Integrated approach for delineating potential zones to explore for groundwater in the Pageru River basin, Cuddapah District, Andhra Pradesh, India

P. D. Sreedevi · K. Subrahmanyam · Shakeel Ahmed

Abstract Hydrogeomorphological, hydrogeological and geophysical investigations were carried out in the Pageru River basin of Cuddapah district, Andhra Pradesh, to delineate potential zones for future groundwater exploration. The study area is underlain by Proterozoic formations of the Indian Peninsula comprising limestones and shales as the sedimentary cover. Limestone and shale formations of the Cuddapah Super group that are later overlain by the Kurnool group (shale, limestone and quartzite) are exposed extensively. The high drainage density (2.61 km/km^2) in the western region also suggests that the area is characterized by low permeable zones compared with low drainage density (1.04 km/km^2) of the flood plains, which form the potential aquifers in the east. The hydro-geomorphological data are further supported from evidence of the water-table fluctuation in wells and resistivity of the saturated formations. The results indicate that the favourable, moderately favourable and poor zones characterized geomorphologically, have water-level fluctuations in the range of 0–2, 2–6 and above 6 m, respectively. The resistivities of these zones are also in the range of 1–26, 40–466, and >1,900 ohm-m. A few pumping tests have also been conducted to assess the broad range in the values of aquifer parameters. Based on these data, good to poor potential zones for obtaining groundwater have been delineated in the study area.

Résumé Des investigations hydrogéomorphologiques, hydrogéologiques et géophysiques ont été menées sur le bassin de la rivière Pageru du district de Cuddapah, Andhra Pradesh, pour délimiter les zones potentielles dans la future recherche d'eaux souterraines. La zone étudiée est, à la base, constituée par les formations protérozoïques de la péninsule indienne comprenant les calcaires et les shales de la couverture sédimentaire. Les calcaires et les shales du Super Groupe Cuddapah qui sont recouverts par le Groupe Kurnool (shale, calcire, quartzite) sont exposés de manière extensive. La densité importante de drainage (2.61 km/km^2) dans la région ouest montre également que la zone est caractérisée par des perméabilités faibles par comparaison avec les plaines d'inondation (densité de drainage: 1.04 km/km^2), formant les aquifères potentiels de l'Est. Les données hydrogéomorphologiques vont également dans le sens des données de fluctuation de la nappe et de résistivité des formations saturées. Les résultats indiquent que les zones caractérisées géomorphologiquement comme favorables, moyennement favorables et pauvres, possèdent des fluctuations respectives de l'ordre de 0 à 2, 2 à 6 et de plus de 6 m. La résistivité de ces zones est également de l'ordre de 1 à 26, 40 à 466 et de plus de 1900 ohm-m. Quelques pompages d'essais ont également été conduits pour déterminer les valeurs moyennes des paramètres de l'aquifère. En se basant sur ces données, des zones potentielles bonnes à pauvres pour l'exploitation des eaux souterraines ont été délimitées.

Resumen Se llevaron a cabo investigaciones hidrogeomorfológicas, hidrogeológicas y geofísicas en la cuenca del Río Pageru del distrito Cuddapah, Andhra Pradesh, con objeto de delimitar zonas potenciales para exploración futura de aguas subterráneas. El área de estudio consiste de formaciones Proterozoicas de la Península India con calizas y lutitas como cubierta sedimentaria. Las formaciones de caliza y lutita del Grupo Cuddapah Superior afloran extensamente y están cubiertas por el Grupo Kurnool (lutita, caliza, y cuarcita). La alta densidad de drenaje (2.61 km/km^2) en la región occidental también indica que el área se caracteriza por zonas de baja permeabilidad en comparación con las planicies de inundación de baja densidad (1.04 km/km^2) que forman los acuíferos potenciales del oriente. Los datos hidrogeomorfológicos tienen apoyo adicional a partir de evidencia proveniente de la fluctuación del nivel freático en pozos y resistividad de las formaciones saturadas. Los resultados indican que las zonas caracterizadas geomorfológicamente como zonas favorables, moderadamente favorables, y pobres tienen fluctuaciones de niveles de agua en el rango de 0–2, 2–6, y mayor de 6 m, respectivamente. Las resistividades de estas zonas también se encuentran en el rango de 1–26, 40–466, y mayores de 1,900 ohm-m. Se realizaron algunas pruebas de bombeo

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para evaluar los amplios rangos que tienen los valores de los parámetros de los acuíferos. Basado en esta información se delimitaron zonas con potencial bueno a pobre para obtener agua subterránea en la zona de estudio.

Keywords Hydrogeomorphology · Pageru River basin, India · Resistivity · Water-level fluctuations · Zonation for obtaining groundwater

Introduction

The Cuddapah basin is a significant tectonic and orogenic belt of the unfossiliferous Precambrian rocks of Peninsular India. The study area forms a part of the crescent-shaped Cuddapah basin (King 1872; Pascoe 1950; Wadia 1957; Dutt 1966; Krishnan 1968; Crawford and Compston 1973; Murthy et al. 1979; Krishnaswamy 1981) located at the southwestern boundary. Vaidyanadhan (1962, 1967), based on the landforms in the Cuddapah Basin and over the Eastern Ghats, concluded that the Eastern Ghats were heaved up a little due to cymatogenic upwarp during the Mid-Tertiary. Janardhana Raju et al. (1994) have demarcated potential zones for developing groundwater in an adjacent area in the Cuddapah district, based on integrated geological, hydrological and geophysical (electrical resistivity) surveys. In order to ascertain the potential for locating groundwater, the study area has been demarcated into different zones based on geomorphology. The results so obtained have been further corroborated through hydrogeological and geophysical data. The electrical conductivity of groundwater was also measured and areas demarcated to determine its suitability for general use.

