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Spatial Distribution of Groundwater Fluctuation Mapping Using Arc-GIS in Hosur-1 Micro-watershed of Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Groundwater is a primary source of freshwater and used mainly for agriculture and irrigation purposes. Recharge to groundwater is the most important component in all the water balance studies. In the present study kriging technique was used for interpolate the groundwater level of the Hosur-1 micro watershed (Kanakvad sub watershed) in Gadag district of Karnataka state. In Hosur-1 micro- watershed 41 wells are there in the vicinity of major stream of the micro- watershed. The mean depth of ground water levels in the micro- watershed were monitored at a monthly

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frequency during January-2023 to March-2024. It was found that the maximum average depth of bore wells are about 9.55 mts and lowest average depth of borewell about 4.64 mts. The groundwater table between 2.48 to 14.70 mbgl during summer season period and 3.18 to 21.50 mbgl during the Rabi season. The pH of ground water varied between 7.0-9.0, maximum pH was recorded as 8.9 and minimum was recorded as 7.29 and maximum conductivity >3.82 ds/m and minimum 0.87 ds/m was recorded at Hosur-1 micro-watershed. The average infiltration rate of clay soil 2.73 mm/hr and R^2 value for the trend line reaches the value of 0.5876. In case of sandy clay loam average infiltration rate was 3.83 mm/hr and R^2 value for the trend line reaches 0.6572. It necessitates continuous monitoring of groundwater for assessing the possible damage on salinity and alkalinity induced soil health.

Keywords: Chemical properties; drainage; geology; groundwater level; infiltration and krigging.

1. INTRODUCTION

"Growing population, high production agriculture practices, development of industries and various other domestic and recreational water uses has resulted in the overexploitation of the groundwater resources. The estimation of groundwater quantity and quality is crucial for most hydrological studies by supplementing the water demand for a variety of purposes. Ground water constitutes a major issue in regions where there is a large demand, such as in deficit irrigation commands, where irrigation water supply is confined only for few months and farmers have to inevitably depend on ground water, which is a key factor to agricultural development in these areas. Land and water are the two main resources of the watershed. The watershed not only is a useful unit for physical analyses, it can also be an appropriate socio-economic-political component for the execution of management strategies. In essence, a watershed is a basic organizing unit to manage resources" [1].

"The availability of groundwater in the terrain is based on the presence and pervasiveness of secondary permeability in the forms of fractures and/ or weathered zones and the degree of connectivity of these structures" [2]. "The rise in the water table indicates the condition when the recharge exceeds discharge, whereas fall in water table indicates the situation when the discharge exceeds recharge" [3].

"National Water Policy, 2012 has laid emphasis on periodic assessment of ground water resources on scientific basis. To meet the increasing demands of water, it advocates direct use of rainfall, desalination and avoidance of inadvertent evapotranspiration for augmenting utilizable water resources. The National Water Policy 2012 also states that safe water for drinking and sanitation should be considered as pre-emptive needs followed by high priority allocation for other domestic needs (including needs of animals), achieving food security, supporting sustenance agriculture and minimum eco- system needs. In the present assessment, the total annual groundwater recharge in the country has been assessed as 449.08 billion cubic meters (bcm). The average annual groundwater extraction for the country for Irrigation, Domestic & Industrial uses 241 bcm (59.26 %)" [4].

"Karnataka State is underlain by rock types ranging in age from Archaean to Recent. Major portion of the State is covered by Peninsular Gneisses, Granites and Dharwad Schists of Archaean age. Substantial area in the northern part of Karnataka is underlain by basalts, which form a continuation of the Deccan Traps occurring in Maharashtra. The aquifer systems are classified into nine major groups depending upon their characteristics and are Banded Gneissic Complex (BGC), Basalt, Schists, Granites, Charnockites, Limestones, Laterites, Sandstones and Alluvium. The Annual Ground Water Recharge has been assessed as 18.9 bcm and the Annual Extractable Ground Water resource is 17.1 bcm. The present Annual Ground Water Extraction is 11.3 bcm and the Stage of Ground Water Extraction is 66.3% CGWB, 2023)" [4]. As compared to 2022 assessment, there is increase in Annual Ground Water Recharge from 17.7 bcm to 18.9 bcm, Annual Extractable Ground Water Resources from 16.04 bcm to 17.08 bcm.

