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Development of Groundwater Potential Zone in North-Karnataka Semi-Arid Region Using Geoinformatics Technology

***Basavaraj Hutti and Nijagunappa. R.**

Environmental Science Department, Gulbarga University, Gulbarga 585 106 INDIA

***Corresponding Author: urbasu@gmail.com**

Abstract:

A systematic planning of groundwater exploitation using modern techniques is essential for proper utilization and management of this precious but shrinking natural resource. With the advent of powerful and high-speed personal computers, efficient techniques for water management have evolved, of which Geoinformatics technology are of great significance. In the present study, an attempt has been made to delineate possible groundwater potential zones in semi arid region of Ghataprabha basin. The thematic layers considered in this study are lithology, landform, drainage density, recharge, soil, land slope and surface water body, which were prepared using the Google Earth imagery and conventional data. All these themes and their individual features were then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the Saaty's analytical hierarchy process. The thematic layers were finally integrated using AutoDeskMAP and MapInfo GIS software to yield a groundwater potential zone map of the study area. Thus, three different groundwater potential zones were identified, namely 'good', 'moderate' and 'poor'. Moreover, the average annually exploitable groundwater reserve in the good zone was estimated to be 915 million cubic meter (MCM), whereas it is 381.25 915 MCM for the moderate zone and 228.75 MCM for the poor zone. Finally, it is concluded that the Geoinformatics technology are very efficient and useful for the identification of groundwater potential zones.

Keywords: Geoinformatics, drainage, semi-arid, GIS, groundwater.

1.0 Introduction:

Groundwater is one of the most valuable natural resources, and supports human health, economic development and ecological diversity. Due to its several inherent qualities (e.g. consistent temperature, widespread and continuous availability, excellent natural quality, limited vulnerability, low development cost and drought reliability), it has become an important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd and Mays, 2005). Of the 37Mkm3 of freshwater estimated to be present on the earth, about 22% exists as groundwater, which constitutes about 97% of all liquid freshwater potentially available for human use (Foster, 1998). In India, more than 90% of the rural and nearly 30% of the urban population depend on groundwater for meeting their drinking and domestic requirements (Reddy et al., 1996). Thus, groundwater is emerging as a formidable poverty reduction tool in developing countries and can be delivered to poor communities far more cheaply, quickly and easily than the conventional canal irrigation water (IWMI, 2001).

As mentioned above, groundwater studies have become crucial not only for targeting groundwater potential zone, but also for monitoring and conserving this vital resource. In order to determine the location of aquifer, quality of groundwater, physical characteristics of aquifers, etc., in any basin, test drilling and stratigraphy analysis are the most reliable and standard methods. However, such an approach for groundwater investigations is very costly, time-consuming and requires skilled manpower (Sander et al., 1996). In contrast, remote Geoinformatics technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources (Jha et al., 2007). The hydrogeologic interpretation of satellite data has been shown to be a valuable survey tool in areas of the world where little geologic and cartographic information exists or is not accurate, as well as in inaccessible regions of the world (Engman and Gurney, 1991). As remote sensors cannot detect groundwater directly, the presence of groundwater 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; Jha and Peiffer, 2006). Moreover, Geoinformatics have emerged as powerful tools for handling spatial data and decision-making in several areas including engineering and environmental fields (Stafford, 1991; Goodchild, 1993). Since the delineation of groundwater prospect zones and groundwater modelling involve a large volume of multidisciplinary data, an integrated application of Geoinformatics techniques has become a valuable tool.

In the past, several researchers (from India and abroad) have used Geoinformatics techniques for the delineation of groundwater potential zone with successful results (Krishnamurthy et al., 2000; Shahid et al., 2000; Khan and Moharana, 2002; Jaiswal et al., 2003; Rao and Jugran, 2003; Sikdar et al., 2004; Sener et al., 2005; Ravi Shankar and Mohan, 2006; Solomon and Quiel, 2006). In these studies, the commonly used thematic layers are lithology, geomorphology, drainage pattern, lineament density, soil and topographic slope. On the other hand, some researchers have integrated Geoinformatics techniques to delineate groundwater potential zone (Sreedevi et al., 2001; Shahid and Nath, 2002; Hadithi et al., 2003; Rao, 2003; Sreedevi et al., 2005; Israil et al., 2006; Srivastava and Bhattacharya, 2006). All the studies have been carried out in India; the majority of which focus on hard-rock terrains. The details about the applications of Geoinformatics technology in groundwater hydrology, including groundwater prospecting, can be found in (Jha et al., 2007; Jha and Peiffer, 2006). The type and number of themes used for the assessment of groundwater resources by Geoinformatics techniques varies considerably from one study to another. In most studies, local experience has been used for assigning weights to different thematic layers and their features. Only (Shahid and Nath, 2002) used Saaty's Analytical Hierarchy Process (AHP) for normalizing the assigned weights.

Ghataprabha sub basin of Krishna river in peninsular India has been facing a severe water shortage problem for both irrigation and domestic purposes over the past few years (GOK, 2008). Every year in summer most surface water sources dry up, causing serious water shortages for both domestic and irrigation purposes. In addition, because of the capricious nature of the south-west monsoon in India, the availability of surface water cannot be ensured in the right quantity at the required time. Hence, the majority of the irrigated area in the Ghataprabha basin is being cultivated with the help of groundwater acquired from dugwells and tubewells. However, the unrestricted excessive pumping of groundwater has resulted in groundwater lowering in some parts of the study area. Dugwells and hand pumps also become inoperative every year during the dry period, thereby aggravating the water problem in the study area. To date, very limited studies using Geoinformatics techniques have been conducted in peninsular India in general and North Karnataka in particular. Therefore, the objective of the present study was to groundwater potential zone in the Ghataprabha sub basin of Krishna river in Karnataka by considering suitable thematic layers that have direct or indirect control over groundwater occurrence using Geoinformatics technology.

2.0 Study Area:

River Krishna is the second largest river in Peninsular India and India's fourth largest river basin and covers 258,948 km^2 of southern India, rises in the Mahadev range of the Western ghats near Mahabaleshwar at an altitude of about 1337m above mean sea level about 64 km from the Arbian sea. After traversing a distance of about 1400 km, traversing the states of Karnataka (113,271 km^2), Andhra Pradesh (76,252 km^2) and Maharashtra (69,425 km^2). The river joints the Bay of Bengal in Andhra Pradesh. The principal tributaries of the river are the Ghataprabha, the Malaprabha, the Bhima, the Tungabhadra, the Musi, the Palleru and the Muneru.

