

## Deciphering potential groundwater zone in hard rock through the application of GIS

R. K. Prasad · N. C. Mondal · Pallavi Banerjee ·  
M. V. Nandakumar · V. S. Singh

Received: 15 March 2007 / Accepted: 9 August 2007 / Published online: 25 August 2007  
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**Abstract** Remote Sensing and Geographic Information System has become one of the leading tools in the field of hydrogeological science, which helps in assessing, monitoring and conserving groundwater resources. It allows manipulation and analysis of individual layer of spatial data. It is used for analysing and modelling the interrelationship between the layers. This paper mainly deals with the integrated approach of Remote Sensing and geographical information system (GIS) to delineate groundwater potential zones in hard rock terrain. The remotely sensed data at the scale of 1:50,000 and topographical information from available maps, have been used for the preparation of ground water prospective map by integrating geology, geomorphology, slope, drainage-density and lineaments map of the study area. Further, the data on yield of aquifer, as observed from existing bore wells in the area, has been used to validate the groundwater potential map. The final result depicts the favourable prospective zones in the study area and can be helpful in better planning and management of groundwater resources especially in hard rock terrains.

**Keywords** Hard rock aquifer · Aquifer yield · Groundwater potential zones · Remote sensing · GIS · Spatial analyst tool

### Introduction

Recently there has been overall development in various fields such as agriculture, industry and urbanization in the Asian countries particularly in India. This has led to increase in the demand of water supply which is met mostly from exploitation of groundwater resources. In hard rock semi-arid terrain that occupies almost two third of India, groundwater is the largest fresh water resource. The groundwater potentiality in such region is largely limited to shallow weathered and fractured zones. In order to meet demand, there has been indiscriminate exploitation of groundwater resources.

In the absence of any planned groundwater withdrawal approach, many times random drilling of bore wells results into failure. Further, this indiscriminate exploitation has led to decrease in groundwater potential, lowering of water level (hence increase in cost of groundwater withdrawal) and deterioration in groundwater quality. It is therefore necessary to develop sustainable groundwater management scheme to properly utilize this vital resources, which in turn requires delineation of groundwater potential zones.

There are several methods such as geological, hydrogeological, geophysical and remote sensing techniques, which are employed to delineate groundwater potential zones. Remote sensing technique provides an advantage of having access to large coverage, even in inaccessible areas. It is rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments, slope, etc. that helps in deciphering groundwater potential zone. A systematic integration of these data with follow up of hydrogeological investigation provides rapid and cost-effective delineation of groundwater potential zones. Although it has been possible to integrate these data

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R. K. Prasad · N. C. Mondal · P. Banerjee ·  
M. V. Nandakumar · V. S. Singh (✉)  
National Geophysical Research Institute,  
Hyderabad 500 007, Andhra Pradesh, India  
e-mail: vssingh77@hotmail.com

visually and delineate groundwater potential zones, however, it becomes time consuming, difficult and introduces manual error.

In the recent years digital technique is used to integrate various data to delineate not only groundwater potential zone but also solve other problems related to groundwater. These various data are prepared in the form of thematic map using geographical information system (GIS) software tool. These thematic maps are then integrated using “Spatial Analyst” tool. The “Spatial Analyst” tool with mathematical and Boolean operators is then used to develop model depending on objective of problem at hand, such as delineation of groundwater potential zones.

In the recent years many workers such as Teeuw (1995), Shahid and Nath (1999), Goyal et al. (1999), Saraf and Choudhary (1998) have used approach of remote sensing and GIS for ground water exploration and identification of artificial recharge sites. Jaiswal et al. (2003) have used GIS technique for generation of groundwater prospect zones towards rural development. Krishnamurthy et al. (1996), Murthy (2000), Obi Reddy et al. (2000), Pratap et al. (2000), Singh and Prakash (2002), have used GIS to delineate groundwater potential zone. Srinivasa Rao and Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data. GIS has also been considered for multicriteria analysis in resource evaluation. Shahid et al. (2000) Boutt et al. (2001), El-kadi et al. (1994) and Jacob Novaline et al. (1999), Saraf et al. (2004) have carried out groundwater modelling through the use of GIS. Mohammed Aslam et al. (2003) have carried out hydrogeomorphological mapping using remote sensing techniques for water resource management around palaeochannels. GIS has been applied to groundwater potential modelling by Rokade et al. (2007).