Methodology

The satellite data (IRS-1B, LISS–II FCC) at 1:50,000 scale was visually interpreted to delineate various geomorphological units based on structural trends, lineaments, soil tones, vegetative cover and relief linearity. The water-level fluctuation in dug wells was monitored for pre- and post-monsoon seasons from a network of 107 wells uniformly spread over the area during 1996–1997. Representative wells in shale, quartzite, limestone and alluvium were selected, and a few aquifer tests were performed. A total of 112 vertical electrical soundings (VES) were conducted, using the Schlumberger method of electrode configuration. Groundwater quality was determined through a study of electrical conductivity (EC). A combined map of the features (geomorphology, water levels and resistivity) was prepared to correlate them with groundwater availability in different zones.

Study Area

The study area (latitudes 14°29′04″ to 14°39′51″N and longitudes 78°19′12″ to 78°41′32″E) covers an area of about 480 km^2 (Fig. 1). The Proterozoic formations of south India occupy a large part of Andhra Pradesh and are designated as the Purana Formations. The Puranas consist of the Cuddapah and Kurnool systems of sedimentary rocks, mainly composed of shales, limestones and quartzites (Table 1). The Pageru River is an ephemeral stream and culminates in the east of the study area into the Papaghni River. The Pageru River basin enjoys a semi-arid climate with temperatures between 24 and 44 °C and an average annual rainfall of 581 mm. The Pageru River basin is a fairly well-drained basin (Fig. 2) with a high drainage density (2.61 km/km^2) in the western region and a low drainage density (1.04 km/km^2) in the east.

The youngest rock formations of the study area are classified as the Cuddapah Super group and the Kurnool group (Fig. 3). The oldest are the Tadipatri formations, belonging to the lower Cuddapah Super group, and are essentially composed of slaty shales with interbedded thin layers of siliceous limestone, quartzite, and basic intrusive sills (Narayanaswami 1966). The formations trend generally NNE–SSW with a gentle dip of about 10° east (Fig. 3). The Tadipatri formation is overlain by the rocks of the Kurnool group, which include quartzite, limestone and shale (Table 1). A distinct angular unconformity separates the Cuddapah formations from the Kurnool rocks, and occurs as horizontal beds over the tilted Cuddapah rocks. An alluvial geomorphic unit of Holocene and Recent age is a more or less stratified deposit of gravel, sand, silt and clay that occurs all along the course of the streams. The alluvium at the confluence of the Rivers Pageru (flowing eastwards) and Papaghni (flowing northwards) near Putlampalli was found to be comprised sand of variable thickness and composed of sandy aquifers occupying the easternmost part of the study area (Sreedevi et al. 2001).

Hydrogeomorphology

Water is an important agent in the formation of landforms (Scheidegger 1973). The satellite images were examined based on visual interpretation and the study area was divided into several geomorphological units such as valley fills, flood plains, alluvial plains, shallow buried pediplains, moderately buried pediplains, pediments and structural landforms (Fig. 4).

Valley fills were identified along the Pageru River course in the south. Flood plains and alluvial plains (Fig. 4) were demarcated at the confluence of River Pageru (Fig. 2) and River Papaghni (not shown as it is located at the eastern tip of Fig. 2) in the east (Lokesh and Narayana Shenoy 1996; Pandey et al. 2002). The depth to the water table is 2 m below ground level (b.g.l.) in these landforms. The average yield from bored wells varies from 19,200 to 25,200 l/h.

The denuded landforms are the result of weathering and erosion caused by different exogenetic geomorphic agents to form pediments and pediplains, etc. Pediments with a weathered zone thickness of less than 2.5 m predominantly occur in and around Turakapalle and Nal-

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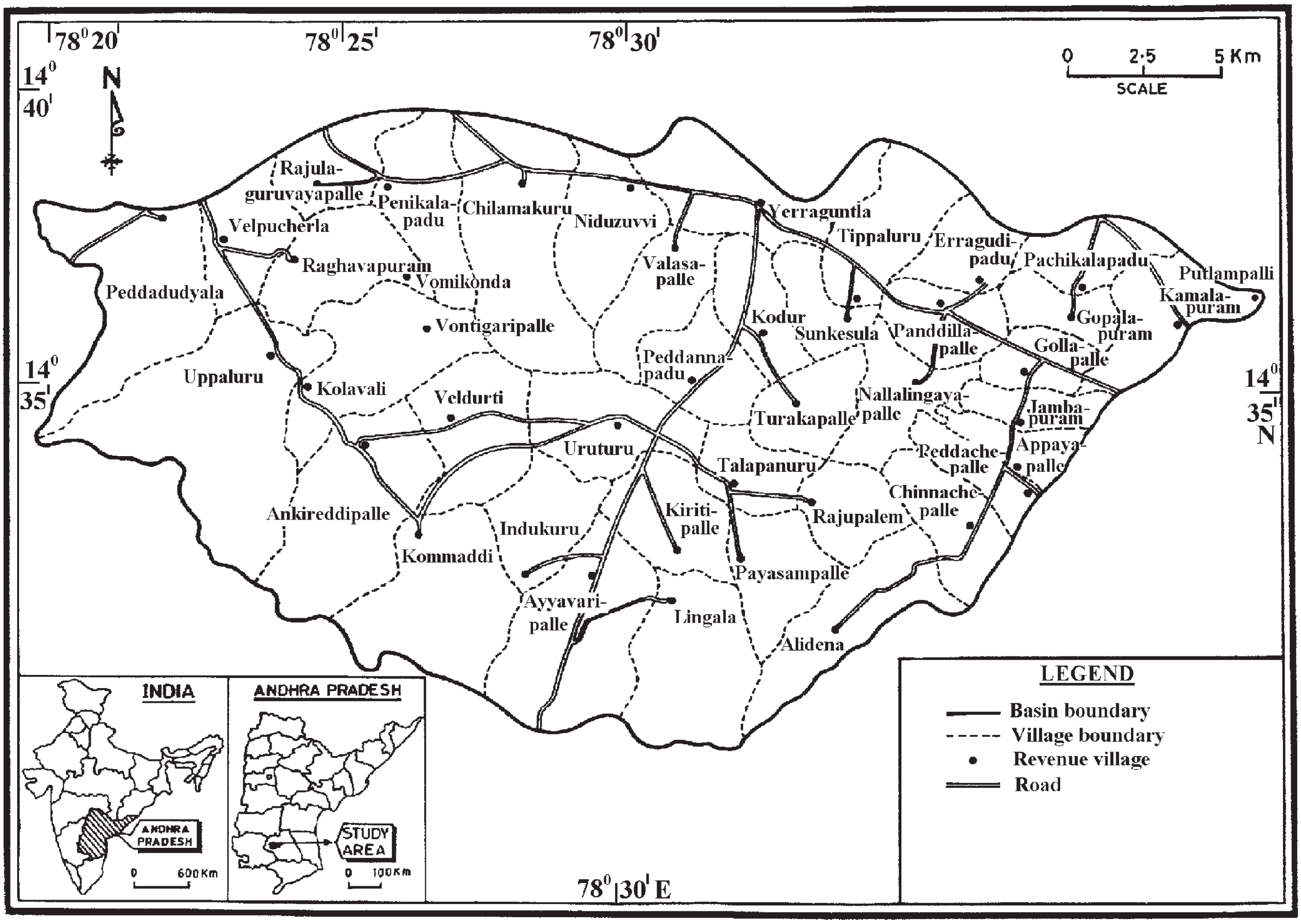