The basin has been divided into 12 sub-basins for the hydrological study: Upper Krishna, Middle Krishna, Ghataprabha, Malaprabha, Upper Bhima, Lower Bhima, Lower Kishna, Tungabhadra, Vedavati, Musi, Palleru and Munnaru. The Ghataprabha basin is one of them. Ghataprabha River is one of the southern tributaries of the Krishna in its upper reaches. The catchment of the sub-basin lies approximately between the northern latitudes 15° 45' and 16° 25' and eastern longitudes 74° 00' and 75° 55'. The index map of the sub-basin is at Figure 1. The river Ghataprabha raises from the western ghats in Maharastra at an altitude of 884m, flows eastward for 60 Km through the Sindhudurg and Kolhapur districts of Maharastra, forms the border between

Maharastra and Karnataka for 8 Km and then enters Karnataka. In Karnataka, the river flows for 216 Km through Belgaum district past Bagalkot. After a run of 283 Km the river joins the Krishna on the right bank at Kudalasangama at elevation of 500m, about 16 km from Almatti.

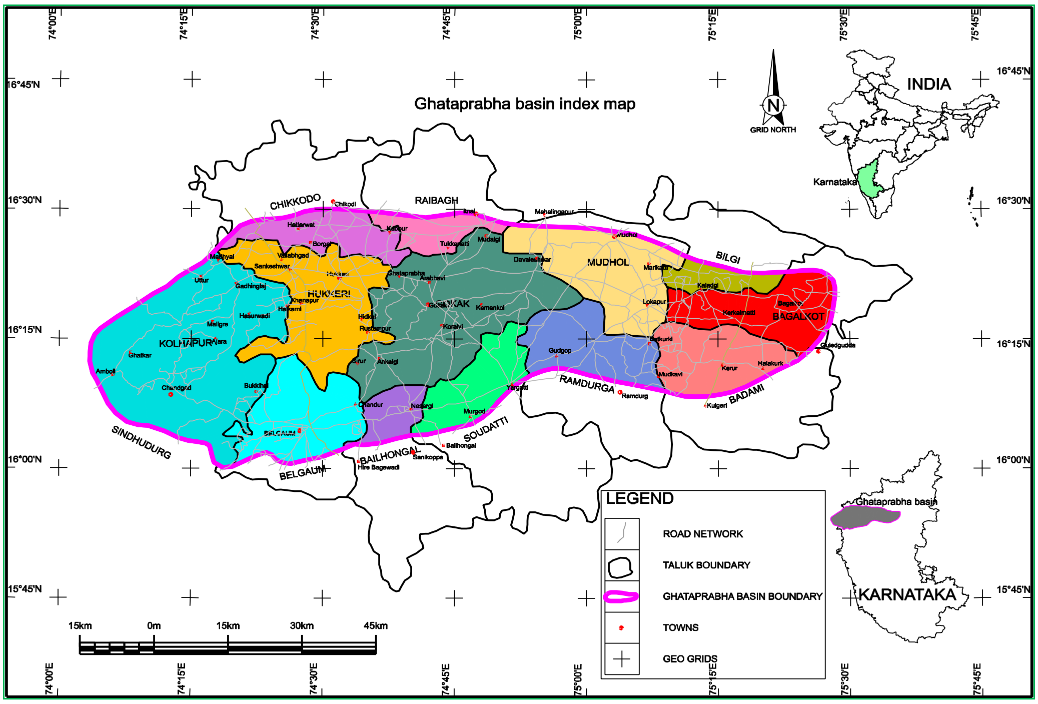

Fig. 1: The index map of Ghataprabha sub basin

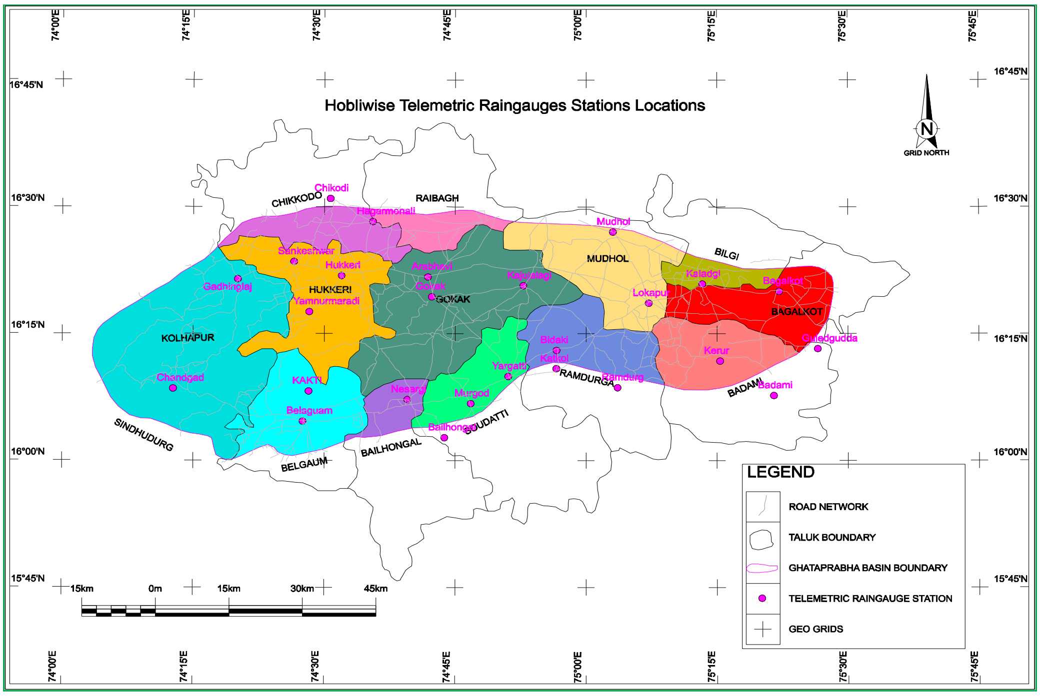

Fig. 2: Telemetric raingauge stations locations

Table 1: Land use/land cover pattern in the study area

Land use/land cover	Area covered (%)
Net area sown	63.7
Forest	12.6
Current fallows	8.7
Non agricultural use	4.0
Barren land	3.9
Cultivable waste	2.7
Grazing land	2.3
Other fallows	1.8
Land under misc. crops and trees	0.3

The principal tributaries are the Tamraparni, the Hiranyakeshi and the Markandeya. Tampraparni rising in Maharastra for 26 Km and after a run of another 26 Km in Karnataka joins the Ghataprabha. Hiranyakeshi rising at Amboli village in Sindudurg district of Maharastra flows in and Karnataka for 6 Km and after a run of 19 Km in Karnataka, joins the Ghataprabha on the left bank. Markandeya rising in Maharastra flows in Maharastra for 8 Km and after a run of 66 Km in Karnataka, joins the Ghataprabha on the right bank. Total catchment area of the sub-basin is 8829 km2, out of which 6815.988 km2 (77.2%) lies in Karnataka and rest 2013.012 km2 (22.8%) falls under Maharastra. In Karnataka and Maharastra parts of two districts in each, namely Belgaum, Bagalkot, Bijapur and Kolhapur, Sindhudurg respectively lies in the sub-basin. Most of the sub-basin area is flat to gently undulating except for isolated hillocks and valleys. The areas covered by different land use/land cover types as obtained from the satellite imagery are presented in Table 1.