"This is mainly due to increase in rainfall recharge, recharge from surface water irrigation, recharge from water conservation structures and recharge from tanks and ponds. There is marginal increase in the Current Annual Ground Water Extraction for all uses from 11.22 to 11.32

bcm during this period. Hence overall, the Stage of Ground Water Extraction has decreased from 69.93% in 2022 to 66.26 % in 2023 indicating improvement in overall ground water scenario. As compared to 2022, 17 assessment units (taluks) have improved mainly due to increase in rainfall recharge and recharge from other sources" (CGWB, 2023) [4]. Ground water studies are important tools to comprehend the hydrological behavior of the watersheds. Hence the spatial distribution of groundwater fluctuation mapping using Arc-GIS have been take up at Hosur-1 micro-watershed of Gadag district, Karnataka.

2. METHODOLOGY

2.1 Study Area

Hosur-1 micro-watershed (Kanakvad sub-watershed, Shirahatti taluk, Gadag district) is located in between 15⁰2'40"–15⁰4'20" North latitudes and 77⁰39'40"–75⁰41'0" East longitudes. The study area falls under the watershed codification of 4D4A3J2c with an area of 408.30 ha (Fig.1). The average annual rainfall was 712 mm and length of growing period (LGP) is varying from June 4th week to 4th week of November (150-180 days) [5].

2.2 Geology

Major rock formation observed in the micro-watershed is Gadag Schist with thick coating of Banded Ferruginous Quartzite [5]. The ridges have capping of Banded Ferruginous Quartzite (BFQ), whereas side slopes near the streams are dominated by schist. They are fine grained and show a distinct weathering pattern similar to that of basalt. Due to its fine texture, the soils formed from these rocks are mostly clayey in nature. The presence of iron rich banded ferruginous quartzite is responsible for the dark red colour of the soils observed in the Hosur-1 micro-watershed.

2.3 Drainage

The area is drained by several small seasonal streams that join Dodd Halla along its course. Though, it is not a perennial one, during rainy season it carries large quantities of rain water. The micro-watershed has only few small tanks which are not able to store the water flow during the rainy season. Due to this, the ground water recharge is very much affected in the villages. 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

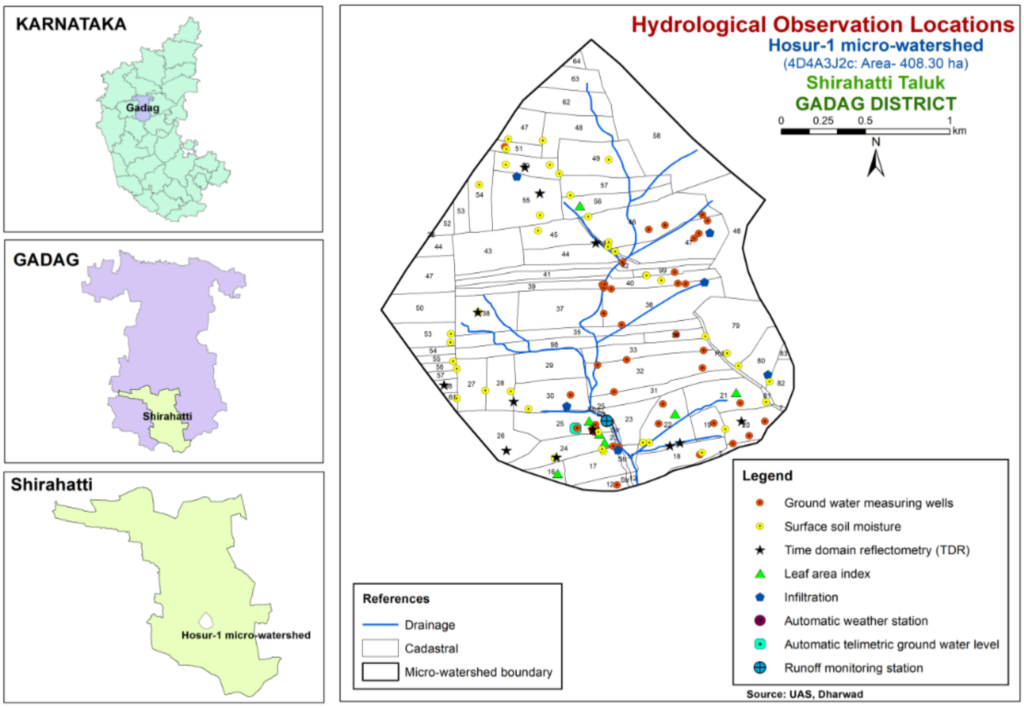

Fig. 1. Location and extent of Hosur-1 Model micro-watershed, Shirahatti taluk, Gadag district

recharge structures at appropriate places in the village, then the drinking and irrigation needs of the entire area can be easily met. The drainage network is dendritic to sub parallel.