Fig. 1 Location of Pageru River basin

Table 1 Stratigraphic succession. After Murthy et al. (1979)

	Series	Stage	Thickness (m)
Kurnool Group	Kundair	Nandyal shales	50–100
		Koilakuntla limestone	15–50
	Paniam	Plateau quartzite	10–35
	Local disconformity		
	Jammalamadugu	Auk shales	10–15
		Narji limestones (massive and flaggy limestone)	100–200
	Banaganapalle	Quartzite with conglomerate	10–57
Unconformity			
Cuddapah Super Group	Chitravati Group	Tadipatri formation (shale, tuff, dolomite/limestone, quartzite and basic intrusives: sills)	4,600 1–75

lalingayapalle, and as isolated patches in the north-central region in and around Niduzuvvi and Valsapalle (Fig. 1). Generally, these areas are not favourable for groundwater exploration (Krishna Murthy and Srinivas 1995; Sarfaraz Ahmed and Nagi 1999). The water table varies from 4 to 6 m b.g.l. during the pre- to post-monsoon season with average yields ranging from 840 to 2,100 l/h.

Shallow buried pediplains (BP-S) occur along the sloping foothills and are covered by Tadipatri shale, Auk shale, Narji limestone, Koilkuntla limestone and Nandyal shale. The thickness of the weathered zone is less than 5 m and is covered with soil. The water table varies from 2 to 6 m b.g.l. Moderate yields (3,120–5,160 l/h) occur along the fracture zones and bedding planes (Krishna Murthy and Srinivas 1995; Palanivel et al. 1996; Gowd et al. 1998).

Moderately buried pediplains (BP-M) are gently sloping, flat and smooth on the surface of the Tadipatri

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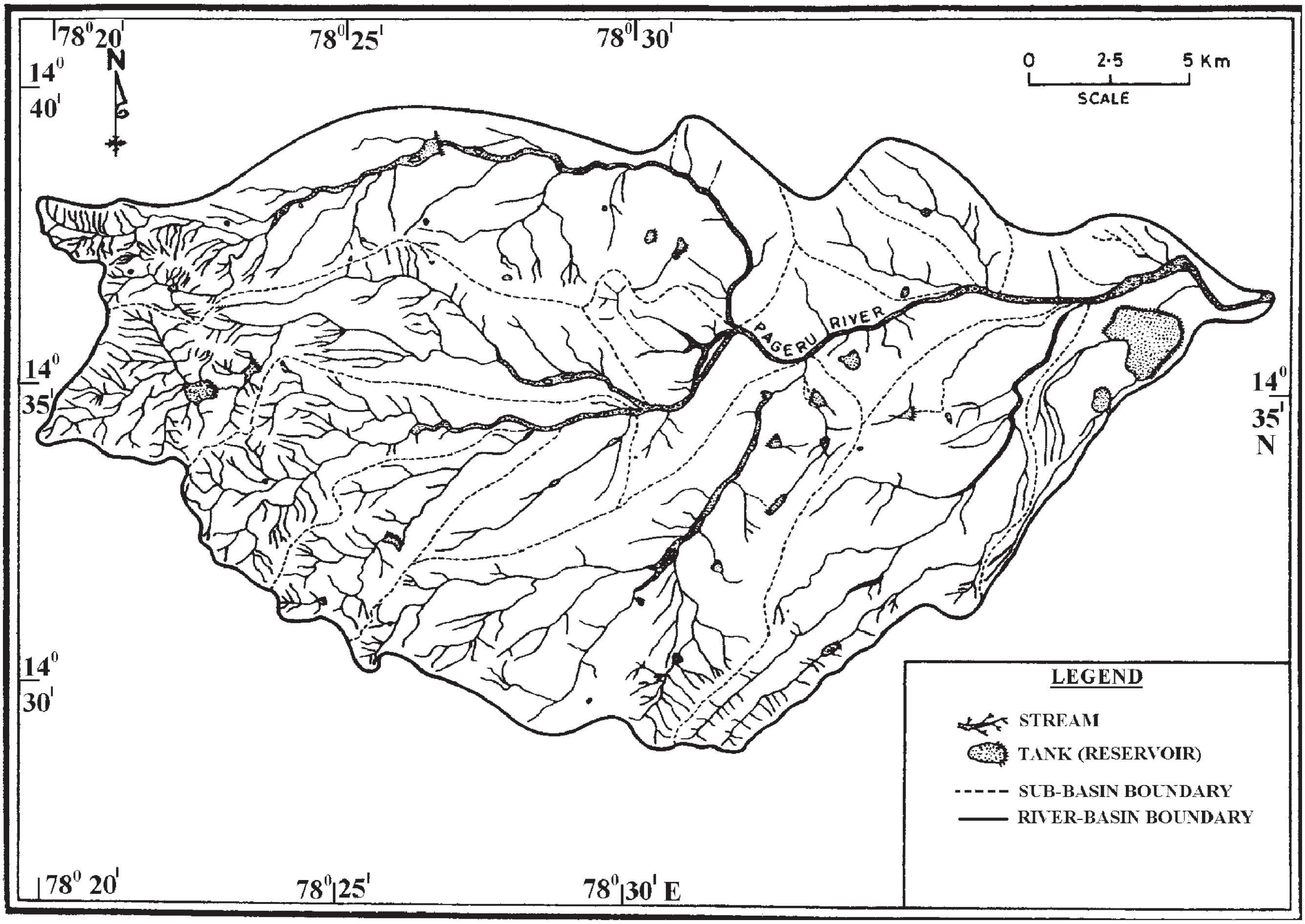