3.0 Materials and Methods:

3.1 Generation of Thematic Layers:

In order to differentiate the groundwater potential zone in the study area, a multiparametric dataset comprising satellite data, Google Earth data and conventional maps including Survey of India (SOI) topographic sheets was used. IRS-1D LISS-III data collected from the National Remote Sensing Center (NRSC), Hyderabad, India has been used for the preparation of thematic maps of drainage density and surface water body. The SOI toposheets were collected from the District Natural Resource Data Management System (NRDMS) center, Zilla Panchayat, Gulbarga. All the 4 toposheets (NE 43-15, NE 43-14, ND 43-2 and ND 43-3) covering the study area at 1:250,000 scales were scanned separately and all the scanned images were rectified and geometrically corrected. These images were then mosaicked to form a single image and transferred into MapInfo software to prepare thematic layers, namely study area boundary and slope. Further, the thematic layers of geology and geomorphology were prepared from existing maps obtained from the NRDMS center. The soil layer was prepared by digitizing the soil map obtained from the Karnataka State Remote Sensing Application Center (KSRSAC), Gulbarga. Considering the data availability in the study area, the groundwater fluctuation method was used in this study to estimate groundwater recharge. Average annual groundwater fluctuations at all the study area sites Figure 2 over the study area were calculated using the 10 year (1995-2005) pre- and post-monsoon groundwater-level data of each site collected from Drought Monitoring Cell, Karnataka, Central Groundwater Board and State Groundwater Board. Thereafter, these fluctuations were multiplied by the corresponding storage coefficient values ranging from 0.0004 to 0.07, which yielded average annual groundwater recharge estimates at the 6 sites. Based on these recharge estimates, a recharge map of the study area was prepared using the Kriging technique.

All the digitized coverages were spatially organized in the Geoinformatics environment with the same resolution and coordinate system. The checking of these spatial maps was done with respect to other database layers by the overlaying technique, and refined mutually as part of standardization of the database. The errors due to digitization and mis-mapping were removed in this process. In the present study, the cloud-free digital image of IRS-1D LISS-III (Linear Imaging Self Scanner) sensor having 23.5m spatial resolution was classified using ERDAS IMAGINE-8.6 digital image processing software. Initially, the satellite image was registered with the base map after matching some of the identifiable features such as crossing of roads, railways, canals, bridges, etc., on both the base map as well as on the satellite image. The projection type used was 'Polyconic' with the spheroid and datum as 'Modified Everest'. Efforts were made to ensure that the ground control points are uniformly distributed on the image. A second order polynomial model was generated and due care was taken to keep the rms error (RMSE) less than a half pixel.

3.2 Integration of Thematic Layers:

The thematic layers of geology, geomorphology, soil, slope, recharge, surface water bodies and drainage density were used for the delineation of groundwater potential zone in the study area. To differentiate development zones, all these thematic layers were integrated using AutoDeskMAP and MapInfo GIS software. The weights of the different themes were assigned on a scale of 1 to 5 based on their influence on the groundwater development. Different features of each theme were assigned weights on a scale of 1 to 9 according to their relative influence on groundwater development. Based on this scale, a qualitative evaluation of different features of a given theme was performed, with: poor (weight = 1–1.5); moderate (weight = 2–3.5); good (weight = 4–5.5); very good (weight = 6–7.5); and excellent (weight = 8–9). Thereafter, a pair-wise comparison matrix was constructed using the Saaty's analytical hierarchy process (Saaty, 1980) to calculate normalized weights for individual themes and their features. To differentiate groundwater potential zone, all the seven thematic layers after assigning weights were integrated (overlaid) step by step using MapInfo GIS software. The total weights of different polygons in the integrated layer were derived from the following equation to obtain groundwater potential index (Rao and Briz-Kishore, 1991):

GWPI = ((GGw) (GGwi) + (GMw) (GMwi) + (GRw) (GRwi) + (DDw) (DDwi) + (STw) (STwi) + (SLw) (SLwi) + (SWw) (SWwi)) ------ (1)

where GWPI = groundwater potential index, GG = geology, GM = geomorphology, GR = groundwater recharge, DD = drainage density, ST = soil type, SL = slope, SW = surface water body, and the subscripts 'w' and 'wi' refer to the normalized weight of a theme and the normalized weight of the individual features of a theme, respectively. GWPI is a dimensionless quantity that helps in indexing probable groundwater potential zones in the area. The range of GWPI values were divided into three equal classes (called zones) and the GWPI of different polygons falling under different range were grouped into one class. Thus, the entire study area was qualitatively divided into three groundwater potential zones and a map showing these zones was prepared using MapInfo and AutoDesk Map GIS software. The complete process of groundwater potential zoning is shown in Figure 3.

3.3 Assessment of Groundwater Potential:

Some researchers have validated groundwater potential maps with the available well-yield data of the study area. However, (Solomon and Quiel, 2006) reported that the well-yield values are often limited by the capacity of pumps and thus may underestimate the true capacity of the wells. Therefore, to estimate the aquifer yield with proper accuracy the Central Ground Water Board (CGWB), Government of India, New Delhi has suggested the concept of exploitable dynamic groundwater reserve which actually represents the long-term average annual recharge under conditions of maximum groundwater use (Karanth, 1999). Using this concept, the aquifer yields of different groundwater potential zones (as identified by Geoinformatics techniques) were estimated by using the following equation (CGWB, 1984):

$$Re = \Delta h \times A \times S \qquad (2)$$

where Re = average annual dynamic exploitable/utilizable groundwater reserve, Δh = average groundwater level decline between November of the current year and May of next year, A = area of the groundwater potential zone, and S = storage coefficient of the aquifer.

4.0 Thematic Layers of Ghataprabha Basin:

The details of geomorphology and geology, soil type, land slope, drainage density, recharge pattern and surface water body together with their spatial distribution in the study area are presented below.