2.4 Natural Vegetation

The natural vegetation is sparse comprising few tree species, shrubs and herbs. The mounds, ridges and bouldery areas occupy very sizeable area which is under thin to moderately thick forest vegetation. Apart from the continuing deforestation, the presence of large population of goats, sheep and other cattle in the micro-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 micro-watershed [5].

2.5 Infiltration Measurement

"The infiltration rate was measured at different soil phases. The measurement was taken at three watershed positions like top, middle and lower. A double-ring infiltrometer was installed 10 cm deep in soil, care was taken to maintain the same instruction depth in all the soil phases. One of the two cylinder, 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 a regular interval of one hour" [6]. The measurements were continuous until the flow rate remained constant and the steady-state infiltration capacity was measured.

2.6 Groundwater Level Measurements

In Hosur-1 micro- watershed, 41 wells 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. 2).

There are 41 bore wells are located for monitoring groundwater depth. The ground water level should be recorded once in a month using water level indicator. The dipper probe with tape is gradually let into the borewell, one would hear a clear sound indicating that the probe is touching the water. The sound is hearing continuously as the probe is immersed in water, a few trails are recorded and also station coordinates are noted using GPS. The ground water level should be gathered at least 5 to 8 hours after the pumping is stopped.

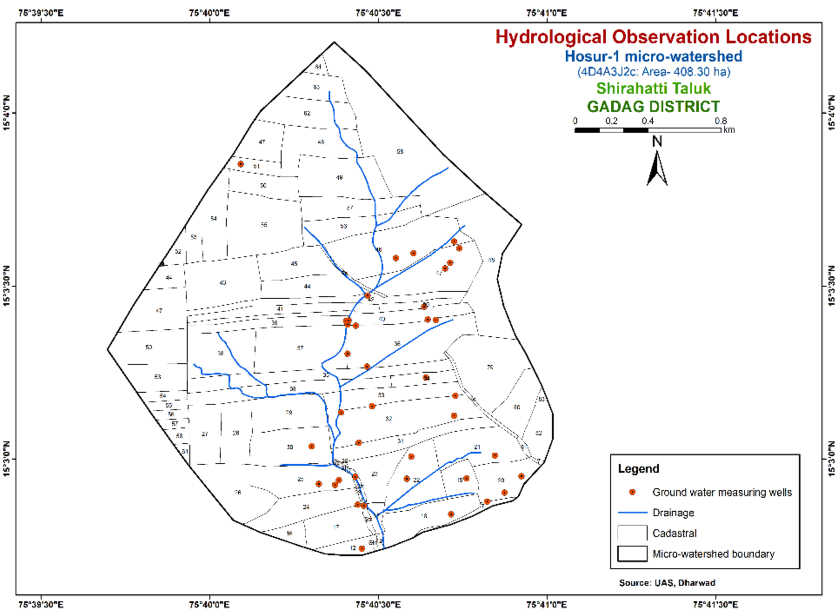

Fig. 2. Location of borewells in Hosur-1 study area

2.7 Chemical Properties

The ground water samples were collected from bore wells of Hosur-1 micro-watershed every two months to analyse different chemical parameters to comprehend the quality of ground water of that locality. In the end samples were analyzed in the laboratory for their quality parameters *viz*, pH, EC, Cl, SAR, RSC, Cations and Anions etc. the pH and EC were estimated using pH meter remaining all other parameters were assessed using titration method.