Fig. 2 Drainage pattern of Pageru River basin

shale, Auk shale, Narji limestone, Koilkuntla limestone and Nandyal shale, which is weathered to a depth of 15 to 20 m. The groundwater prospects are moderately high in these areas (Krishna Murthy and Srinivas 1995; Srinivas Rao et al. 1997; Gowd et al 1998). The water table varies from 2 to 6 m b.g.l. The average yield from wells ranges from 5,640–11,340 l/h.

The structural landforms identified in the study area are mesas/buttes, Cuesta hill, structural hill and linear ridges. Mesas/buttes are composed of quartzite formations, which are found on the western side of Uppaluru and the northwestern side of Vomikonda villages.

Cuesta hills are gently sloping surfaces, underlain by hard and compact Banaganapalle quartzite, which are nearly parallel to the dip of the bedding planes with escarpments cutting across the bedding planes. This type of landform with a limited horizontal area is observed in the eastern and central parts of the study area.

The structural hills are exposures of linear to acute hills exhibiting definite trends composed of varying lithology. They mostly occupy the western part of the basin. They are mainly composed of the Tadipatri formation. The trend of the structural hills ranges from northwest to southeast. The run-off is high with negligible infiltration, making them poor aquifers (Raju et al. 1989; Gowd et al. 1998). The water levels are below 6 m b.g.l. The average yield ranges from 800 to 1,680 l/h. Linear ridges (LR), observed in the southern region, and composed of basic intrusives, are narrow, and have low relief and generally no vegetative cover. The ridges are mostly strike controlled.

Lineaments

The lineaments in the Precambrian shield areas extend into the sedimentary rocks overlying them and exert their influence in the tectonic history of the younger formations (Vaidyanadhan 1971). It has been suggested that south India has been subjected to certain epeirogenic uplifts since the Jurassic (Vaidyanadhan 1967). The lineaments of the study area have been traced from the satellite data of IRS 1B-LISS II imagery of false colour composite (FCC). A number of mega- and micro-lineaments are identified from the satellite imagery, further checked by field studies, and demarcated at a 1:50,000 map scale. A few faults with clearly visible displacements have been identified running parallel to the trends of regional fea-

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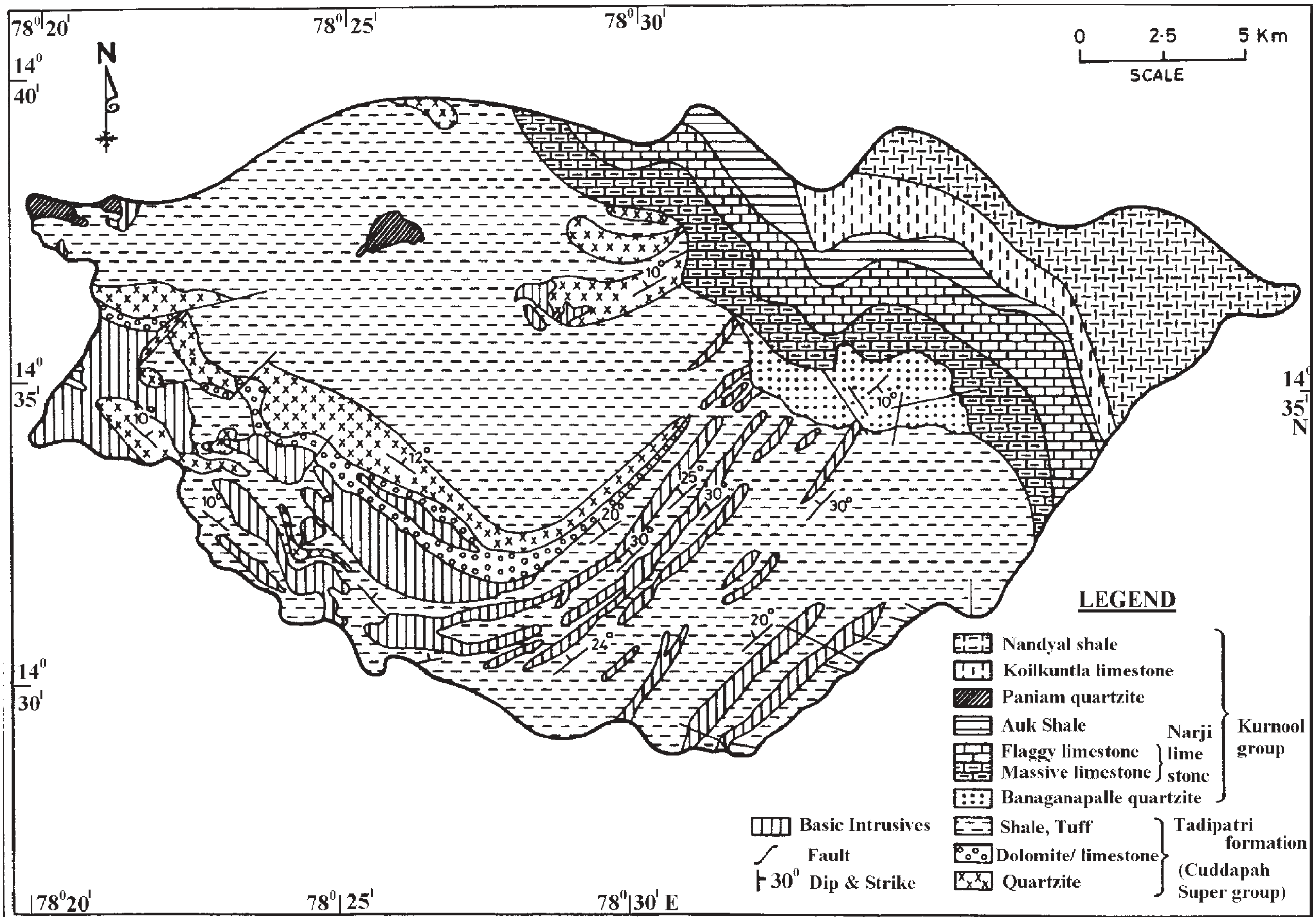