4.1 Geomorphology:

It is well known fact the climate and geomorphological characteristics of a basin affect its response to a considerable extent. Thus, linking of geomorphological parameters with hydrological characteristics of a basin provides a simple way to understand their hydrological behavior. Geomorphologically the catchment is relatively flat and gently undulating with isolated hillocks intervened by valley. The catchment is somewhat oval in shape. The relief of the basin varies between 600 m and 1200 m. Very steep contours Figure 4 are observed towards the western side of the sub basin. The high basin relief observed in the Ghataprabha basin is an indication of the higher potential energy available to move water and sediment downstream regions, i.e. the region in and around Daddi. However, in the northern part of the basin they are not as steep as in the south and western part of the basin. This part (southwestern part) may easily be subjected to erosion due to its higher relief.

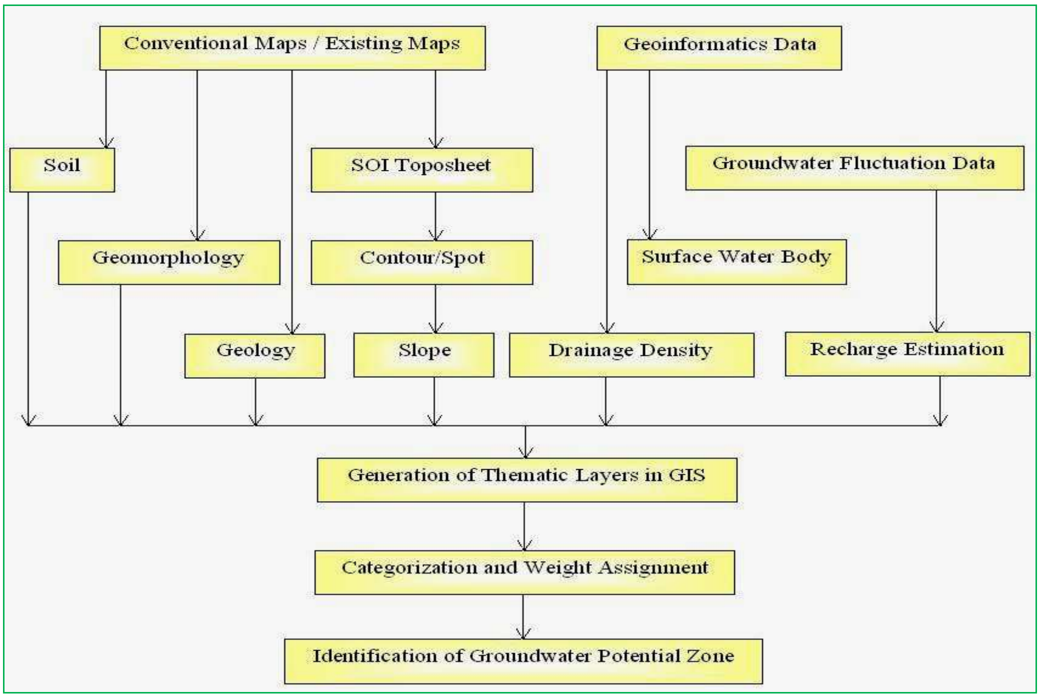

Fig.3: Flowchart for groundwater potential zone using Geoinformatics techniques

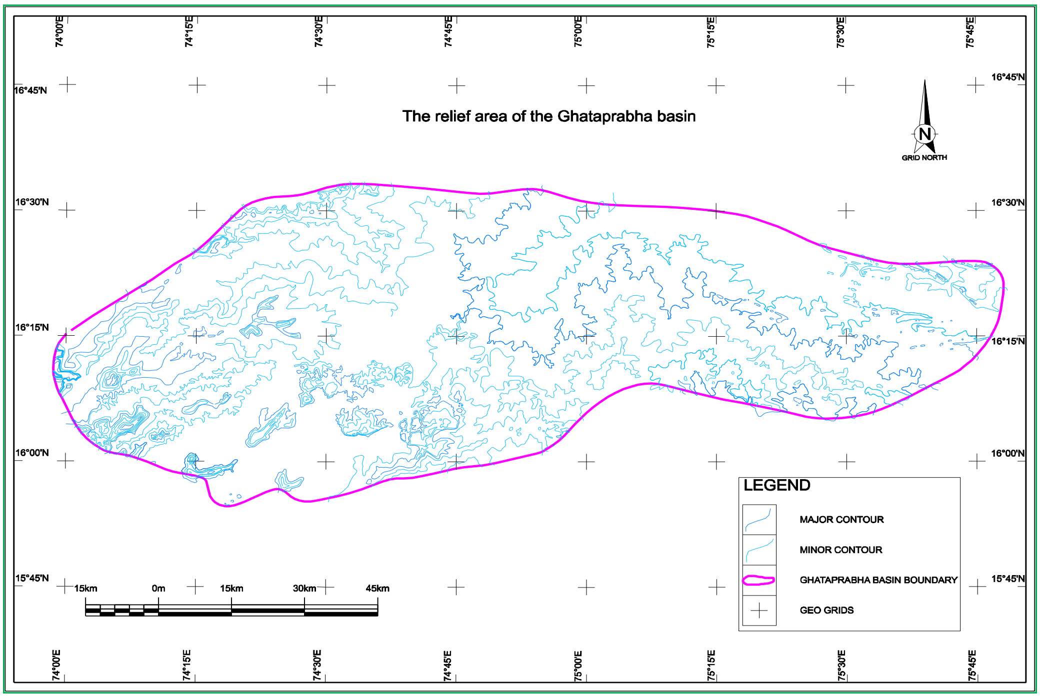

Fig. 4: Contours of the study area

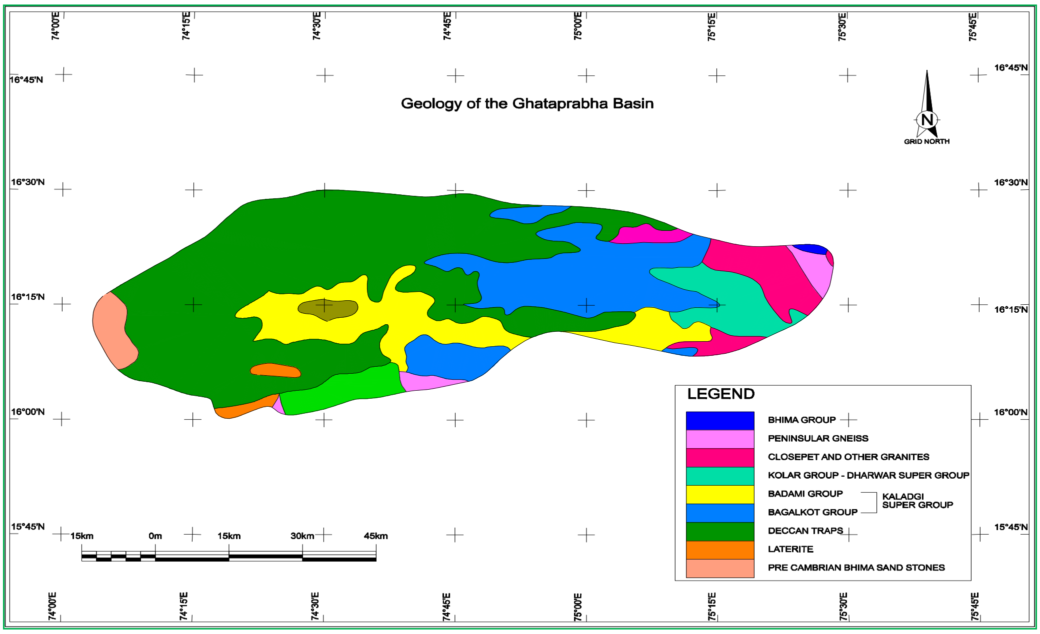

Fig. 5: Geology of the study area

4.2 Geology:

In the present study area six types of geology, namely river alluvium, laterites, sandstone and quartzite of Kaladgi group, schists and phylites of Dharwar super group, Deccan trap and granites & gneiss's, are found Figure 5. Water yielding properties of these rock types are summarized below as Table 2.

4.3 Land Slope:

A land slope map prepared from the Google Earth and Survey of India toposheets of the study area. The slope percentage in the area varies from 0 to 30%. On the basis of the slope, the study area can be divided into five slope classes. The area with 0 to 1% slope falls in the 'very good' category due to the nearly flat terrain and relatively high infiltration rate. The eastern portion of the study area (60% of the total area) falls under this category. The area with 1–3% slope is considered as 'good' for groundwater storage due to slightly undulating topography with some run-off. Apart from a small portion in the extreme western portion of the basin, the entire central portion and the southern portion (40% of the total area) fall under this category. The area with a slope of 3–5% causes relatively high run-off and low infiltration, and hence is categorized as 'moderate'. The fourth (5–10%) and fifth (10–30%) category are considered as 'poor' due to higher slope and run-off. The forest cover of the catchment is 13.8%. The wet deciduous forest occurs in the west zone of the Kolhapur and Sindhudurg districts of Maharastra. The entire basin is divided into as many as 5 divisions ranging from < 700 to > 1000 m. The spatial distribution of different altitudinal zones. It is found that a total of 686.3 km^2. (65.05%) area is lying within 700-800 m. contour line. A small part of type catchment falls under higher altitudinal groups Table 3.

