Int.J.Curr.Microbiol.App.Sci (2018) *7*(1): 273-288

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 01 (2018)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2018.701.030

Delineation of Groundwater Potential Zones using Remote Sensing and GIS Techniques in Kanakanala Reservoir Subwatershed, Karnataka, India

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Keywords

RS, GIS, LULC, Weighted Index Overlay Analysis, Groundwater potential zones, ArcGIS, Drainage density etc.

Article Info

Accepted:
04 December 2017
Available Online:
10 January 2018

A B S T R A C T

As the demand and needs of the population towards water is growing the value of water is felt in all sectors. At the same time, surface water resources are becoming insufficient to fulfill the water demand. So that systematic planning of groundwater improvement using modern technique is fundamental for the proper management and utilization of this precious resource. But still groundwater resources have not yet been properly exploited, keeping this in view, the present study has been undertaken to demarcate the groundwater potential zones in Kanakanala Reservoir Subwatershed, Karnataka by using RS and GIS approach. Thematic maps of geology, geomorphology, soil, slope, Land Use/Land Cover (LULC) and drainage density were used and groundwater potential zones were demarcated by Weighted Index Overlay Analysis (WIOA) in Arc GIS 10.1 software. During overlay analysis the ranking has been given for each individual parameter of each thematic map and weights were assigned according to the influence towards groundwater. Finally, four groundwater potential zones were delineated *viz*., very good, good, moderate and poor. From the study it was concluded that, demarcation of groundwater potential zones helpful for effective recognition of suitable locations for its extraction and better planning and management.

Introduction

Water is prime requirement for survival of living beings and it plays an important role in the countries like India as its economy predominantly depends on agriculture. With improvement in standard of living and growing number of population, demand for water resources has increased along with reducing availability of water throughout the nation. Groundwater is one of the very precious natural resources of earth that sustains all human activities (Chaudhary *et al.*, (1996) and also it is more dynamic renewable natural resource available with good quality and quantity in appropriate time/space.

The demand of groundwater is continuously in the rise because of its several inherent qualities, such as; slow moving, large storage volume, long retention time, could be drawn on demand, less risk free than surface water sources, consistent temperature, continuous availability, excellent natural quality, limited vulnerability, low development cost and drought reliability *etc*. So that timely and reliable information on the occurrence and movement of groundwater is a prerequisite for meeting its increasing demand for drinking, domestic, industrial sector (Arivalagan *et al.*, 2014). It might be noted that not only its requirement has increased over years but it seems that the demand would never cease (Sitender and Rajeshwari, 2011). Hence, delineation of groundwater potential zones has acquired great significance (Sitender and Rajeshwari, 2011).

According to investigation made by the CGWB (Koppal and Raichur, 2013), annual replenishable groundwater resources (2004) in the Koppal and Raichur district ranged from 701.49 to 820.95 ham. In which net annual groundwater draft was 337.80 to 262.8 ham. As depth to water level is considered it was ranges between 0.65-10.70 (m bgl) to 1.910 to 12.200 m bgl during pre-monsoon (2011) and in post-monsoon it ranges between 0.05-11.00 (m bgl) to 1.320 to 1355 m bgl (CGWB (2013) respectively for Raichur and Koppal districts. Hence, stage of groundwater development in the study area is about 48.12 %. Projected demand for domestic and industrial use up to 2025 is estimated about 42.44 to 60.48 ham respectively for Raichur and Koppal districts. Totally, groundwater draft is overdeveloped due to variations in the availability of precipitation and lack of perennial surface water bodies. Therefore, the development of groundwater assumes greater significance.

The traditional approach of groundwater investigation applying geological, hydro-geological and geophysical methods are costly due to high cost of drilling, time consuming and cumbersome for groundwater exploration on a regional scale (Ndatuwong and Yadav, 2014). Meanwhile, Remote Sensing (RS) and Geographic Information Systems (GIS) are useful in search of its prospect zones. As remote sensors cannot detect groundwater directly, its presence is inferred from different surface features derived from satellite imagery such as geology, landforms, soils, land use/ land cover, surface water bodies, *etc*., which act as indicators of groundwater existence (Todd, 1980 and Jha and Peiffer, 2006). RS and GIS have proved to be main tools to prepare those thematic maps from satellite images and it is also used as a multi-criteria decision analysis tool (Vittala *et al.,* 2005; Madrucci *et al.,* 2008; Mondal *et al.,* 2008; Javed and Wani, 2009; Jha *et al.,* 2010 and Dar *et al.,* 2010).

Materials and Methods

Description of study area

Kanakanala Reservoir Subwatershed covered a maximum area from Koppal and minimum area from Raichur districts. This comes under D43E5 toposheet and located at 15° 46' 13.30" to 15° 54' 21.45" North latitude and 76° 19' 54.08" to 76° 27' 15.91" East longitude. It covers an average area of 195 km^2 with an elevation of 500feet. The major agricultural crops grown in the study area are Paddy, Jowar, Maize, Cotton, pulses and oil seeds. The study area is prevailed with subtropical climate with mild winters (December=16.85

ºC) and hot summers (April =45 ºC). The average annual rainfall is 580-600 mm with the annual numbers of the rainy days 48 days. The location of the Kanakanala Reservoir Subwatershed is shown in the figure 1.

Preparation of thematic layers

Total six thematic layers were considered under study *viz*., slope, geology, geomorphology, soil, drainage density and Land use Land Cover (LULC) Map. The DEM was prepared (3D analyst tool in ArcGIS 10.1) from the contours which were digitized from the toposheet of the study area. Then the DEM was imported to Arc GIS 10.1 software to prepare slope map.

Geology, geomorphology and soil maps were extracted from the shape files which have been collected from the Karnataka State Remote Sensing Applications Centre, Bangalore, Karnataka. Drainage map was used to prepare the drainage density map by Spatial Analyst Tools in the Arc-GIS 10.1 software. Satellite Data Landsat Enhanced Thematic Mapper (ETM) data acquired on November, 2009 from that the Kanakanala Reservoir Subwatershed with an area of 195 km^2 was extracted. Land use land cover map was prepared in ERDAS imagine by applying unsupervised classification.