Fig. 3 Geology of Pageru River basin

tures (river drainage, lineaments, strike of formations, etc.) with some in a transverse direction to these trends (Fig. 5). The ridges of the crystalline quartzites (adjoining Uppaluru) are marked by faulting with fractures in a NW–SE direction.

The three lineament sets (NE–SW, NW–SE and latitudinal) exist all over the Precambrian region in India although the actual orientation with respect to the azimuth might differ from place to place by a few degrees (Vaidyanadhan et al. 1971). The lineaments are of varying dimensions and orientations, trending NW–SE and are roughly parallel to the trends of geological formations. A few lineaments strike E–W along the river course. The perfect linearity of the second- and third-order streams also indicates that drainage is controlled by the structural trends of these features. Thus, the Pageru River drainage pattern in general, and tributaries in particular, are controlled by the structures present in the area. The study also indicates that the maximum compressional deformation occurred in the western margin of Cuddapah basin. The interpretation of satellite data also indicates that the rocks appear to have been deformed repeatedly.

Lineament Density

After preparing 2x2-cm grids, the total length of lineament within each grid (1 km^2) was measured by a similar method as used by Haridas et al. (1994). These were plotted on the respective grid centres. These values were joined by isolines to prepare a lineament density map (Fig. 6). Quite often it was found that groundwater seepage was along certain prominent lineaments and that this property could be utilised in the search for groundwater (Vaidyanadhan et al. 1971). Lineaments are the main features that control the occurrence of groundwater in the study area. Secondary porosity is imparted by joints and fractures in the areas of higher lineament density. The lineament-density map reveals the variations in the potential for obtaining groundwater in the basin. Stephen Mabee et al. (1994), from a study of regional-scale lineament analysis for fractured bedrock aquifers, concluded that wells located on or near fracture-correlated lineaments are generally more transmissive. Although the majority of the area is underlain by Tadipatri shales, the potential for locating groundwater is moderate (central part), but there are certain significant pockets with a high density of fractures that have a comparatively high potential. There are also medium lineament-density patches

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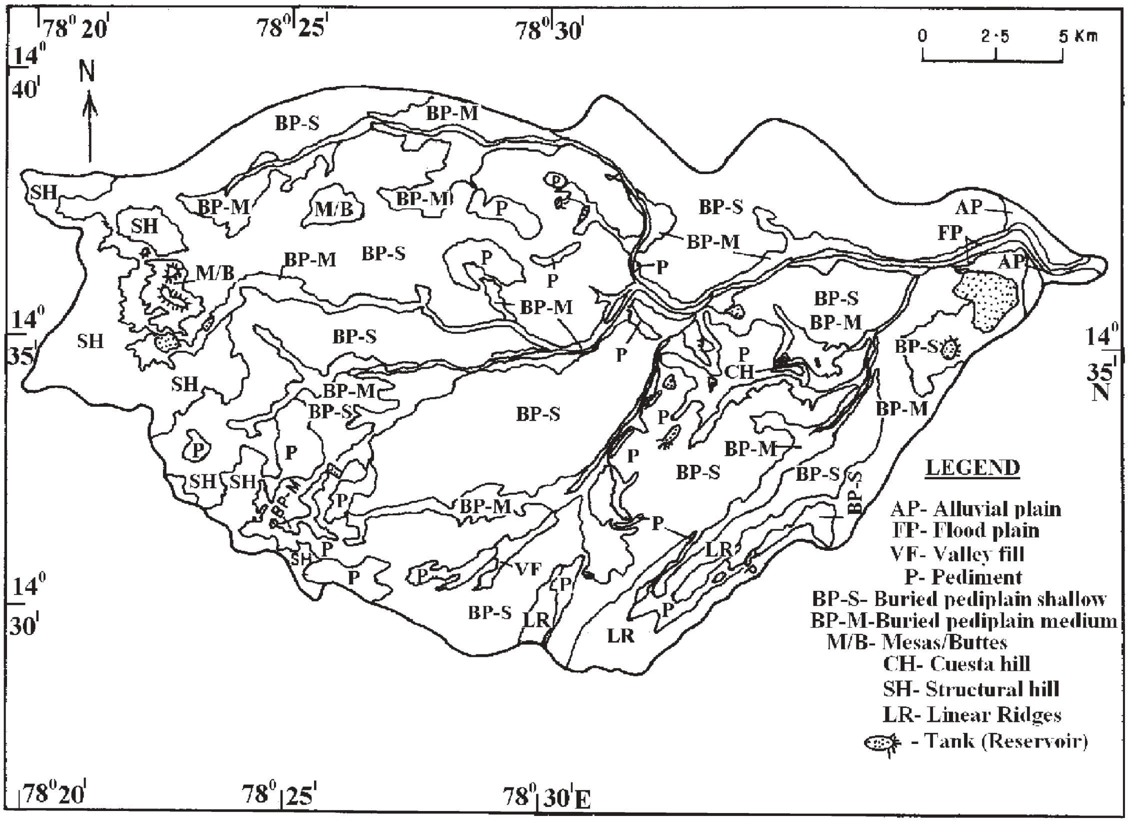

Fig. 4 Hydrogeomorphology of Pageru River basin

with limited areal extent, indicating a moderate potential distributed mostly in the central part and as small patches in other parts of the basin. A large part of the basin area, however, has a low lineament density indicating a poor potential. Based on lineament density, it is inferred that the groundwater prospects are poor in a large part of the study area.