Table 3: Distribution of area under dfferent atitudinal zones of the Ghataprabha basin

Altitudinal Zones	Area in km^2.	Area in %
<700	169.85	16.1
700-800	686.28	65.05
800-900	183.04	17.35
900-1000	14.24	1.35
>1000	1.58	0.15

4.4 Soil:

The thematic layer on soil (Figure 6) for the study area reveals seven main soil classes: deep black soil, medium black soil, mixed red & black soil, coarse shallow back soil, lateritic soil, coarse shallow soil and medium deep soil. It is apparent from Figure 6 that the majority of the study area is dominated by deep black soil to medium black soils, with other soil types covering relatively small areas. These seven soil classes can be categorized into four classes 'very good', 'good', 'moderate' and 'poor' according to their influence on groundwater occurrence.

Table 2: Water yielding properties of various rock types in Ghataprabha sub-basin
(DANIDA, 1996; CGWB, 1997)

Rock Type	**General features**	**Water yielding Properties**	
		Radhakrishna & Pathak	**CGWB**
River alluvium	Mostly composed of gravel, sand and silt	Dug well yields could be expected around 400 cum/day very much limited.	Development of potential very much limited
Laterites	Weathered product with cavities	Dug well yield may vary from 20 to 180 cum/day	Dug well yield ranges from 25 to 300 cum/day
Sandstone and quartzite of Kaladgi Group	Hard and Compact	Poor aquifers	Dug well yield ranges from 25 to 150 cum/day where bore well yields are less than 1.0 lps to 7.6 lps
Schists and phylites of Dharwar Super group	Highly folded, weathered to form clay material	Dug well yield varies 30 to 200 cum/day where as bore well yields are of the order of 30 cum/day	Dug well yield ranges from 20 to 150 cum/day whereas bore well yielded 0.4 lps
Deccan trap	Horizontal lava flows, columnar joints, vesicular and amygdaloidal structures	Well yield varies from 0.5 to 200 cum/day. Red bole between two flows are good aquifers	Dug well yield ranges from 20 to 250 cum/day whereas bore well yields less than 1.0 lps to 7.6 lps
Granites and Gneiss's	Coarse grained, occasionally transversed by joints	Dug well yield is of the order of 50 to 250 cum/day and bore well yield varies from 50 to 480 cum/day	Dug well yield ranges from 20 to 150 cum/day whereas bore well yielded 0.4 lps