Delineation of groundwater potential zones by Weighted Index Overlay Analysis (WIOA)

The groundwater potential zones of Kanakanala Reservoir Subwatershed were obtained by overlaying all the thematic maps in terms of weighted overlay method using the spatial analysis tool in ArcGIS 10.1 software. Weighted index overlay is applied where maps were added together in a weighted combination. This method is used in the present study because of its several advantages *viz*., it is frequently used models, easy and straightforward for a combined analysis of multiclass maps and also human judgment could be integrated with this analysis (Boobalan and Gurugnanam, 2016).

After understanding the behavior of geology, geomorphology, soil, slope, land use land cover and drainage density features with respect to groundwater control, the groundwater potential zones were delineated. Every thematic map was converted into raster format and gave weight. The rank of every thematic map was scaled by the weight of that theme (Arkoprovo *et al.,* 2012). A weight (1-9) represents the virtual importance of a parameter and the objective (Boobalan and Gurugnanam, 2016) which was given by Multi Influencing Factor (MIF). There is no standard scale for simple weighted overlay methods, for this purpose, criteria for the analysis are defined and each parameter was given its due importance (Saraf and Choudhury, 1998; Chaturvedi *et al.,* 1983; Raj and Sinha, 1989; Baldev *et al.,* 1991; Gustafsson, 1993; Krishnamurthy and Srinivas, 1995; Saraf *et al.,*1997; 1998; Shahid *et al.,* 2000; Jasrotia *et al.,* 2007a; Jasrotia *et al.,* 2012b; Mandal, 2011; Sedhuraman *et al.,* 2014 *etc*). The weights and rank have been given by considering the works carried out by Krishnamurthy *et al.,* (1996), Dey (2014) and Waikar and Nilawar (2014). The weight assigned to different classes of all the thematic layers are given in table 1. In this simplest type of weighted model, input maps are binary and each map carries a single weight factor (Jhariya *et al.,* 2015). The representative weight of a factor of the potential zone is the sum of all weights from each factor. A factor with a higher weight value shows a larger impact and a factor with a lower weight value shows a smaller impact on groundwater potential zones (Magesh *et al.,* 2012). Moreover, these factors are interdependent. While assigning the weight, geology and geomorphology were assigned higher weight and slope and drainage density were assigned lower weight.

In order to get all information unified, it is necessary to integrate data with proper factor and it is also possible to superimpose this information manually (Horton, 1945). After assigning weights groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay method using the spatial analysis tool in ArcGIS 10.1 software.

Results and Discussion

Digital Elevation Model (DEM) and slope map

Topography (land surface elevation) is one of the factors which influence groundwater potential. Higher the elevation, lesser would be the groundwater availability (Sener *et al.*, 2005). A digital elevation model (DEM) is a digital representation of ground surface topography of terrain. It indicates a digital explanation of the terrain relief and it could be stored in different forms such as contour lines, raster based array of cells and Triangulated Interface Network (TIN). The Digital Elevation Model (DEM) prepared for Kanakanala Reservoir Subwatershed is shown in figure 2 which shows the highest elevation of 624 m and lowest elevation of 500 m.

The slope of a surface refers to the maximum rate of change in height across a region of the surface and is main terrain parameter to influence the land stability (Manjare, 2014). Slope of terrain is one of the main factor governing the infiltration of groundwater into subsurface makes it a suitable groundwater indicator (Sikakwe *et al.*, 2015). The surface runoff is slow allowing in the gentle slope area so that it takes more time for rainwater to percolate, whereas, steep slope area facilitates high runoff so which allows less residence time for rainwater and hence somewhat less infiltration (Sitender and Rajeshwari, 2011).

The slope percentage in the study area varied from 0 to 40 percent and it was divided into seven classes. Most of the area (96.12 km^2) was covered by 0-1 percent slope (nearly level) which exhibits good groundwater potential because of less runoff. About 64.16 km^2 area was considered under good groundwater occurrence because of the very gently slope category (1-3 percent). An area of 21.97 km^2 with 3-6 percent (gently sloping) was assumed to exhibit moderate potential for groundwater. An area of 2.60 km^2, 2.56 km^2, 5.40 km^2 and 2.19 km^2 with slope of 6-9 percent (moderately sloping), 9-13 and 13-21 percent (moderately steep sloping) and 21-40 percent (steep) respectively were considered as poor and very poor classification for groundwater potential. Here, the lower slope values indicate the flatter terrain (gentle slope) and higher slope values correspond to steeper slope of the terrain. It gives an idea that lands having lesser slope are useful for groundwater recharge where as steep slopes are unfit for the recharge of groundwater. Figure 3 shows the slope map of the Kanakanala Reservoir Subwatershed.

Geology

It is one of the most important factor which plays significant role in the distribution and occurrence of groundwater (Ramu *et al.*, 2014). The storage capability of the rock formations depends on porosity of the rock. In the rock formation the water moves from areas of recharge to areas of discharge under the influence of hydraulic gradients depending on the permeability or hydraulic conductivity (Manikandan *et al.*, 2014). Figure 4 shows the geological map of the Kanakanala Reservoir Subwatershed. It is helpful to study the aquifer characteristics like aquifer thickness, type of aquifer, porosity, permeability *etc*. and also for selecting site for construction of check dam, ponds *etc*., (Radhakrishnan and Ramamoorthy, 2014).

Phyllite quartz chlorite schist and greywalke and metavolcanics covers large amount of area of 78.98 km^2 and 61.07 km^2 respectively and are considered as moderate for groundwater potential. Migmatites and granodiorite - tonalitic gneiss occupied 39.19 km^2 area which was also moderate for groundwater potential. Granodiorite and granite and grey / pink granite covered 13.60 km^2 and 2.16 k m^2 area and exhibits very poor and poor potential for groundwater occurrence respectively. The weightage were assigned based on the rock's influence in the groundwater potential.