Hydrogeology

The hydrogeological condition of the study area is controlled by the lithology, structure and geomorphology. The area is mainly divided lithologically into quartzites, shales and limestones. The groundwater in all the rock formations occurs in unconfined and semi-confined aquifers (Janardhna Raju et al. 1994). The permeabilities of all the formations depend on secondary porosity, except for alluvium where the porous material (gravel and sand) is highly permeable. Alluvium mainly occurs along the river and stream courses and the groundwater is unconfined.

The water-level fluctuations in dug wells were monitored during the pre- and post-monsoon seasons from a network of 107 wells uniformly spread over the study area in 1996–1997. The fluctuations in water levels vary from 1.7 to 7.0 m b.g.l. with a mean water level of 2.03 m b.g.l. Table 2). The total depth of dug wells ranges from 8–15 to about 30–70 m b.g.l. in bored wells.

Since it was not possible to conduct pumping tests on a large number of wells, the average seasonal fluctuations in water levels was determined to evaluate potential zones for obtaining groundwater, and to also consider the specific yield on a qualitative basis.

Pumping tests have been conducted in four different geological formations (Fig. 5), the details of which are included in Table 3.

Groundwater quality was determined from water samples collected from dug wells and bored wells. The electrical conductivity (EC) variations (post-monsoon measurements) for the entire basin were determined and classified into three categories, as shown on Fig. 7.

Geophysical Investigations

Although indirect, the geophysical methods provide information on aquifer geometry that is useful in conceptualization of the aquifer system. A vertical electrical sounding (VES) method was used and a good resistivity contrast was measured between weathered rock containing water and the hard rock without water. Thus, 112 vertical electrical soundings were carried out covering the entire study area, using the Schlumberger method of electrode configuration. Quantitative interpretation of the electrical resistivity data was made by considering the variation in the apparent resistivity for each electrode

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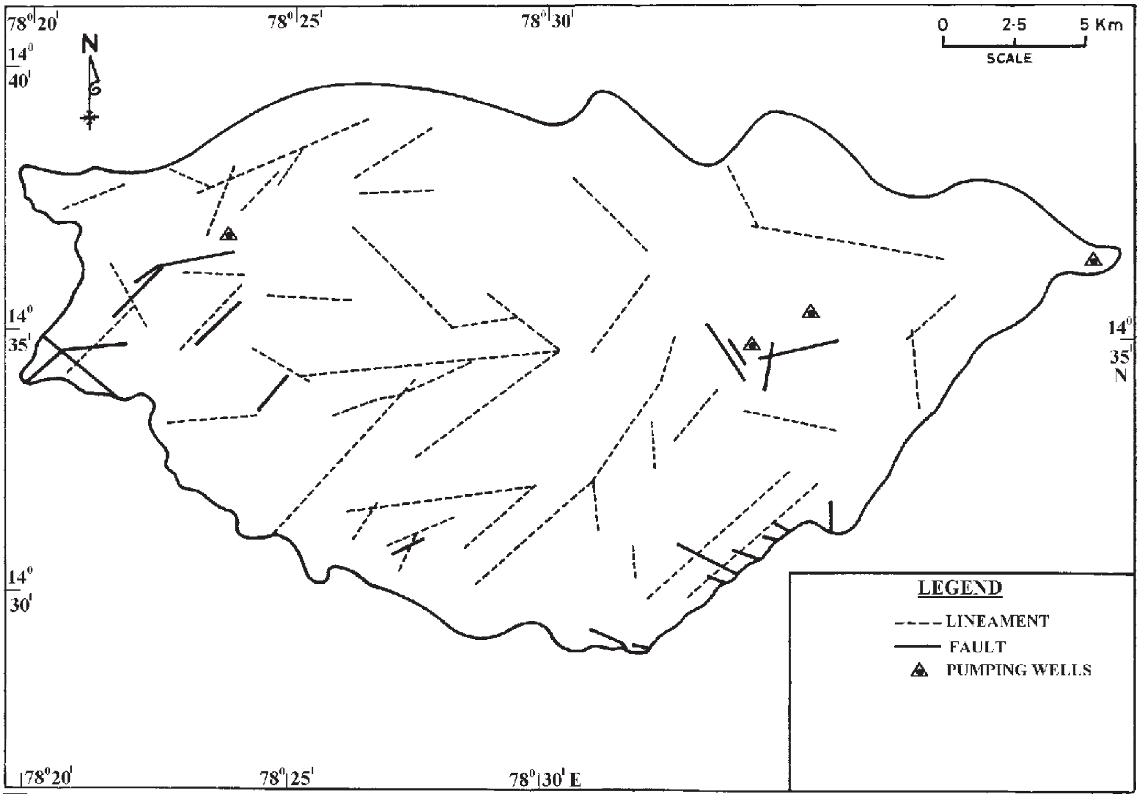