2.8 Point Interpolation: Kriging

Kriging is a geostatistical method for estimating values in unknown areas by considering both the distance and variation between known data points. It involves creating an estimated surface from scattered points with z- values by fitting a mathematical function to nearby points. The process includes statistical analysis, variogram modeling, surface creation, and variance exploration. Predicted values are calculated using a weighted average technique based on the relationship between samples. The search radius can be fixed or variable and generated cell values may exceed the sample range [7].

$$Z(S_0)^N=\sum_{i=1}^{N} \lambda Z(Si)$$

Where,

Z(Si) = the measured value at the Ith location
λ_i = an unknown weight for the measured value at the Ith location

S_0 = the prediction location
N = the number of measured values

The Kriging method is an interpolation method based on principles of zero bias and minimum mean square error. It determines values for a process over an entire domain, finite-volume block or specific point using a linear combination of data values. The summation may be over an entire area or restricted region centered at the estimation point [8].

3. RESULTS AND DISCUSSION

Infiltration rate was conducted at different soil phases and groundwater level during pre-monsoon and post-monsoon are observed at 41 borewells located in Hosur-1 micro-watershed.

3.1 Geology and Soil Texture

The micro-watershed area has been identified as Schist Landscape based on geology. Soil formation is the result of the combined effect of environmental and terrain factors that are reflected in soil morphology. The soils are very shallow (<25 cm), well drained, have very dark grayish brown gravelly clay soils and occur on very gently sloping uplands.

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. Maximum area of 295 ha (72%) has soils that are clayey at the surface and are distributed in all parts except in the northeastern part of the micro-watershed and about 107 ha (26%) area has soils that are sandy clay loamy soils. They are distributed in the eastern and southwestern part of the micro-watershed (Fig.3). The most productive lands (72%) with respect to surface soil texture are the clayey soils that have high potential for soil-water retention and availability and nutrient retention and availability but have problems of poor drainage, low infiltration rate, workability and other physical problems [9].

3.2 Infiltration Rate

Soil infiltration rate was measured at different soil phases in the watershed in the year 2023-24. The majority of the area contributed clay soil (68.85 %) followed by sandy clay loam (20.23 %) and very less area contributing sandy clay (3.48 %). The result shows that average infiltration rate of clay soil 2.73 mm/hr and R^2 value for the trend line reaches the value of 0.5876, so it is shows that amount of clay particles is more has the lowest effect on water infiltration rate and it create more surface runoff. In case of sandy clay loam average infiltration rate was 3.83 mm/hr and R2 value for the trend line reaches 0.6572 (Fig. 4), the amount of sand particles more it effects the more infiltration rate and creates less runoff, despite the rise in water table during the onset of rainfall over the managed watershed. Similar results were found [10].

3.3 Groundwater Table

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 Hosur-1 micro- watershed of the study area. The mean depth of ground water observed from ground level during the different months (since January 2023) was found highest of 11.9 mts and lowest of 4.64 mts during the month of March 2024 and January 2023 respectively (Fig.5). These data indicate marked spatial variability in the distribution of wells with distinct rates of change across the different geomorphic units visible [11]. 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 [12].