In the present study, the remotely sensed data (IRS 1C LISS III) of 7th April 2004, geocoded at the scale of 1:50,000 and Survey of India (SOI) toposheet nos.56L/9,56L/13 have been used for preparation of various thematic maps such as geology, lineament, geomorphology, slope and drainage-density. These thematic maps were converted into raster form so that they can be easily integrated using GIS. Each of these thematic maps has been assigned suitable weightage factor. These weightage factors have been taken considering the works carried out by researchers such as Srinivasa Rao and Jugran (2003), Krishnamurthy et al. (1996) and Saraf and Choudhary (1998). These thematic maps were then integrated using “Spatial Analyst” tool of GIS to delineate groundwater potential zones.

The well yield data has been prepared from the monitoring of yield of 438 existing wells in the study area. These data have been used to validate the groundwater potential map which can be very useful in directly sitting

well for tapping groundwater or developing schemes for the management of groundwater in the area.

### Study area

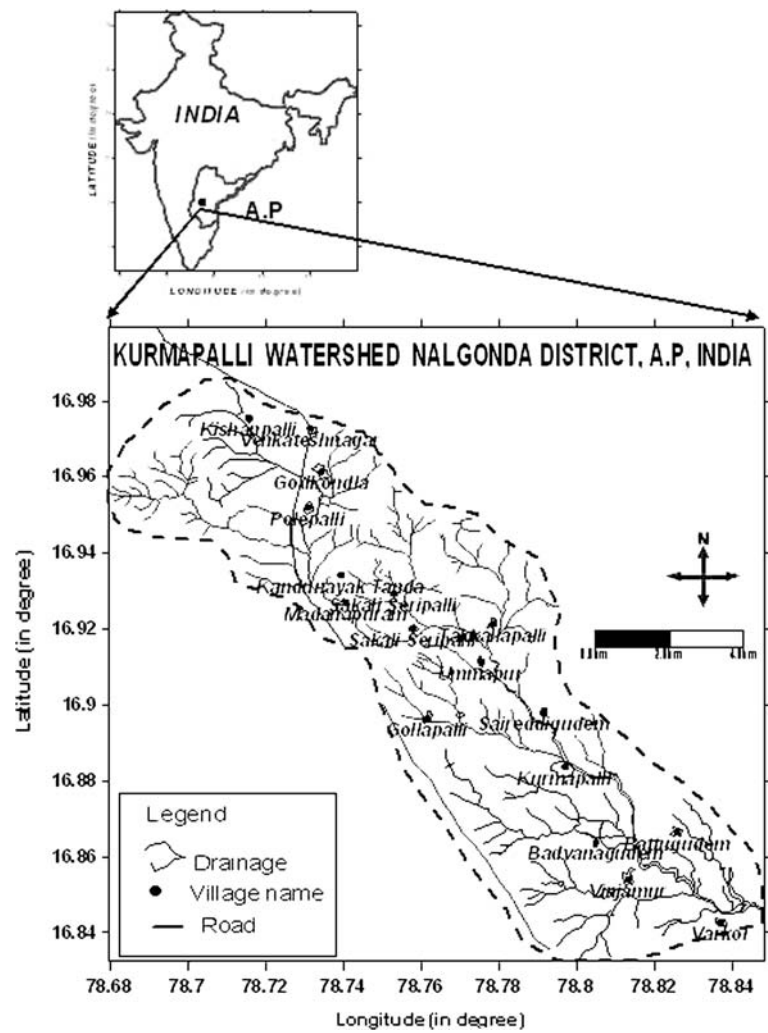
The study area (Fig. 1) lies between longitude 78.67°–78.84°E and latitude 16.82°–16.98°N in Nalgonda District (Andhra Pradesh), India, which is situated about 60 km from capital Hyderabad in SE direction. It covers about 108 km<sup>2</sup>, which is one of the drought prone areas of Nalgonda district. The basin is characterized by poor soil cover, scarce vegetation, erratic rainfall and lack of soil moisture for most part of the year. Recurring drought coupled with increase in ground water exploitation results in decline in ground water levels. In order to manage and develop sustainable scheme, it is vital to delineate the groundwater potential zones.