Geomorphology

Geomorphological studies is one of the most significant aspects in the assessment of water resources both surface and groundwater. Geomorphological mapping involves the recognition and categorization of various landforms and structural features, which are favorable for the occurrence of groundwater (Sitender and Rajeshwari, 2011). An integrated study of the evolution of landforms and geology is useful to recognize the occurrence of permeable and porous zones (Karanth, 1987). For the assessment of groundwater resources, a geomorphological terrain classification leading to the delineation of hydro-morphological is helpful by taking both morphological and lithological factors into consideration (Verstappen, 1983). The study of geomorphology plays a considerable control over the groundwater region, slope, relief, depth of weathering, nature of the deposited materials, thickness of deposition and the assemblage of different landforms (Radhakrishnan and Ramamoorthy, 2014). The geomorphic units identified in the study area include pediment-inselberg complex, pediplain weathered/buried, structural hills (small) and water body which are shown in figure 5. Maximum extent of area is covered by pediplain weathered/buried about 154.08 km^2 (79.01%) and included under moderate to good for groundwater potential. Pediment Inselberg Complex (PI) occupied an area of 34.52 km^2 (17.70 %) and considered as moderate to good for groundwater potential. Structural Hills (SH) and water bodies were occupied 1.62 km^2 (0.83%) and 4.78 km^2 (2.46%) respectively and considered under moderate to good zone for groundwater potential.

Soil map

Soil is one of the natural resources, which is an important parameter to delineate potential groundwater zones and it plays a vital role in groundwater recharge and encounters the basic requirements of all agricultural production (Radhakrishnan and Ramamoorthy, 2014). Soil features invariably control penetration of surface water into groundwater system and they are directly related to rates of infiltration, percolation and permeability (Sedhuraman *et al.,* 2014) and those affects the water holding and infiltrating capacity of a soil. Soil moisture and permeability is an indicator of potential zone (Jose *et al.,* 2012).

It is apparent from figure 6 that the majority of the study area is dominated by clay and loam soils with an area of coverage 68.71 km^2 (35.23 %) and 63.52 km^2 (32.57 %) respectively. Similarly, sandy loam, loamy clay, clayey loam, water body, sandy clay, loamy sand and habitation covered an area of 32.16 km^2 (16.49%), 17.47 km^2 (8.96%), 4.82 km^2 (2.47 %), 4.81 km^2 (2.46%), 1.91 km^2 (0.98%), 0.84 km^2 (0.43%) and 0.80 km^2 (0.41%) respectively.

Table.1 Weights and percentage influence considered for parameters of Groundwater potential zones

Theme	Sub-Classes	Category	Weight	Influence (weight) %
Geology	Granodiorite and granite	Very poor	1	25
	Grey / pink granite	Poor	2	
	Phyllite quartz chlorite schist and greywalke	Moderate	3	
	Metavolcanics	Moderate	3	
	Migmatites and granodiorite - tonalitic gneiss	Moderate	3	
Geomorphology	Pediplain weathered/buried	Moderate to good	6	25
	Pediment Inselberg Complex (PI)	Moderate to good	5	
	Structural Hills (SH)	Moderate	3	
	Water body	Good	8	
Soils	Sandy loam	Very good	9	15
	Sandy clay	Good	7	
	Loamy sand	Good	8	
	Loam	Moderate to good	6	
	Loamy clay	Moderate	4	
	Clayey loam	Moderate	4	
	Clay	Very poor	1	
	Habitation	Very poor	1	
	Water body	Very good	9	
Land use land cover	Agriculture	Moderate to good	6	15
	Water body	Moderate to good	6	
	Barren land	Moderate to good	5	
	Scrubland	Moderate	3	
	Rocky outcrop	Very poor	1	
	Settlements	Very poor	1	
Slope	0-1 %	Very good	8	10
	1-3 %	Good	7	
	3-6%	Good	6	
	6-9%	Moderate	4	
	9-13%	Moderate	3	
	13-21%	Poor	2	
	21-40%	Very poor	1	
Drainage density (Km/Km2)	0-0.25	Moderate	5	10
	0.26—0.510	Moderate	4	
	0.52-0.90	Moderate	4	
	0.91-1.42	Moderate	3	
	1.43-2.59	Very poor	1	