Fig. 5 Distribution of lineaments

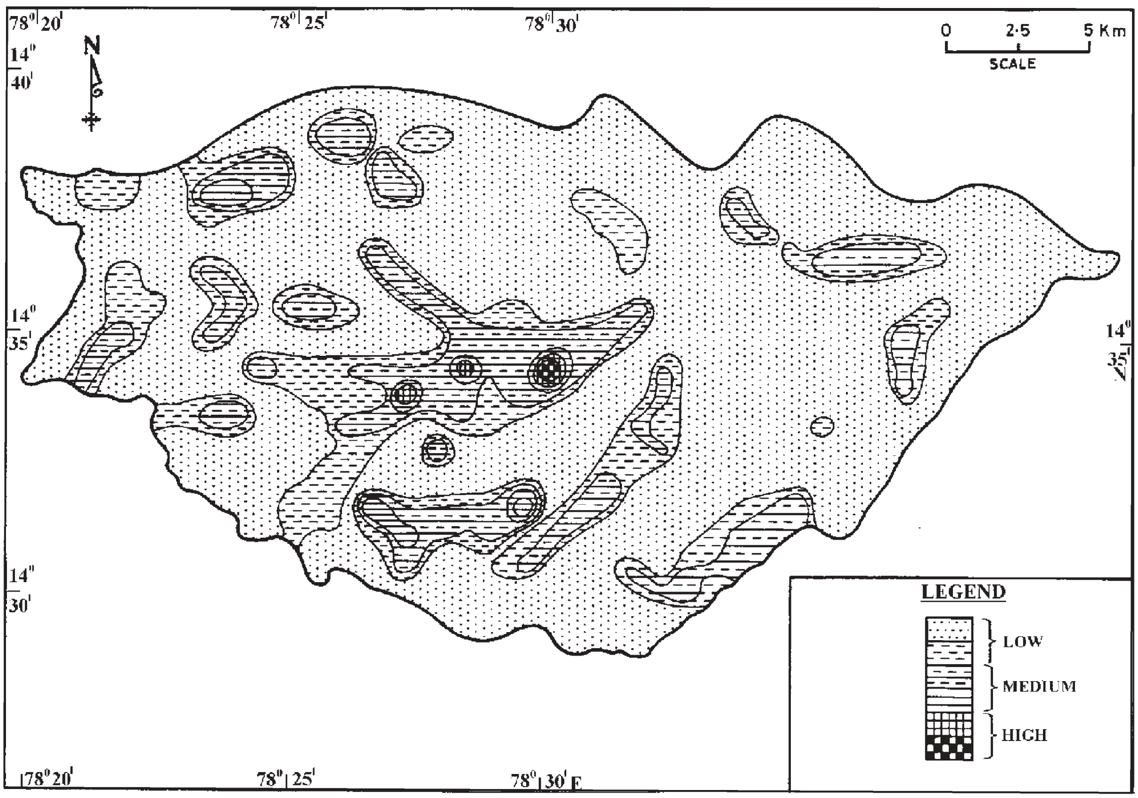

Fig. 6 Demarcation of lineament density

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Table 2 Groundwater occurence in different lithologic/hydrogeomorphological units, Pageru river basin

Hydrogeomorphological Units	Weathered zone thickness	Seasonal water level fluctuations	Resistivity in ohm-m			Potential for obtaining groundwater
			Shale	Limestone	Quarzite	
Valley fills, Flood plains, alluvial plains	-	<2m	-	26-108	-	Favorable
Shallow buried pediplains	<8m	2 to 7m	1-262	1-446	-	Moderately favorable
Moderately buried pediplais	15-20					
Pediment	<2.5	4-6	-	-	60-1053	Moderate to poor
Mesas/buttes	<1.0	<6m	-	-	42-1926	Poor
Cuesta hill						
Structural hill						
Linear ridges						

Table 3 Results of pumping tests

Well no.	Aquifer type	Transmissivity (T) (m^2/day)	Storage coefficient (S)	Specific capacity (C) (m^3/m/m dd)
1	Shale	85	0.106	0.590
2	Quartzite	72	0.027	0.645
3	Cavernous limestone	257	0.456	0.345
4	Alluvium	490	0.112	0.121