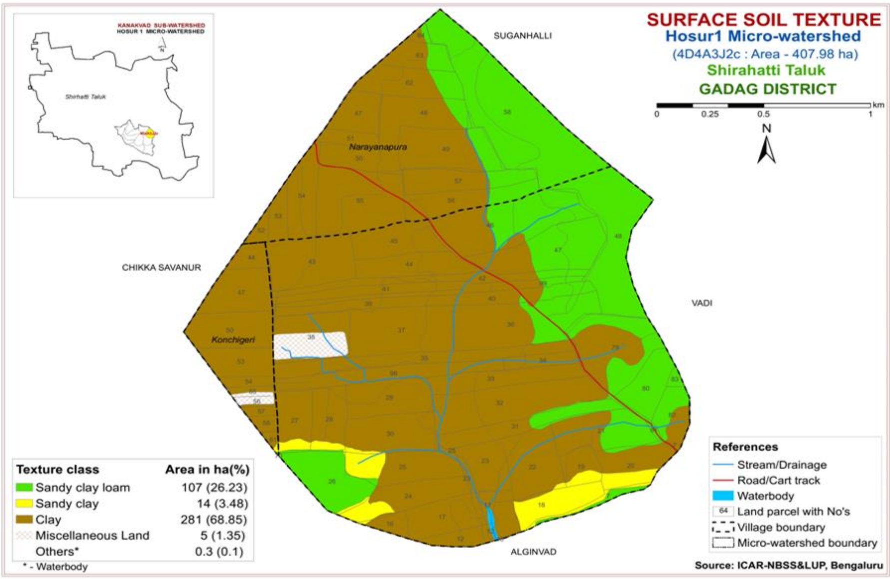

Fig. 3. Surface soil texture of Hosur-1 micro-watershed

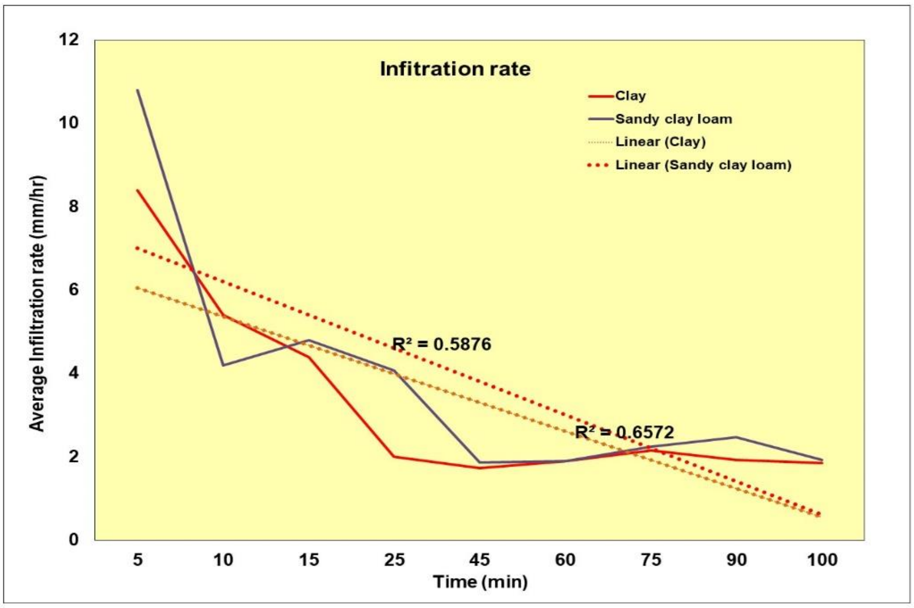

Fig. 4. Infiltration rate of different soils at Hosur-1 micro watershed

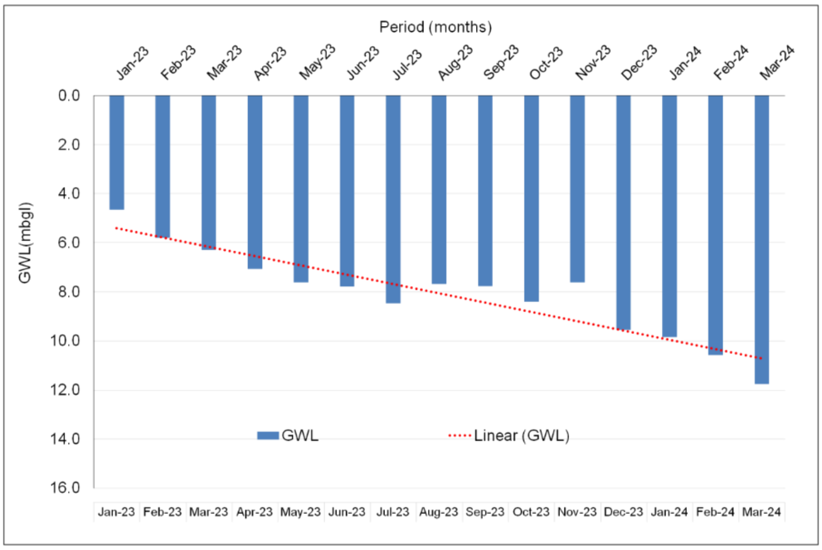

Fig. 5. Ground water status of Hosur-1 model micro-watershed

3.4 Kriging

Remote sensing and GIS applications provide an excellent platform to analyze watershed management and development through prioritization studies [13]. The groundwater levels during the summer, Kharif and Rabi for the year 2023 observed at 39 wells located in Hosur-1 micro-watershed have been used to create point maps in GIS. The groundwater table in the Hosur-1 micro-watershed has been recorded between 2.48 to 14.70 mbgl during summer, 2.80 to 18.70 mbgl during kharif and 3.18 to 21.50 mbgl during the rabi season of the year 2023 (Fig. 6). In summer season most part of the watershed has shallow and the Rabi season has deeper groundwater table in the year 2023 [14]. The map of groundwater elevation determined by this method shows that the highest groundwater elevation occurred in west to western part of the study area and the lowest groundwater elevation obtained in the northeastern part 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 [15].