Fig.1 Location map of the Kanakanala reservoir subwatershed, Karnataka

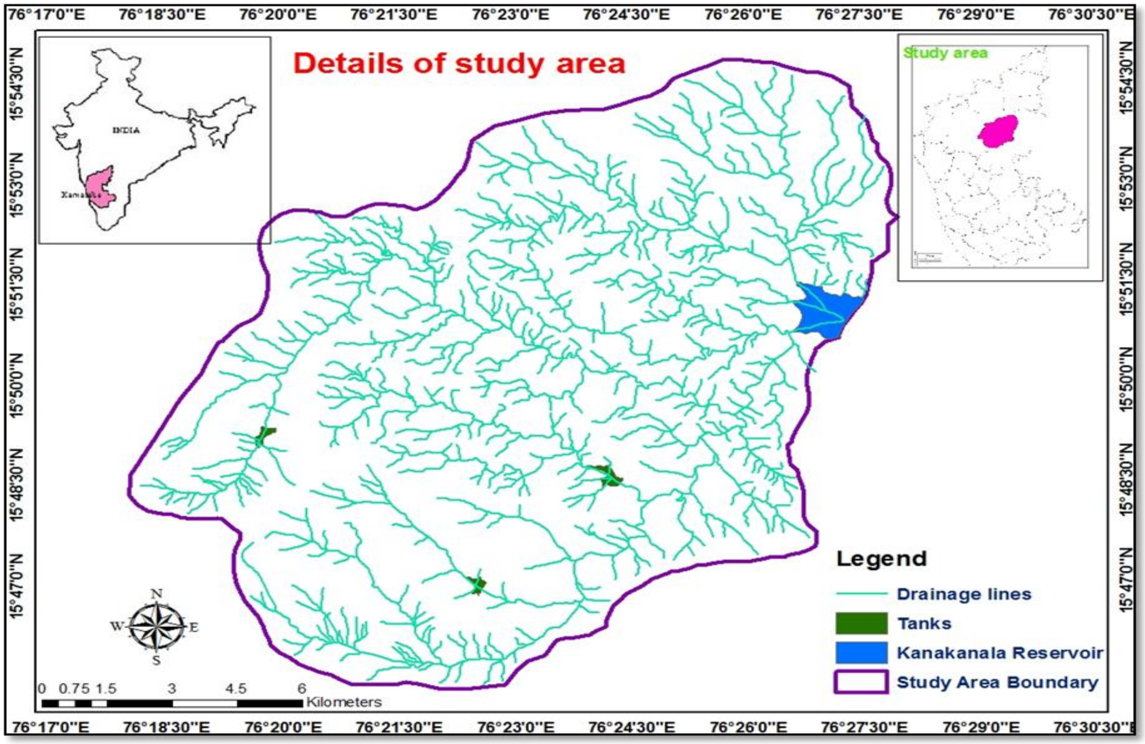


Fig.2 DEM of the Kanakanala reservoir subwatershed

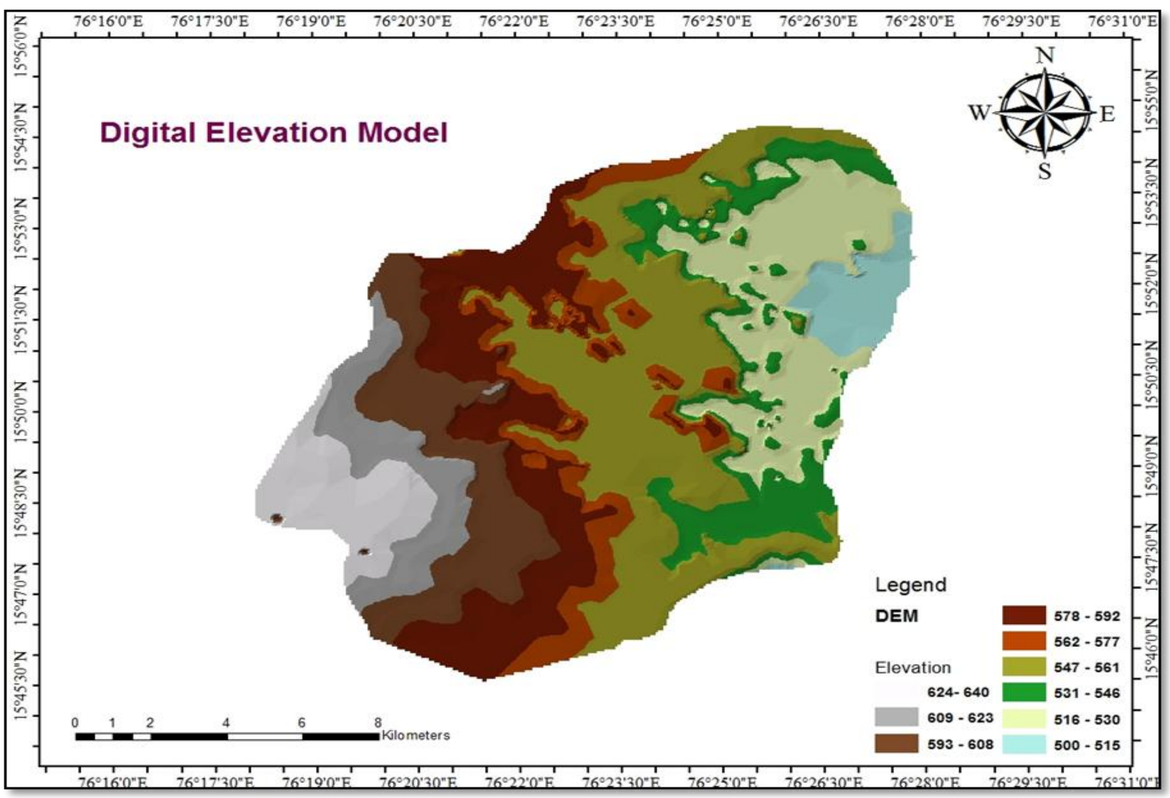


Fig.3 Slope map of the Kanakanala reservoir subwatershed

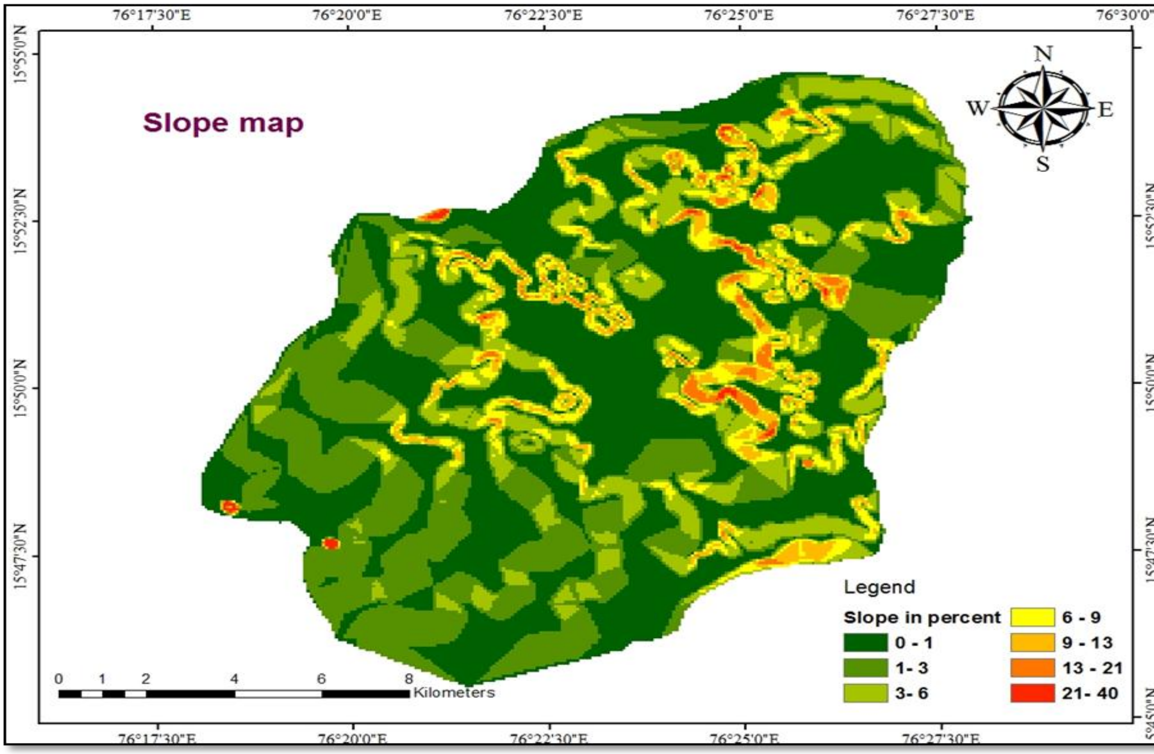