The area is bounded in the north by massive granitic hills where most of the drainage originates. The entire area is drained by small streams, which flow towards southeast. The high altitude area in the northwestern part is at about 683 m above mean sea level (amsl) whereas the southern most part where river flows out is at 360 m amsl. Physiography of the area exhibits three distinct features (1) hilly terrains covering mainly northern and north-western part of the basin, (2) mid-slope region with moderate undulating terrain and (3) relatively flat region with gentle slope covering larger part of the basin. The area receives an average annual rainfall of about 400 mm. The surface runoff goes to stream as instant flow. Most of the drainage flows south-eastward forming upper catchment. There are few tanks across these drainages; however most of these remain dry.

### Geology

The basin is underlain by Archaean rocks. Massive porphyritic granitic rocks occupy high-hill ranges and isolated hills. The northwestern edge and northern part are occupied by such hills of hard crystalline massive granites as shown in Fig. 2. The southern fringe area is occupied with Kankar (calcium concentrate) with clay. The remaining part is occupied by weathered granite and gneisses. These are highly weathered, jointed, fractured and faulted. There are joints and fractures parallel to foliation as well as perpendicular to it. At places these are out cropped while at other places there are underlain by weathered formation as evinced from the lithology of wells in the area. It is this weathered and fractured zone, which forms potential groundwater zones. There are thin strips of alluvium deposits seen along the stream course, which could be potential groundwater zones.

Fig. 1 Study area



### Lineaments

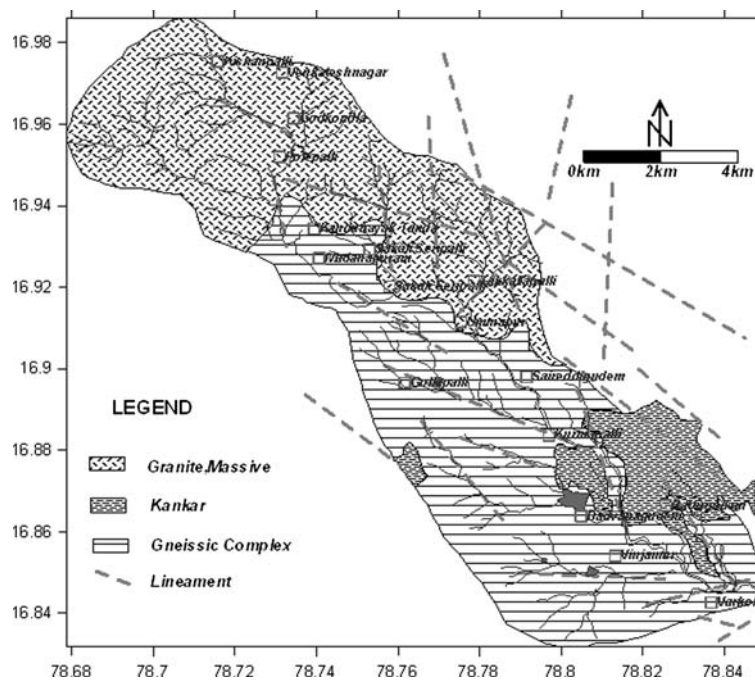
Lineaments are manifestation of linear features that are identified from remote sensing data. The area is criss-crossed with lineaments. The prominent directions of these are NW–SE and NE–SW as shown in Fig. 3. Directional analysis or lineament analysis has been carried out to better describe the occurrence of lineament in the area. The statistics for a number of directional properties of the lineaments is depicted by rose diagram as shown in Fig. 4. The details of analysis is also shown in Fig. 4. The vector mean of lineaments is calculated as N295.51 • E as depicted in Fig. 4.

Although lineaments have been identified through out the area, it is the lineaments in the pediplain or valley fill (VF) which are considered significant from groundwater occurrence point of view. Those across the denudational hills (DH), residual hills (RH), in the high-drainage density and high-slope area or in the area occupied by clay zones are of less significance as there could be high runoff along them and these may act only as conduit to transmit infiltrated rain water.

### Drainage

Drainage pattern reflects the characteristic of surface as well as subsurface formation. Drainage density (in terms of  $\text{km}/\text{km}^2$ ) indicates closeness of spacing of channels as well as the nature of surface material. More the drainage density, higher would be runoff. Thus, the drainage density characterizes the runoff in the area or in other words, the quantum of relative rainwater that could have infiltrated. Hence lesser the drainage density, higher is the probability of recharge or potential groundwater zone.