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 downslope to bring the soil moisture to the field capacity [16]. 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 [17].

3.5 Chemical Properties

Ground water quality of Hosur-1 Micro watershed values of all water quality parameters in the groundwater samples are illustrated in Table-1 and the variation of water quality parameters in ground water samples of study area is depicted in Fig.7. In our study pH of water varied between 7.0-9.0, maximum pH was recorded as 8.9 and minimum was recorded as 7.29, its indicating that most of study area having groundwater of alkaline water [18]. The pH of water is very important indication of its quality and provides information in many types of geochemical equilibrium or solubility calculations [19]. The electrical conductivity of water depends upon the concentration of ions and its nutrient status. In the present investigation maximum conductivity >3.82 ds/m and minimum 0.87 ds/m was recorded at Hosur-1 micro-watershed. High values of conductivity indicate high concentration of soluble salts present in ground water sources [20].

Sodium adsorption ratio value of groundwater provides a useful index of the sodium hazard of the water for soils and crops. Maximum SAR was recorded as 6.01 and minimum was recorded as 1.34. High sodium water may produce harmful levels of exchangeable sodium in most soils and requires special soil management like good drainage, high leaching and organic matter addition [21]. The high values of SAR indicate that sodium in the water may replace calcium and magnesium ions in the soil, possibly causing a damage to the soil structure [18].

Table 1. Chemical properties of groundwater samples of the Hosur-1 Micro-watershed

Sl. No	Survey No.	pH	EC (dS/m)	Na	Ca+Mg	HCO3	Cl	SAR	RSC	cations	anions
				(me/L)					(me/L)		
1	47/4	7.45	0.94	2.81	6.80	1.00	7.60	1.52	-5.80	9.61	8.60
2	40	7.70	1.87	3.72	13.00	2.00	16.80	1.46	-11.00	16.72	18.80
3	25	7.55	1.77	5.95	10.60	2.80	12.40	2.58	-7.80	16.55	15.20
4	32	7.52	0.97	2.50	6.00	1.20	8.40	1.44	-4.80	8.50	9.60
5	36/1	7.59	1.84	9.30	9.60	3.00	16.00	4.25	-6.60	18.90	19.00
6	36/1	7.60	1.81	9.80	11.00	5.00	17.20	4.18	-6.00	20.80	22.20
7	17	7.69	1.80	7.80	10.00	2.60	16.40	3.49	-7.40	17.80	19.00
8	12	8.90	1.61	7.38	9.00	1.60	12.00	3.48	-7.40	16.38	13.60
9	40	7.52	1.38	4.41	9.80	2.00	8.00	1.99	-7.80	14.21	10.00
10	46/3	7.63	0.98	3.21	6.20	2.60	6.00	1.82	-3.60	9.41	8.60
11	30/1	7.55	0.94	2.73	6.60	2.40	4.80	1.50	-4.20	9.33	7.20
12	46	7.73	1.86	8.38	10.40	4.20	12.80	3.67	-6.20	18.78	17.00
13	25	7.86	1.38	8.29	3.80	3.20	7.60	6.01	-0.60	12.09	10.80
14	36	7.51	1.07	6.25	4.80	1.80	8.40	4.03	-3.00	11.05	10.20
15	34/1	7.61	0.78	1.94	4.20	1.00	4.40	1.34	-3.20	6.14	5.40
16	21	7.37	0.94	2.43	6.20	1.20	7.20	1.38	-5.00	8.63	8.40
17	19/2	7.47	0.95	2.84	7.00	1.20	6.80	1.52	-5.80	9.84	8.00
18	32	7.94	1.37	8.33	4.00	2.40	10.00	5.89	-1.60	12.33	12.40
19	23	7.28	1.32	8.12	5.20	4.00	8.00	5.03	-1.20	13.32	12.00
20	29/3	7.45	0.83	4.63	3.80	1.40	6.40	3.36	-2.40	8.43	7.80
21	42	7.49	1.33	7.16	5.00	2.40	11.20	4.53	-2.60	12.16	13.60
22	51	7.44	3.82	19.79	17.00	9.00	24.00	6.79	-8.00	36.79	33.00
23	32	7.64	0.98	5.58	7.20	2.00	9.60	2.94	-5.20	12.78	11.60
24	32/1	7.77	0.93	2.35	6.40	1.00	6.40	1.31	-5.40	8.75	7.40
25	33	7.49	1.61	8.20	6.20	2.20	10.40	4.66	-4.00	14.40	12.60
26	51	7.42	3.62	20.97	17.20	8.60	24.00	7.15	-8.60	38.17	32.60
27	36/1	7.57	1.56	8.37	4.80	2.00	10.00	5.40	-2.80	13.17	12.00