Fig.4 Geological map of the Kanakanala Reservoir Subwatershed

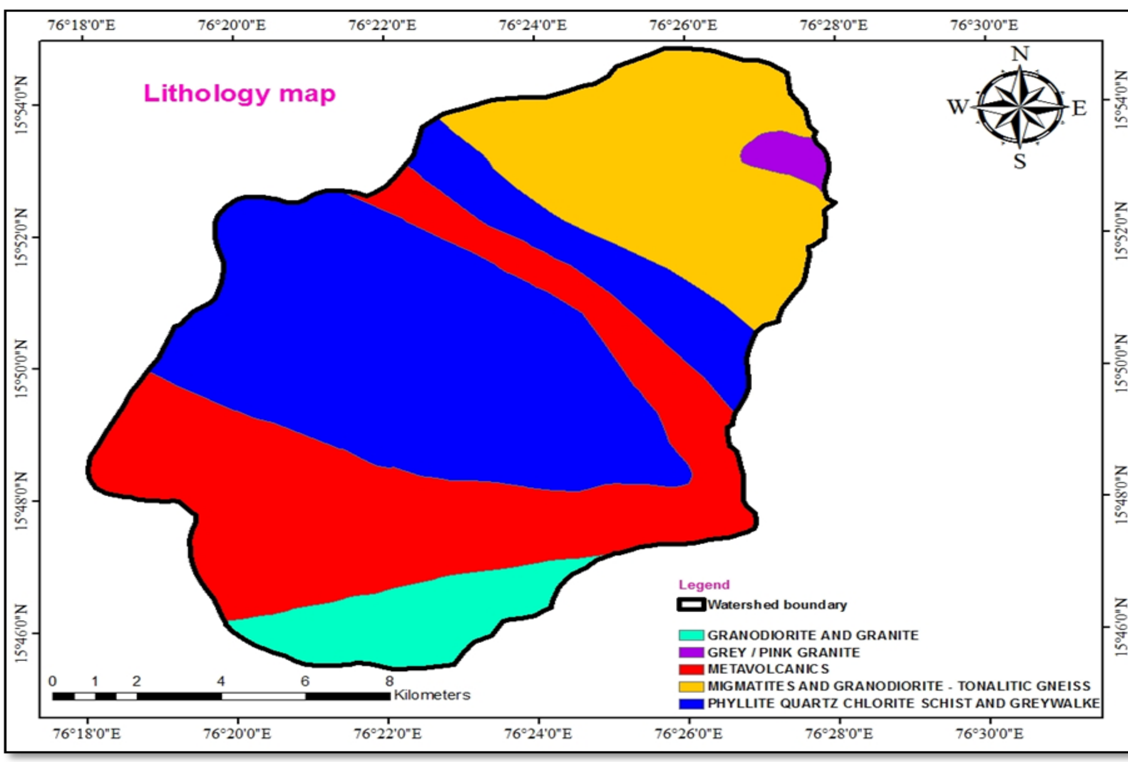


Fig.5 Geomorphological map of the Kanakanala reservoir subwatershed

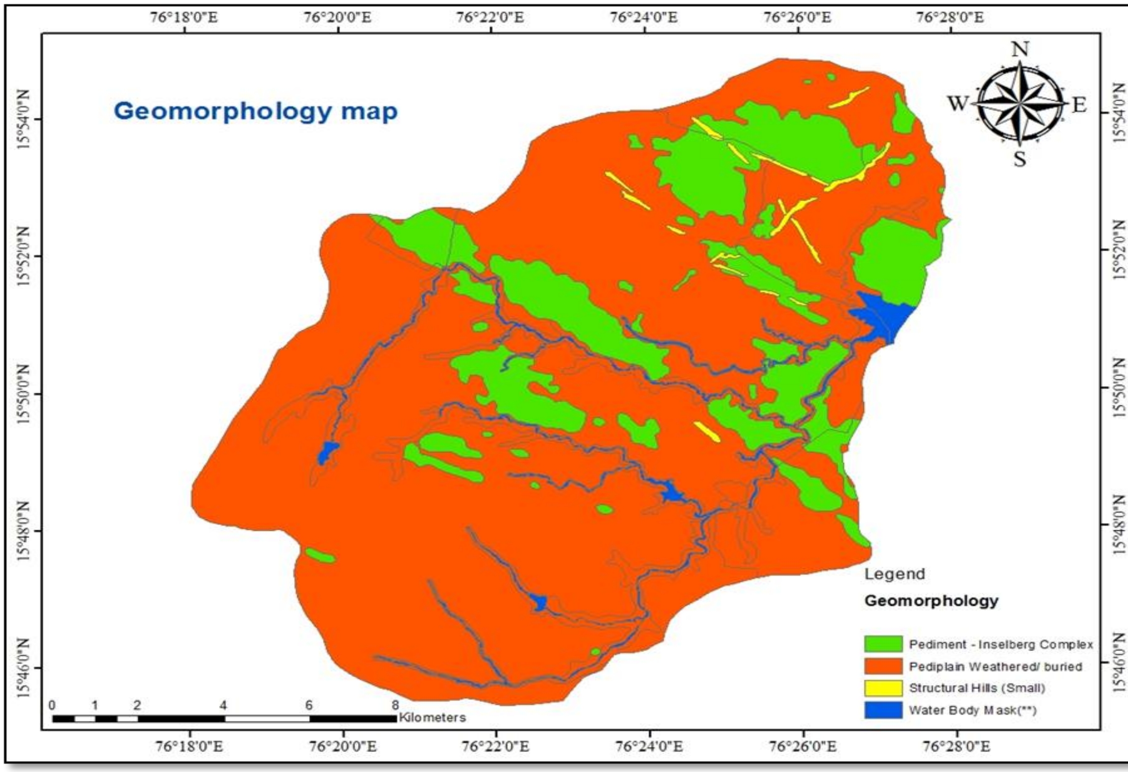


Fig.6 Soil map of the Kanakanala reservoir subwatershed

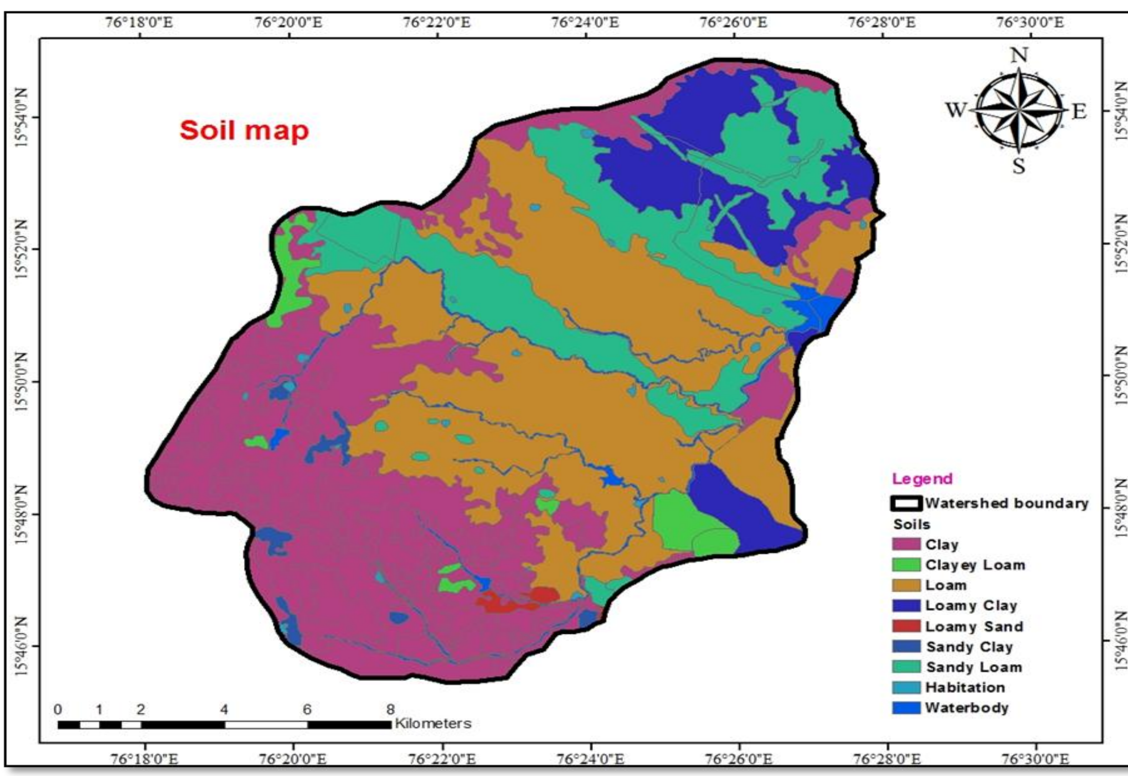