As mentioned earlier, most of the drainage originates from the granitic hills in the northern part of the basin (Fig. 1). The drainage pattern, in general, is dendritic, typical of granitic terrain. In the northern part these are dense. The drainage density in the area has been calculated after digitization of the entire drainage pattern and shown in Fig. 5. It varies from 0.02 to more than  $6 \text{ km}/\text{km}^2$ . The high drainage density area indicates low-infiltration rate whereas the low-density areas are favourable with high-infiltration rate.

**Fig. 2** Geology of the area

### Slope

Slope is one of the factors controlling the infiltration of groundwater into subsurface; hence an indicator for the suitability for groundwater prospect. In the gentle slope area the surface runoff is slow allowing more time for rainwater to percolate, whereas high slope area facilitate high runoff allowing less residence time for rainwater hence comparatively less infiltration.

The slope map prepared from topographical and satellite data has been obtained from State Agency. Slope

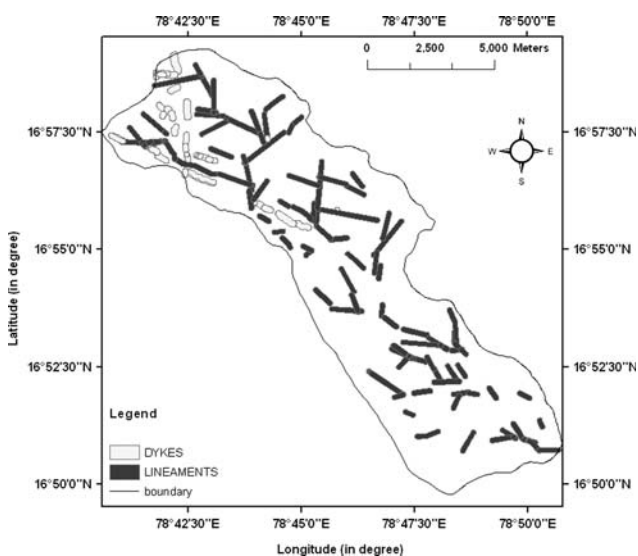
map of the area as shown in Fig. 6, indicates that it varies from 0–1 to more than 35%. We have classified the slope into seven categories, i.e. 0–1, 1–3, 3–5, 5–10, 10–15, 15–35 and more than 35%. Most of the study area occupies slope category of 0–1%. Since, slope is also a criterion for infiltration of precipitation, most of the area has favourable slope from groundwater potential point of view.

### Geomorphology

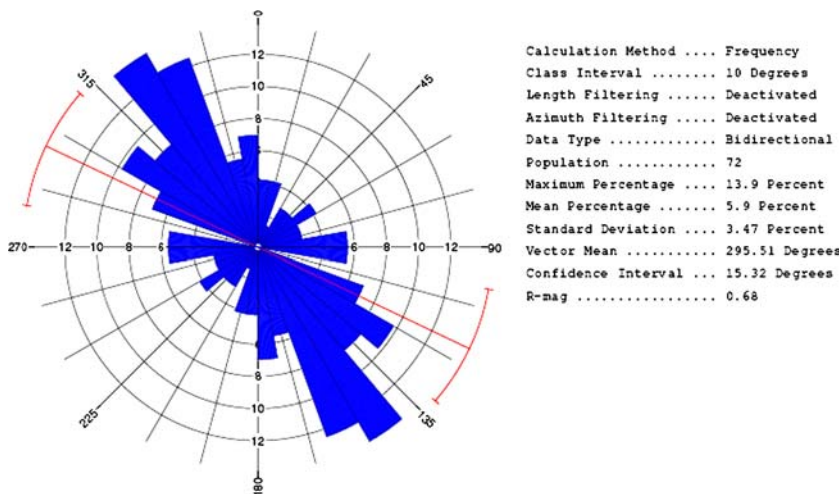
Geomorphology reflects various landform and structural features. Many of these features are favourable for the occurrence of groundwater and are classified in terms of groundwater potentiality. These units are deciphered from the remote sensing data (GeoInfos Pvt. Ltd., 2005, Personnel communication) as shown in Fig. 7. There are major geomorphological units namely shallow weathered pediplain (SWPP), moderately weathered pediplain (MWP), rocky pediment (RP), RH, DH and VF. These are briefly described as follows.

#### *Shallow weathered pediplain*

These are the areas of nearly level terrain with low gradient. These are covered with shallow weathering material ranging from 0 to 5 m. The top soil is generally red soil. Most of the study area is occupied by this unit. The groundwater prospect in such zone is described as poor to moderate.

