing settlement. The soil depth of the micro-watershed is shallow (25-50 cm) an area of about 26 ha (2.8 %), moderately deep soils (75-100 cm) cover an area of about 127 ha (13.51%), deep soils (100-150 cm) cover an area of about 50 ha (5.3 %) and very deep soils (>150 cm) cover an area of about 684 ha (72.7 %). The most productive lands with deep (100-150 cm) and very deep (>150 cm) soils cover about 734 ha (78.38 %) where all climatically adopted long duration crops be grown. Infiltration rates for all the sites of the micro-watershed was 1.72 to 4.78 mm/hr. There was falling trend of depth to water table (8.8 to 17.6 mbgl) in the watershed during Oct-2023 to March-2024, as these months were lower rainfall and indicates utilization of groundwater to buffer the lower rainfall moths. The groundwater map shows the natural topography and prevailing conditions in the watershed are favorable for declining water table. The point recharge and farm ponds may be constructed in the lower most corner of the agricultural fields to increase the natural recharge of rain water during the monsoon period.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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