Fig.7 Drainage density map of the Kanakanala reservoir subwatershed

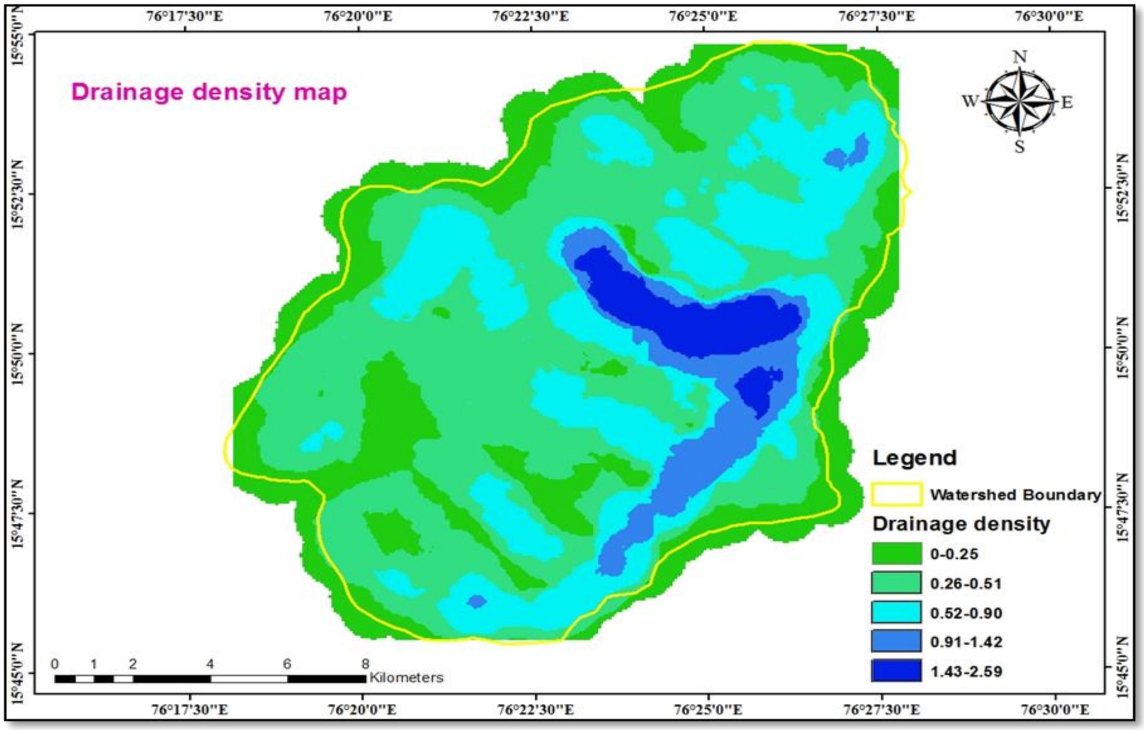


Fig.8 Land use/land cover map of the Kanakanala reservoir subwatershed

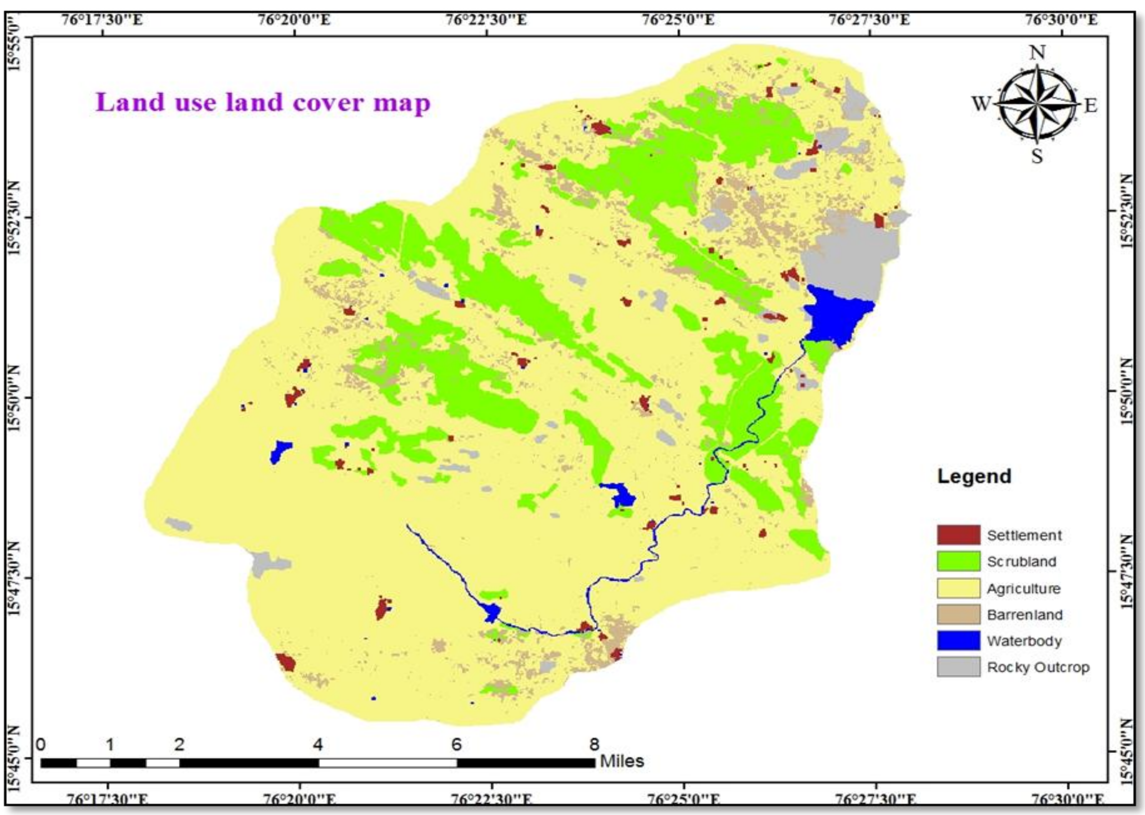
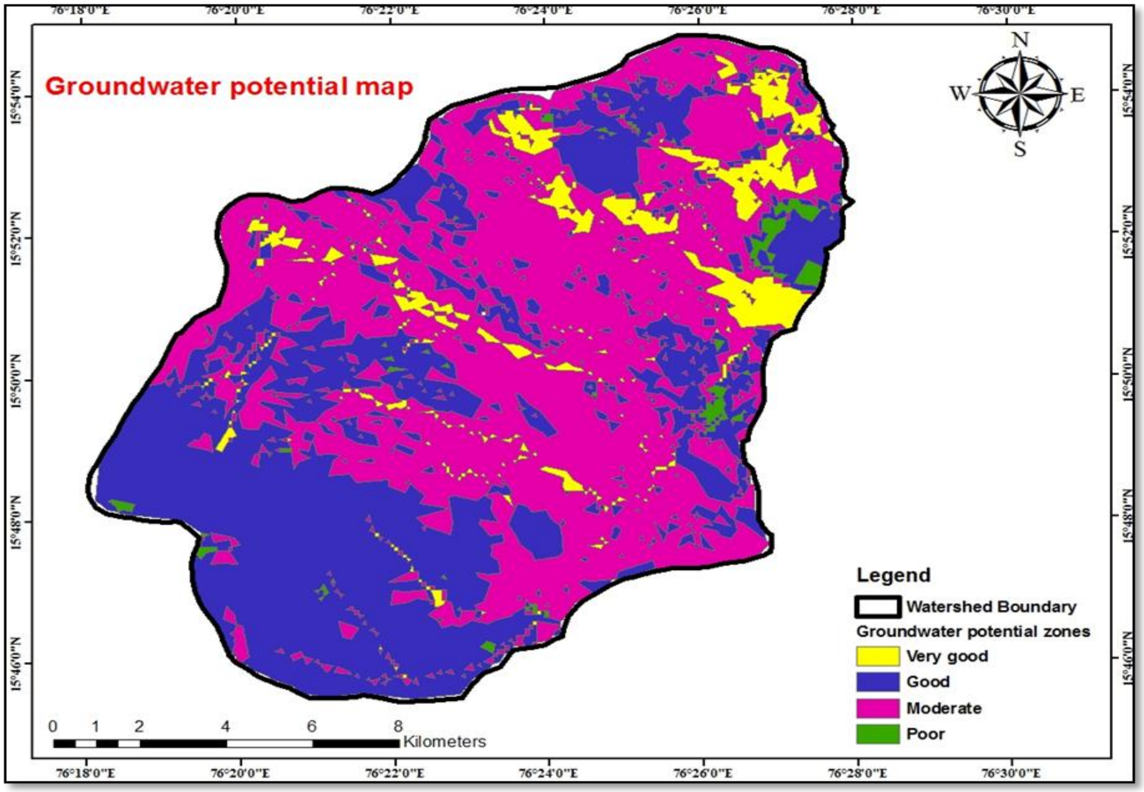


Fig.9 Groundwater potential zones of Kanakanala reservoir subwatershed



Clay soils show poor potential for groundwater and clayey loam and loamy clay are considered to exhibit moderate for groundwater potential. Loam and sandy loam soils were categorized under moderate to good and good potential for groundwater respectively. Sandy clay and loamy sands were considered to show good condition for groundwater occurrence.