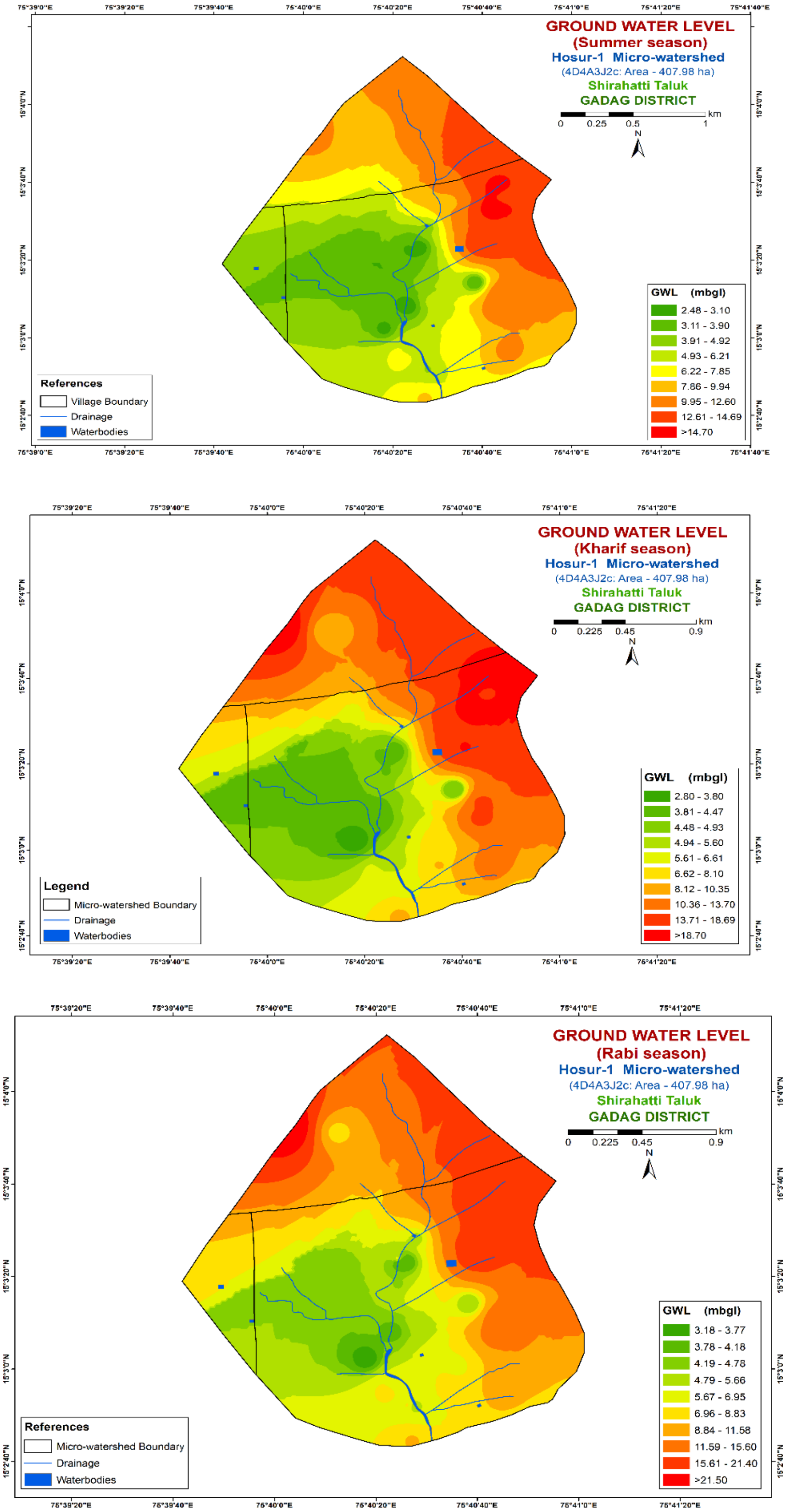

Fig. 6. Ground water depth in Hosur-1 micro-watershed during summer, kharif and rabi season