**Fig. 3** Lineament map of the area

**Fig. 4** Rose diagram of lineaments



*Moderately weathered pediplain*

These areas are described as nearly flat terrain with gentle slope. The area is covered with relatively thick weathered material ranging from 5 to 15 m covered with red soil. These are found almost along all the major drainage courses. The groundwater prospect in these areas is described as moderate to good depending upon the thickness of weathered zone.

*Rocky pediment*

These are the gentle sloping surfaces with erosional bed rock. These are lying between hills and plain. They occupy very small areas scattered in the north-western and north

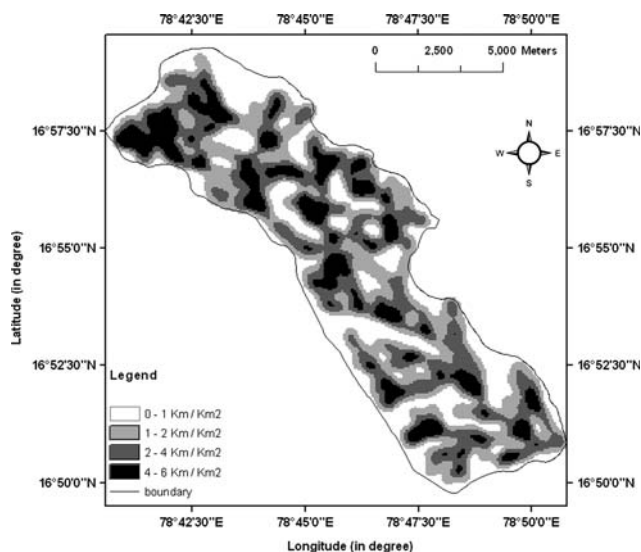
eastern part of the study area. The groundwater prospect in these zones is negligible to poor.

*Residual hills*

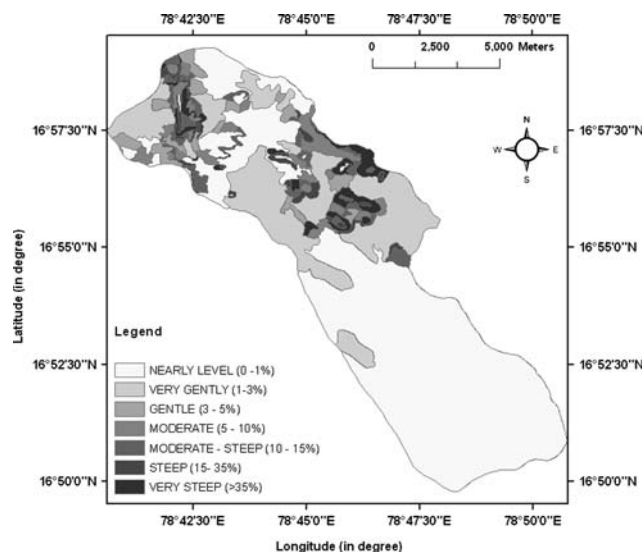
These are described as isolated hills. They occupy very small areas scattered in the north-western and north eastern part of the study area. The groundwater prospect in this zone is also described as poor.

*Denudational hills*

These are the hill ranges. These are formed due to differential erosion and weathering. These occupy the western edge of the area. The groundwater prospect in this zone is also described as poor.

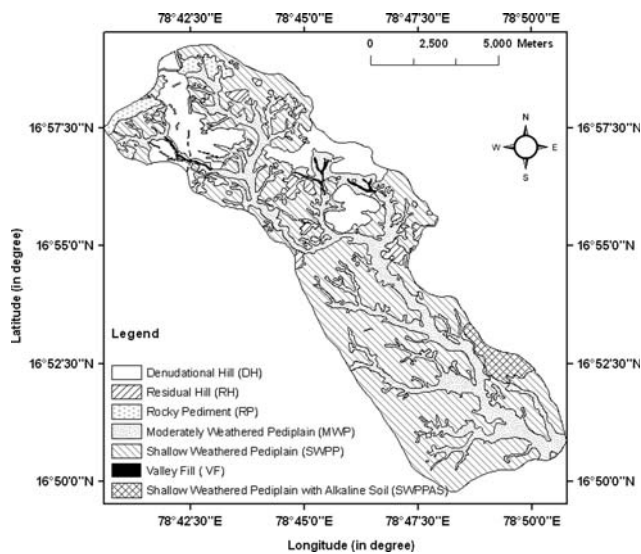


**Fig. 5** Drainage density of the area



**Fig. 6** Slope map of the area





**Fig. 7** Geomorphology of the area

### Valley fill

This is described as the deposition of unconsolidated materials in the narrow valley. These are fluvial deposits. It occupies a very small patch at the south-western boundary of the area. The groundwater prospect in this area is expected to be moderate to good.