Drainage density

Drainage density is defined as the closeness of spacing of stream networks because of its relation with surface runoff and permeability (Magesh *et al.*, 2012). It is an inverse function of permeability. Sub-surface hydrological condition of any area is controlled by the drainage characteristics of the basin that leads to decipher the groundwater condition. The drainage density could indirectly point out the groundwater potential of an area due to its relation to surface runoff and permeability (Pradhan, 2009). If there is less permeable rock, the infiltration of rainfall would be less, which conversely tends to be concentrated in surface run-off (Hutti and Nijagunappa, 2011).

Low drainage density generally found in the areas of highly resistant or permeable subsoil material, low relief and dense vegetation, similarly high drainage density is found in the areas of sparse vegetation, weak or impermeable subsurface material and mountainous relief (Choudhari *et al.,* 2014). Normally, groundwater potential is found to be poor in very high drainage density areas because of the main part of the water poured over them during rainfall is lost as surface runoff with small infiltration to meet groundwater (Sitender and Rajeshwari, 2011). On the contrary areas of low drainage density permit more infiltration and recharge to the groundwater so that they have more potential for groundwater occurrence (Sitender and Rajeshwari, 2011).

Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Choudhari *et al.*, 2014), so that, the Kanakanala Reservoir Subwatershed was occupied by coarse drainage texture at maximum areal extent (130 km^2) and remaining area of 65 km^2 was covered by fine drainage texture.

The drainage density map of the Kanakanala Reservoir Subwatershed is shown in figure 7. The drainage density was classified in to five types, very low (0-0.25 km^2), low (0.26-0.51 km^2), moderate (0.52-0.90 km^2), high (0.91-1.42 km^2) and very high densities (1.43-2.59 km^2) (Patil and Mohite, 2014). The maximum area of the Kanakanala Reservoir Subwatershed occupied by low drainage density with an area of 80.71 km^2 (41.39%) followed by very low and moderate drainage density with an area of 49.38 km^2 (25.32%) and 45.07 km^2 (23.11%) respectively. Remaining area is covered by high, 12.02 km^2 (6.16%) and very high 7.82 km^2 (4.02%) drainage densities respectively. Accordingly groundwater potential was considered as moderate and very poor zones respectively.

Land use/land cover map

The term land cover narrates to the type of characteristic present on the surface of the earth whereas land use refers to the human activity relates with the specific piece of land (Lillesand and Kiefer, 1979). Land use/land cover mapping is one of the significant applications of remote sensing as it plays a considerable role in the development of groundwater resources (Waikar and Nilawar, 2014). It controls many hydro-geological processes in the water cycle *viz*., evapotranspiration, infiltration, surface runoff *etc*., (Waikar and Nilawar, 2014). Surface cover provides roughness to the surface thereby reduces discharge and increases the infiltration. In the forest areas, infiltration would be more because of less runoff whereas in urban areas rate of infiltration might decrease (Waikar and Nilawar, 2014). It is one of the chief parameter for the geo-hydrological study because the land use pattern of any terrain is an indication of the complex physical processes acting upon the surface of the earth (Arivalagan *et al.*, 2014).

Land use land cover classes control the occurrence of groundwater and also causes for infiltration for recharge, with various classes among itself. The effect of land use land cover is manifested either by reducing runoff and facilitating or by trapping water on their leaf (Patil and Mohite, 2014). The land use/land cover of the study area is characterized by a mixture of agriculture, scrubland, barren land, rocky outcrop, water body and settlements which is shown in figure 8. Agriculture covered maximum extent of the Kanakanala Reservoir Subwatershed about 139.28 km^2 (71.43%). Similarly, scrubland, barren land, rocky outcrop, water body and settlements covered 32.12 km^2 (16.47%), 11.66 km^2 (5.98%), 7.19 km^2 (3.68%), 2.77 km^2 (1.41%) and 1.97 km^2 (1.01%) respectively.

Agriculture, water body and barren lands are considered to exhibits moderate to good groundwater potential. Meanwhile, scrubland, rocky outcrop and settlement showed moderate and very poor potential of groundwater occurrence respectively.

Groundwater potential zoning

The thematic maps of geology, geomorphology, soil, slope, land use/land cover and soil were considered for identifying groundwater potential zones in the

Kanakanala Reservoir Subwatershed. Totally four groundwater potential zones are classified as very good, good, moderate and poor which is shown in the figure 9. Most of the area covered by moderate potential zones with an aerial extent of 98.97 km^2 (50.74%) followed by good groundwater zones with an area of 80.88 km^2 (41.47%). Remaining area was categorized as very good and good potential zones with an aerial extent of about 12.85 km^2 (6.59%) and 2.35 km^2 (1.21 %) respectively.

Weighted Index Overlay Analysis (WIOA) approach for assessment of groundwater potential was adopted and potential zones were demarcated. From the study it is noticed that the groundwater occurrence is moderate to good in condition in the Kanakanala Reservoir Subwatershed. Thus it is suggested that, for further improvement of groundwater condition, it is necessary to construct check dams, percolation tanks, form ponds and other water harvesting structures. From the study it was observed that RS and GIS technique could be used effectively in delineation of groundwater potential zones. Also it was found efficient to minimize the labor, time and money so that it enables quick decision making for sustainable water resource management. From the study it was concluded that, for any implementation of groundwater management system and watershed conservation strategies, identification of groundwater potential zones plays a key role.

Acknowledgement

Author is thankful to Mr. Sham Davande, GIS Analyst, FES, Anand, Gujarat, for his guidelines in the preparation of thematic maps in ArcGIS software. Also thankful to Dr. H. K. Mittal and Dr. U. Satishkumar for their useful suggestions in completing the project.

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How to cite this article:

Savita, R.S., H.K. Mittal, U. Satishkumar, P.K. Singh, K.K. Yadav, H.K. Jain, S.M. Mathur and Sham Davande. 2018. Delineation of Groundwater Potential Zones using Remote Sensing and GIS Techniques in Kanakanala Reservoir Subwatershed, Karnataka, India. *Int.J.Curr.Microbiol.App.Sci.* 7(01): 273-288. doi: https://doi.org/10.20546/ijcmas.2018.701.030