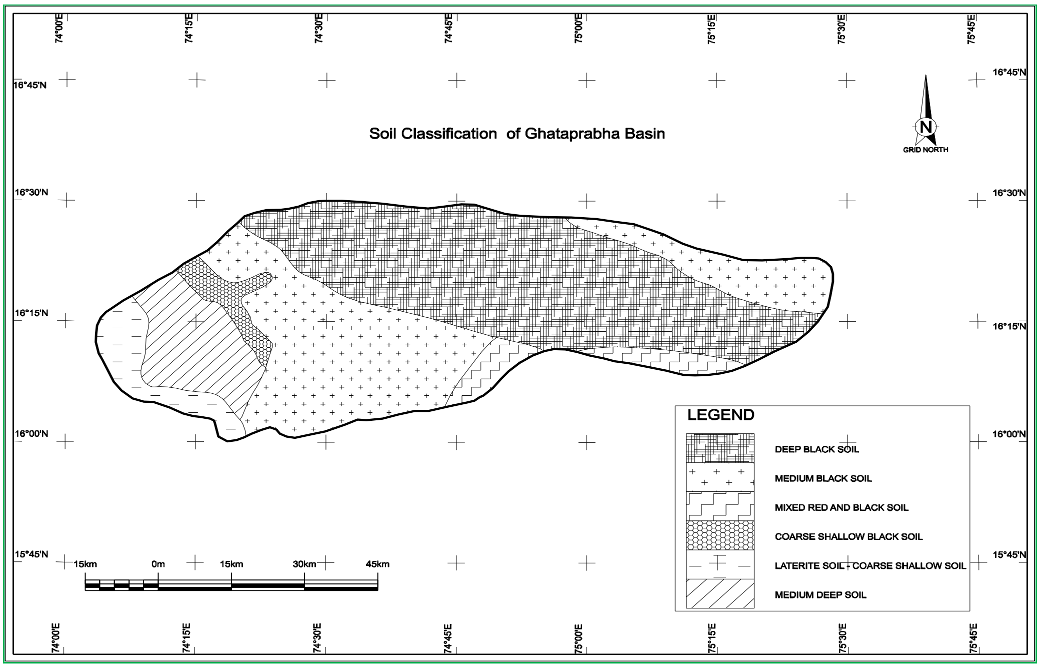

Fig. 6: Soil classification of study area

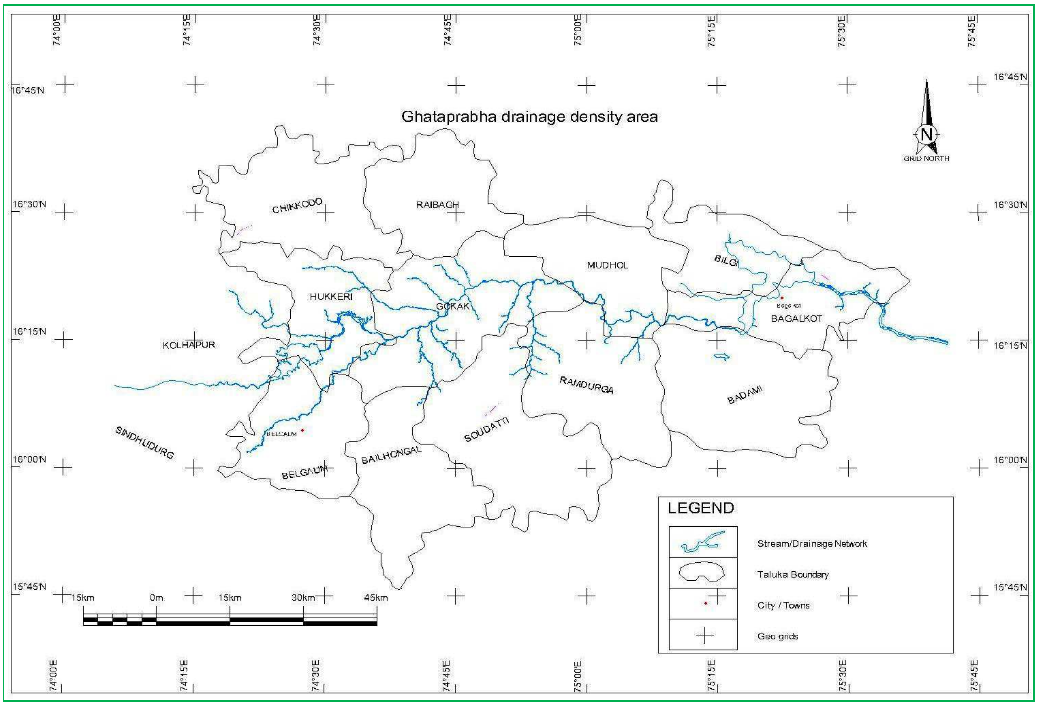

Fig. 7: Drainage / stream network of study area

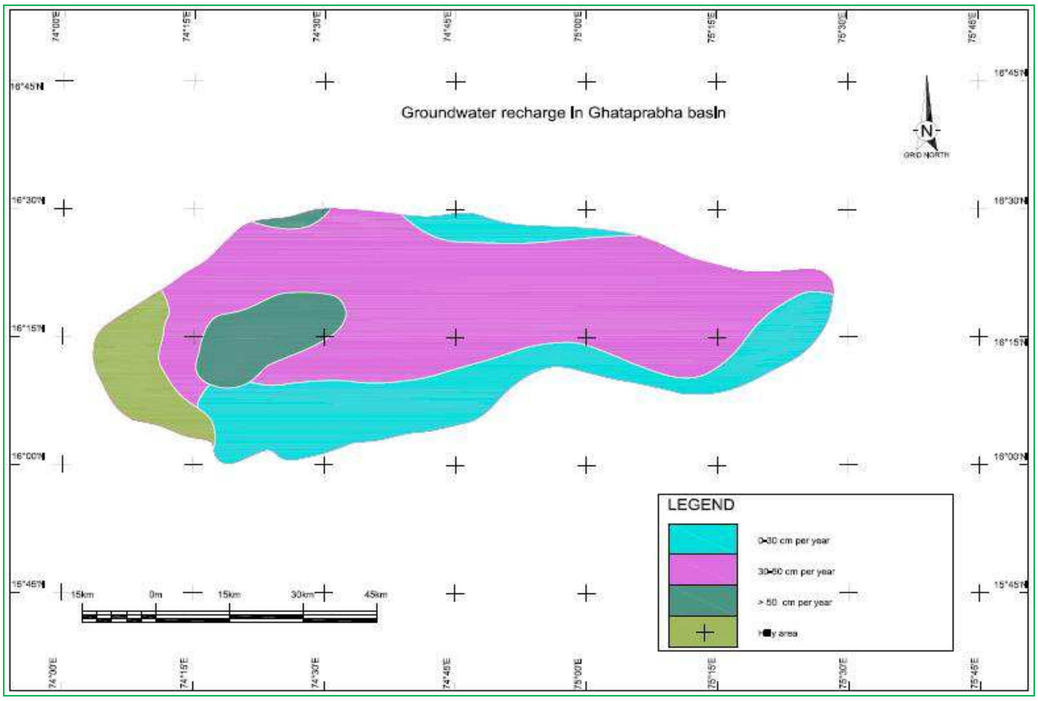

Fig. 8: Average annual groundwater recharge in study area

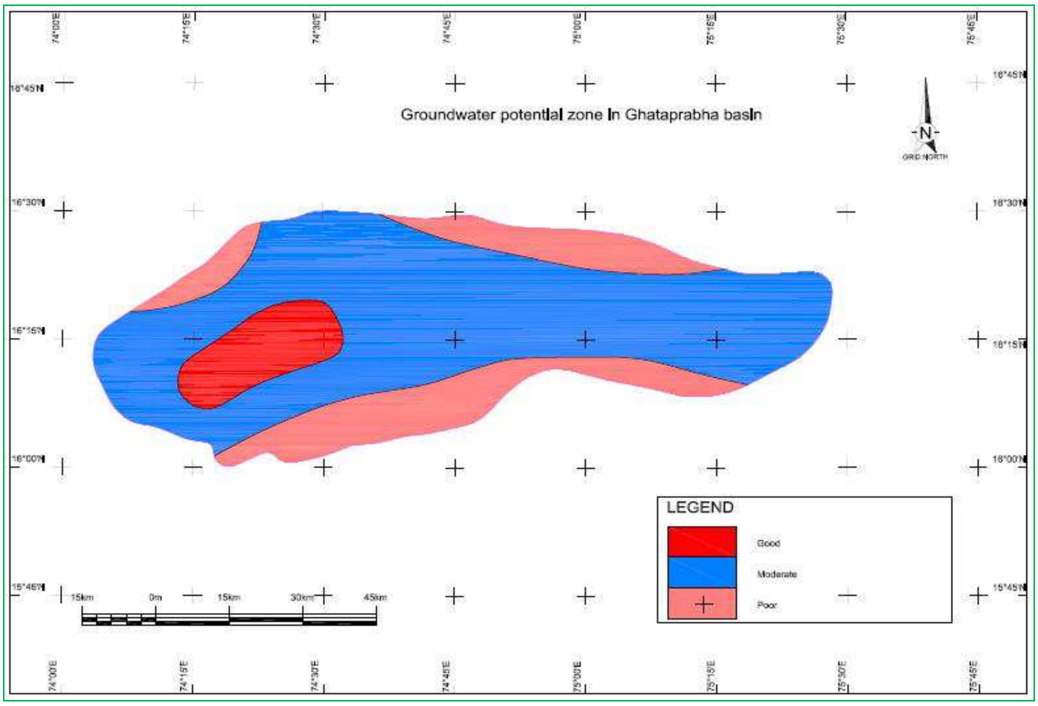

Fig. 9: Groundwater potential zone in study area

4.5 Drainage Density:

Drainage density is an inverse function of permeability. The less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface run-off. This gives origin to a well-developed and fine drainage system. In the present study, since the drainage density can indirectly indicate the groundwater potential of an area due to its relation to surface run-off and permeability, it was considered as one of the indicators of groundwater occurrence. Drainage density measurements have been made for all the micro-watersheds in the area, and range from 0.5 km to 2.5 km. The drainage density map for the study area is shown in Figure 7. Based on the drainage density of the micro basins, it can be grouped into three classes: (i) 0–0.75 km; (ii) 0.75–1.5 km; and (iii) 1.5–2.25 km. Accordingly, these classes have been assigned ‘good’, ‘moderate’ and ‘poor’ categories, respectively. Most of the study area (70%) has a drainage density of 0.75 – 1.5 km.

4.6 Groundwater Recharge:

The groundwater fluctuation method yielded the average annual groundwater recharge in Ghataprabha basin varying from 0.20 to 0.50 cm. These recharge values indicate the actual groundwater recharge from different sources. Based on these recharge estimates, the area can be divided into three recharge zones: (i) 0–30 cm year^{-1}; (ii) 30–50 cm year^{-1}; (iii) 50> cm year^{-1}, as shown in Figure 8. It is apparent from this figure that a recharge rate of 30–50 cm year^{-1} is dominant in the study area. Very low recharge ($\leq$20 cm year^{-1}) occurs in the northern and southern portion of the area and in small scattered patches over the area. A small strip having relatively high recharge rate (above 50 cm year^{-1}) is present in the middle left and small scattered patches over the north portion of the area.

4.7 Surface Water Body:

In this study, the surface water bodies (e.g. ponds, tanks and natural depressions) present in the study area were digitized from the Google Earth maps, satellite image and updated with the SOI toposheets. Large water bodies such as rivers/streams were not considered in this theme as they are already considered in the drainage theme. Finally, the thematic layer was classified into two classes—buffered area and the area outside it. The buffered area was considered as a more suitable zone for groundwater potential than the area away from the buffered area, and weights were assigned accordingly.

5.0 Weight Assignment and Geoinformatics-Based Modeling:

Suitable weights were assigned to the seven themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the study area. The normalized weights of the individual themes and their different features were obtained through the Saaty's analytical hierarchy process (AHP). The weights assigned to different themes are presented in Table 4. The process of obtaining the normalized weights of the themes is presented in Table 5. The weights assigned to different features of the individual themes and their normalized weights are presented in Table 4. The normalized weights of different features of the seven themes were obtained in the similar manner as presented in Table 6. After deriving the normal weights of all the thematic layers and each feature under individual themes, all the thematic layers were integrated with one another using MapInfo GIS software in order to demarcate groundwater potential zones in the study area. In the first step, the geomorphology layer was integrated with the geology layer. The weight of each polygon of the integrated layer was derived by adding the weights of polygons of the original two layers and the process was continued for the remaining five themes to obtain a final integrated layer. The final weights of each polygon in the final integrated layer were derived by summing up the weights of polygons from individual layers and the highest derived sum of the weights in the final integrated layer was divided into three equal classes, i.e. 'good', 'moderate' and 'poor', in order to delineate groundwater potential zones. The delineation of groundwater potential zones was done by grouping the polygons in the final integrated layer having weights of any of the three classes.

6.0 Groundwater Potential Zoning:

The groundwater potential map of the Ghataprabha basin Figure 9 reveals three distinct classes (zones) representing 'good', 'moderate' and 'poor' groundwater potential in the area. The good groundwater potential zone mainly encompasses when fresh but the joints if present will serves as conduits & some quantity of ground water will be recharged & held in the weathered zone & fractured planes. Groundwater occurs under water table conditions & the depth of water table ranges from 3 to 12 m. Ground water recharge take place through precipitation of rain water & morphological features of ground surface around the major river systems. It demarcates the areas where the terrain is most suitable for groundwater storage, and also indicates the availability of water below the ground. The area covered by good groundwater potential zone is about 1324.35 km^2 (15%). Gokak block as well as parts of Begaum, Chikkodi, Daddi and Bailahongal blocks fall under this zone. The eastern portion and some small patches in the central and northern portions of the study area fall under moderate groundwater potential zone, which dominates the area. It encompasses an area of 5297.40 km^2 which is about 60% of the total area. The hydrogeomorphic feature available in this portion is consists of hilly terrain having large patches of forest growth at higher levels & cultivated land at lower levels. The total length of Ghataprabha river up to the confluence with the Krishna river is about 260 km., which also suggests moderate capacity of groundwater storage. However, the groundwater potential in the western, south-western and parts of north-eastern portions of the study area is poor, covering an area of about 2207.25 km^2 (25%). The poor groundwater potential is due to the higher slope and unfavorable geology and geomorphology in this zone, which is an extension of the Deccan plateau. These prospective groundwater zones can provide a basis for the detailed hydrogeologic and/or geophysical investigations needed for well sitting and proper management of scarce groundwater resources.