### Integration through GIS

The integration of various thematic maps describing favourable groundwater zones, into a single groundwater potential map has been carried out through the application of GIS. It required mainly three steps.

1. Spatial database building;
2. Spatial data analysis and
3. Data integration.

### Spatial database building

The tools provided in Arc Catalog have been used to create the scheme for feature data sets, tables, geometric networks and other items inside the database. The secant method of geodatabase building has been followed. Initially, coverage and INFO tables from existing data have been made. The following steps were involved to create coverage and INFO tables for each thematic map:

- a. Digitization of scanned data,
- b. Editing for errors, dangle, etc.,
- c. Topology building,

- d. Attributes assignment,
- e. Projection and
- f. Buffering.

The study area boundary, villages, rivers, streams and ponds have been digitized. The topographical map has been used to prepare drainage map. Similarly various other maps such as geomorphological map, slope map, geological map and lineament map have been digitized. After digitization these maps have been processed for editing of error, dangles, pseudo-nodes, etc. Attributes to these maps have been added. In any coverage attributes needs to be added to available features to differentiate them. Buffering of 100 m in lineament map has been carried out.

### Spatial data analysis

It is an analytical technique associated with the study of locations of geographic phenomena together with their spatial dimension and their associated attributes (like table analysis, classification, polygon classification and weight classification).

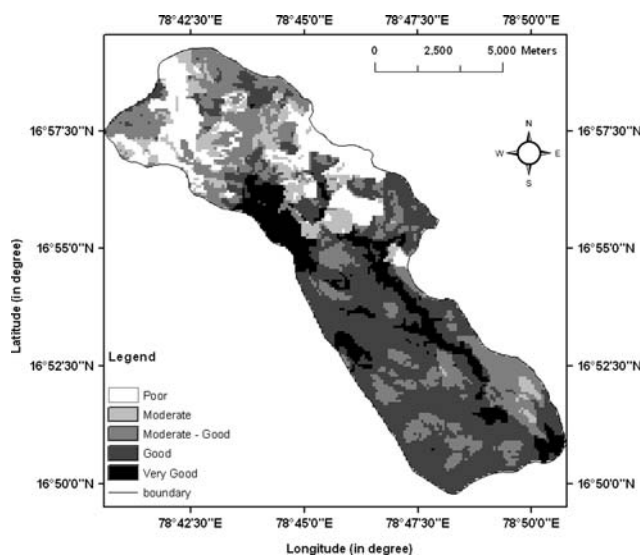
The various thematic maps as described above have been converted into raster form considering 100 m as cell width to achieve considerable accuracy. These were then reclassified and assigned suitable weightage following the patterns as used by Srinivasa Rao and Jugran (2003), Krishnamurthy et al. (1996) and Saraf and Choudhary (1998). These are given in Table 1.

### Data integration

Each thematic map such as geology, geomorphology, drainage density, lineament and slope provides certain clue for the occurrence of groundwater. In order to get all these information unified, it is essential to integrate these data with appropriate factor. Although, it is possible to superimpose these information manually, however it is time consuming and error may occur. Therefore, these information are integrated through the application of GIS. Various thematic maps are reclassified on the basis of weightage assigned and brought into the “Raster Calculator” function of Spatial Analyst tool for integration. The weightage for different layers have been assigned considering similar work carried by many workers such as Srinivasa Rao and Jugran (2003), Krishnamurthy et al. (1996) and Saraf and Choudhary (1998). A simple arithmetical model has been adopted to integrate various thematic maps by averaging the weightage. The final map has been categorized into five zones, from groundwater potential point of view, and are as follows:

**Table 1** Weightage assigned to various thematic maps

Thematic map	Related features	Symbol	Weightage assigned
Geology	Massive granite	(Gr)	1
	Weathered gneiss	(Gn)	3
	Kankar	K	1
Hydrogeomorphology	Denudational hills	DH	1
	Residual hills	RH	1
	Rocky pediment	RP	1
	Moderately weathered pediplain	MWP	3
	Shallow weathered pediplain	SWPP	2
	Valley fill	VF	3
	Shallow weathered pediplain with alkaline soil	SWPPAS	2
	Slope	Nearly level	0–1%
Very gentle		1–3%	3
Gentle		3–5%	2
Moderate		5–10%	1
Moderate–steep		10–15%	1
Steep		15–35%	1
Very steep		>35%	1
Lineament	Present	–	3
	Absent	–	1
Drainage-density	Low density/coarse texture	0–1 km/km <sup>2</sup>	4
	Medium density/medium texture	1–2 km/km <sup>2</sup>	2
	High density/fine texture	2–4 km/km <sup>2</sup>	1
	Very density/superfine texture	4–6 km/km <sup>2</sup>	1
Water yield	Very good	>900 m <sup>3</sup> /day	4
	Good	600–900 m <sup>3</sup> /day	4
	Good–moderate	300–600 m <sup>3</sup> /day	3
	Moderate to poor	100–300 m <sup>3</sup> /day	2
	Poor	<100 m <sup>3</sup> /day	1



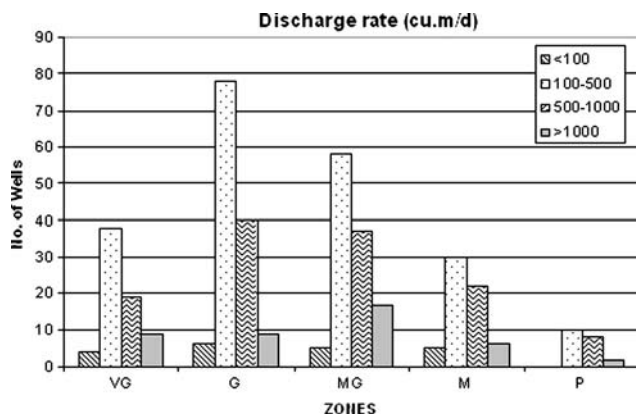
**Fig. 8** Groundwater potential Map

**Table 2** Result showing potential zone without integrating yield layer

Sl. number	Prospective zone	Area in km <sup>2</sup>	Percentage
1	Very good	13.95	12.91
2	Good	42.83	39.43
3	Moderate to good	28.42	26.16
4	Moderate	9.25	8.5
5	Poor	14.17	13.04

1. Very good,
2. Good,
3. Moderate to good,
4. Moderate and
5. Poor.

The groundwater potential map thus derived is shown in Fig. 8. The extent of various zones in terms of percentage of area is shown in Table 2. The maximum area,



**Fig. 9** Frequency diagram showing well yield distribution

particularly the southern part is characterized by good potential occupying about 39% of total area. The very good potential area is marked by only 13% as shown in Fig. 8.

In order to validate classification we have collected data on the yield of existing wells. About 438 wells were monitored and the yield of these wells have been found to vary from 31 to 1,426 m<sup>3</sup>/day. These data were superimposed on the groundwater potential map and number of wells with different yield ranges were classified for different zones of potential map. Frequency distribution of various yields in different zones have been calculated as shown in Fig. 9. It is evident from the diagram that occurrence of number of wells with yield range of 100–500 m<sup>3</sup>/day is more in the zones which are described as “good” as well as “very good” in comparison to the occurrence of wells with these yields in other zones. Another feature is remarkable is that as we move from “good” to “poor” zone the number of occurrence of these better yielding wells are decreasing indication that possibility of getting better yield decreases. Hence, the most favourable zones for high yielding groundwater can be concluded as “good” and “very good” zones derived from the application of GIS.

## Conclusion

GIS approach has been used to integrate various geoinformative thematic maps, which play major role in occurrence and movement of groundwater. The integrated groundwater potential map has been categorized on the basis of cumulative weightage assigned to different features of thematic maps. Further, comparison of groundwater yield data collected from the field also supports that there are more number of high-yield wells in the favourable zones derived from GIS. The integrated map thus deciphered could be useful for various purposes such as development of sustainable scheme for groundwater in the area.

**Acknowledgement** Authors wish to thank Dr. V. P. Dimri, Director, National Geophysical Research Institute, Hyderabad for his encouragement and permission to publish this paper. The work has been financed by Indian National Committee on Irrigation and Drainage, Ministry of Water Resources, Govt. of India and authors are thankful to them.

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