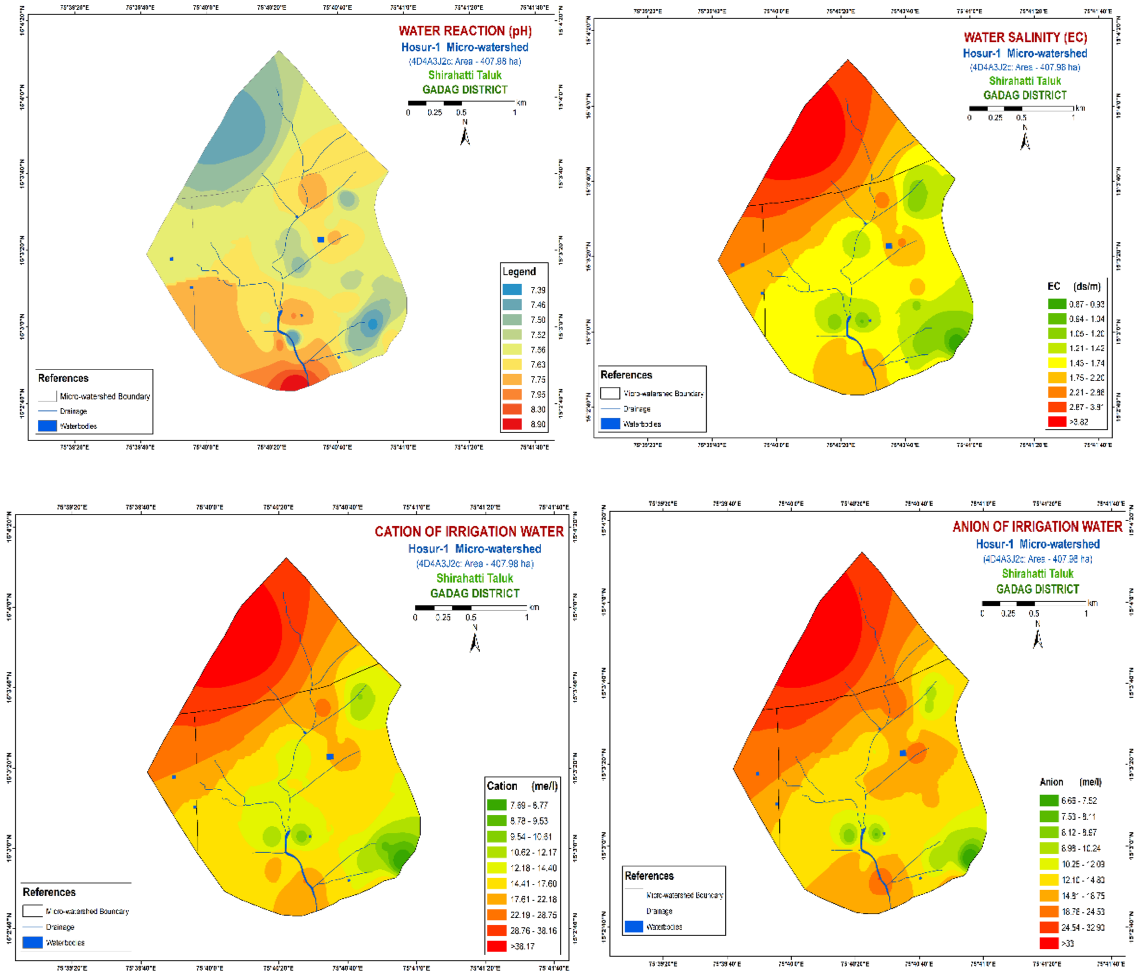

Fig. 7. Ground water quality of Hosur-1 Micro watershed, Karnataka

4. CONCLUSION

To estimate groundwater fluctuation in the Hosur-1 micro-watershed, data were collected at the field scale. The infiltration rate in the sandy clay loam soil was more followed by clay soil. The greater infiltration rate facilitates greater percolation in to the soil. It creates the more groundwater table near to the soil surface. Chemical parameters can be used for improving the groundwater quality in the area. good soil water management strategies are needed for maintaining adequate salt-water balance for appropriate crop growth. 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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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