7.0 Quantification of Groundwater Potential:

The minimum and maximum limits of exploitable/usable groundwater reserve for the good, moderate and poor groundwater potential zones were estimated using the average groundwater-level decline at all the sites over the study area. In the good zone, the average annually exploitable groundwater reserve was estimated to be 228.75 million cubic meters (MCM), whereas it is 915 MCM for the moderate zone and 381.25 MCM for the poor zone. Thus, the total amount of average annually exploitable groundwater reserve is more for the moderate zone compared to the good zone, which is attributable to the larger area under the moderate zone. It should be noted that these estimates of exploitable groundwater reserve for each potential zone are the amounts of groundwater replenished annually. Therefore, these groundwater reserves can be considered as sustainable yields of the respective zones, which can be safely utilized to meet the water demands of different sectors in the study area. However, step-drawdown pumping tests should be carried out at an adequate number of sites in each zone of the study area to determine sustainable yields of individual well sites. Such field tests are essential for ensuring sustainable utilization of vital groundwater resources in a basin, though they are often ignored in developing nations.

Table 4: Weights of the seven themes for groundwater potential zoning

Theme	Weight
Geomorphology	5
Geology	4
Land slope (%)	3.5
Soil	3.5
Drainage density (km)	4
Groundwater recharge (cm/year)	4.5
Surface water body (m)	1

Table 5: Pair-wise comparison matrix of the seven thematic layers

Theme	Theme							Mean	Normalized weight
	GM	**GG**	**RE**	**DD**	**Soil**	**Slope**	**SW**		
GM	5/5	5/4	5/4.5	5/4	5/3.5	5/3.5	5/1	1.51	0.19
GG	4/5	4/4	4/4.5	4/4	4/3.5	4/3.5	4/1	1.21	0.16
RE	4.5/5	4.5/4	4.5/4.5	4.5/4	4.5/3.5	4.5/3.5	4.5/1	1.36	0.17
DD	4/5	4/4	4/4.5	4/4	4/3.5	4/3.5	4/1	1.21	0.16
Soil	3.5/5	3.5/4	3.5/4.5	3.5/4	3.5/3.5	3.5/3.5	3.5/1	1.06	0.14
Slope	3.5/5	3.5/4	3.5/4.5	3.5/4	3.5/3.5	3.5/3.5	3.5/1	1.06	0.14
SW	1/5	1/4	1/4.5	¼	1/3.5	1/3.5	1/1	0.3	0.04
Column Total =								**7.71**	**1.0**

GM = geomorphology; GG = geology; RE = recharge; DD = drainage density; SW = surface water body

Table 6: Assigned and normalized weights for the individual features of the seven themes for groundwater potential zoning

Theme	Class	Groundwater prospect	Weight assigned	Normalized weight
Geomorphology	(i) Valley fill deposit	Very good	6.5	0.25
	(ii) Deep buried pediment	Good	4.5	0.17
	(iii)Rocky outcrops	Moderate	2.5	0.09
	(iv)Pediment	Poor	1	0.04
Geology	(i) River alluvium			
	(ii) Laterites	Very Good	7	0.3
	(iii) Sandstone and quartzite of	Moderate	3.5	0.15
	Kaladgi Group	Poor	1.5	0.07
	(iv) Schists and phylites of Dharwar	Moderate	2.5	0.09
	Super group	Moderate	3	0.12
	(v) Deccan trap	Good	4	0.17
	(vi) Granites and Gneiss's			
Recharge	> 50 cm per year	Very good	7	0.29
	30-50 cm per year	Good	5	0.20
	00-30 cm per year	Moderate	3	0.12
Drainage density	0.00-0.75 km	Good	5	0.53
	0.75-1.50 km	Moderate	3	0.31
	1.50-2.25 km	Poor	1.5	0.16
Soil	(i) Deep black soil	Poor	1	0.05
	(ii) Medium black soil	Poor	1.2	0.06
	(iii) Mixed red & black soil	Moderate	2.5	0.12
	(iv) Coarse shallow back soil	Moderate	2	0.09
	(v) Lateritic soil	Good	4	0.18

	(vi) Coarse shallow soil	Good	3.5	0.21
	(vii) Medium deep soil	Moderate	2	0.09
Slope	Level to nearly level (0–1%) Very gently sloping (1–3%) Gently sloping (3–5%) Moderately sloping (5–10%) Moderate steeply sloping (10–30%)	Very good Good Moderate Poor Poor	6 5 3.5 2 1.2	0.34 0.28 0.20 0.11 0.07
Surface water body	< 75 m > 75 m	Good Poor	4 1	0.80 0.20

8.0 Conclusions:

1) Ghataprabha basin located in the Northwestern part of Karnataka, India is suffering from growing water shortages for both irrigation and domestic purposes. The over exploitation of groundwater has resulted in groundwater lowering in some parts of the study area, there by aggravating the water problem in the basin.
2) A study was carried out to delineate groundwater potential zones in the Ghataprabha basin of Karnataka (India) using a multi-parametric approach by Geoinformatics techniques.
3) Remote sensing satellite imagery, SOI topographic maps and conventional data were used to prepare the thematic layers of seven hydrologic/hydrogeologic parameters, namely geomorphology, geology, land slope, soil, drainage density, recharge and surface water body.
4) These layers were then integrated in the GIS environment using MapInfo software to delineate groundwater potential zones in the study area.
5) The above method divides the study area (Ghataprabha basin) into three groundwater potential zones, 'good', 'moderate' and 'poor', covering 15% 60% and 25% of the study area, respectively. In the good zone, the average annually exploitable groundwater reserve was estimated to be 228.75MCM, whereas it is 915 MCM for the moderate zone and 381.25 MCM for the poor zone.
6) The major portion (more than 85%) of the study area exhibits poor to moderate groundwater potential, it can be inferred that groundwater resource is somewhat limited.
7) Therefore, judicious utilization of groundwater resources coupled with proper water management is essential for ensuring groundwater sustainability.
8) As the methodology adopted in this study is based on logical conditions and reasoning, it can also be applied in other regions of India or abroad.
9) Overall, the results of this study demonstrated that the Geoinformatics technology is a powerful tool for assessing groundwater potential zone, based on which suitable locations for groundwater withdrawals could be identified.
10) Consideration of an adequate number of thematic layers and proper assignment of weights are keys to the success of Geoinformatics techniques in identifying groundwater prospects. Based on the results of this study, concerned decision makers can formulate an efficient groundwater utilization plan for the study area so as to ensure long-term sustainability of this vital resource.
11) Although the Geoinformatics method is effective in identifying groundwater potential zones, which can considerably reduce the cost of well drilling by minimizing the failure of obtaining suitable well sites, the method has some limitations apart from the inherent errors involved in image processing and GIS modelling.
12) The method mainly uses surface features and hydrologic parameters, and hence it would be generally effective in identifying fairly shallow aquifer systems.
13) Future studies should focus on the development of efficient methodology for weight assignment so as to minimize or avoid the bias.
14) The efficacy of the Geoinformatics method for groundwater evaluation could be further improved by considering adequate number of thematic layers having direct or indirect control over groundwater occurrence.

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