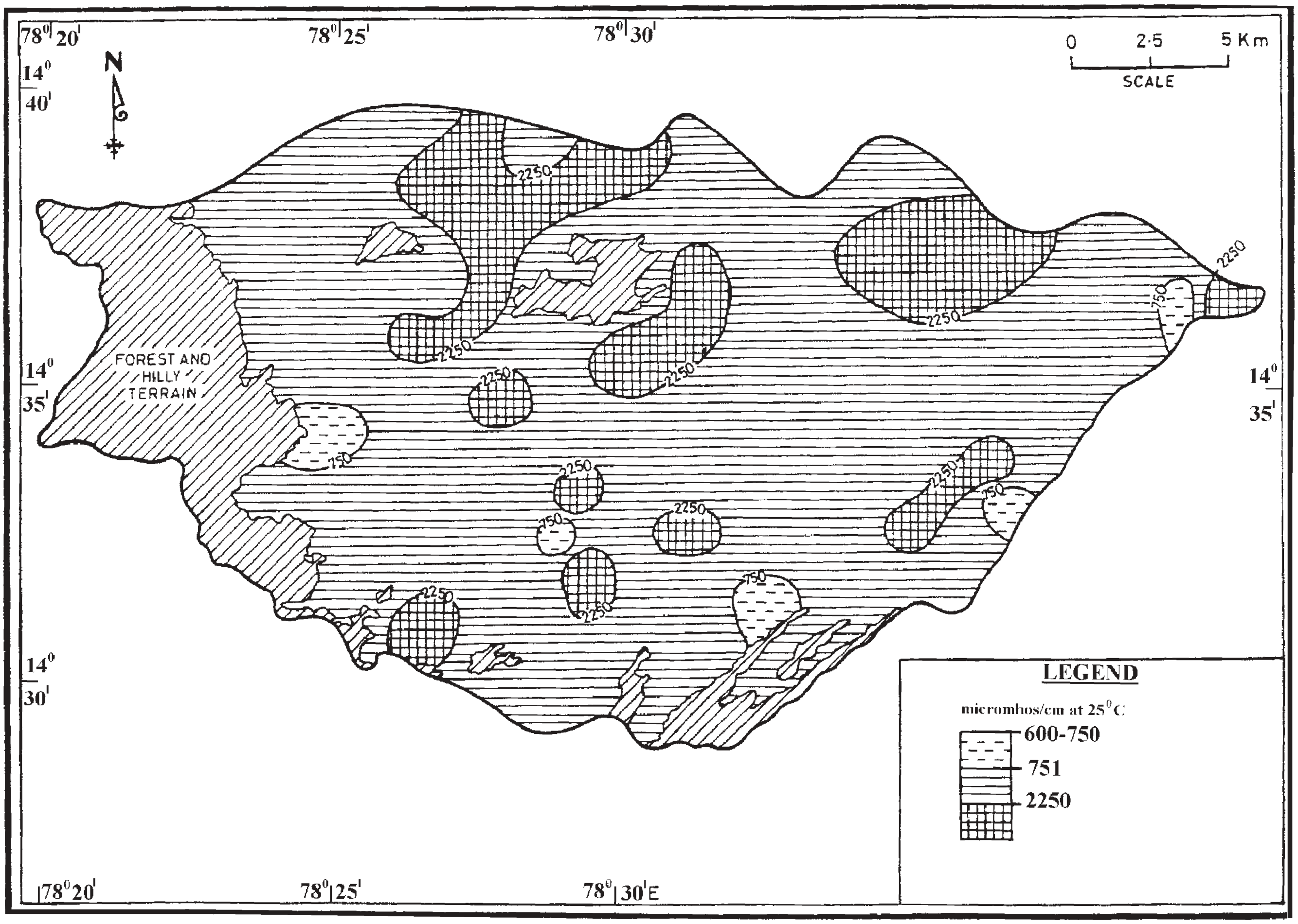

Fig. 7 Distribution of electrical conductivity values

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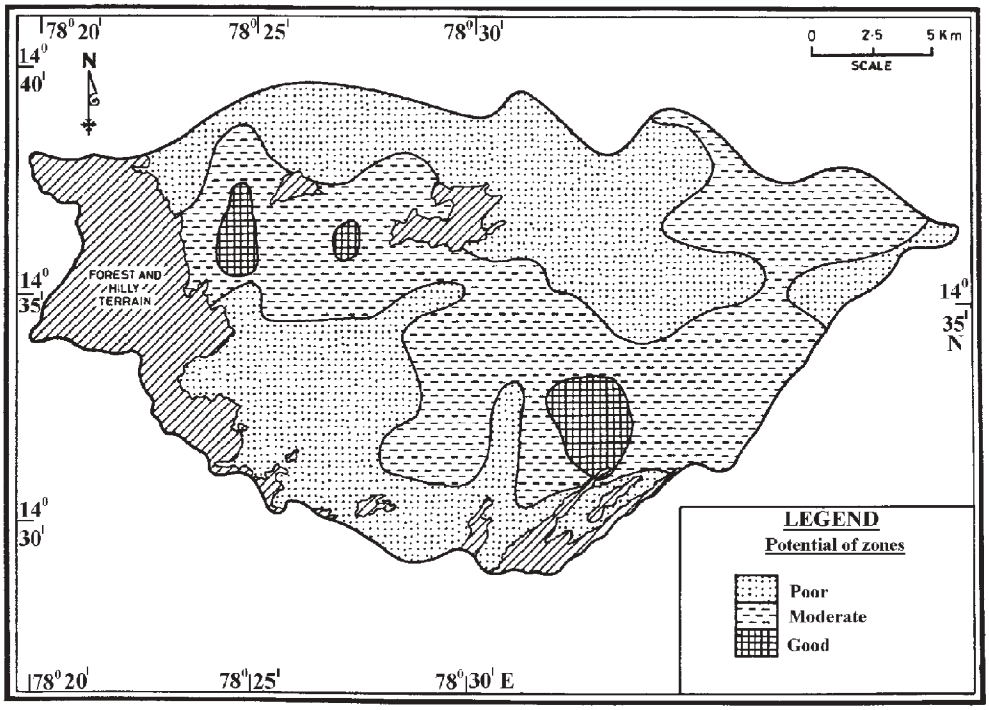

Fig. 8 Demarcation of the potential of zones for obtaining groundwater

separation, keeping the place of observation constant. Master curves depicting different geological sections for two, three and four layers with various ratios of absolute resistivities are available and were fitted with field curves to obtain absolute resistivities for the different layers. This method can provide a lot of freedom and has low ambiguity. If the subsurface consists of three layers with varying thicknesses, there will be four possible configurations for their resistivities and corresponding sounding curves (Sreedevi et al., 2001). These are:

$$\text{H type} = \rho_1 > \rho_2 < \rho_3$$
$$\text{K type} = \rho_1 < \rho_2 > \rho_3$$
$$\text{A type} = \rho_1 < \rho_2 < \rho_3$$
$$\text{Q type} = \rho_1 > \rho_2 > \rho_3 \quad (1)$$

Similarly, for four layers, there could be different configurations. A further 'A' type followed by an 'H' type is common in three-layer cases and 'KA' types followed by 'HA' and 'HH' types are common in four-layer cases. The depths to the basement derived from the sounding interpretations were in good agreement with the actual depth obtained from the lithologic data collected during the fieldwork from dug wells, dug-cum-bored wells and bored wells. This interpretation has helped us to understand the subsurface layering, degree of saturation and depth to basement of these aquifers.

Discussion and Conclusion

The geomorphology, hydrogeology and resistivity interpretations were integrated to make a map of the potential zones for obtaining groundwater (Fig. 8). The map portrays three zones as poor, moderate and good. The area where the depth to solid rock is very shallow and the saturated zone is thin is characteristic of the entire massive limestone area and is demarcated as the poor zone, which occurs at the northern and southern borders of the basin.

The zone of moderate potential occurs in the central portion of the basin between the northern and southern basin boundaries, which is occupied by poor zones in massive limestone, and also at the northeastern boundary. Almost the entire moderate zone is in shale.

The good potential zones occur mainly as two isolated patches at the northwestern portion of the basin in Tadipatri shales, near Kolavali and Vontigaripalle within the moderate zone, and a third good zone is near Payasampalle at the southeastern portion of the basin.

Remote sensing data have been used to identify zones in landforms suitable for groundwater prospecting. Groundwater development in the various geomorphic units is promising in flood plains, alluvial plains and valley fills, which are associated with thick alluvium and weathered material that has high porosity and permeability. However, only a small part of the studied area is occupied by these landforms and, hence, favourable zones for obtaining groundwater are very limited in this basin area. A large part of the area is occupied by pediments, pediplains, structural hills, and mesas and buttes that do not favour much infiltration and, hence, are generally not favourable for groundwater exploration. Irrigation suitability, based on EC and SAR (Fig. 9), shows that many of the samples fall in doubtful to unsuitable classes.

Based on the geophysical surveys, the study reveals that a large part of the area has high-resistivity layers indicating poor potential for obtaining groundwater. The potentially productive groundwater zones are identified as

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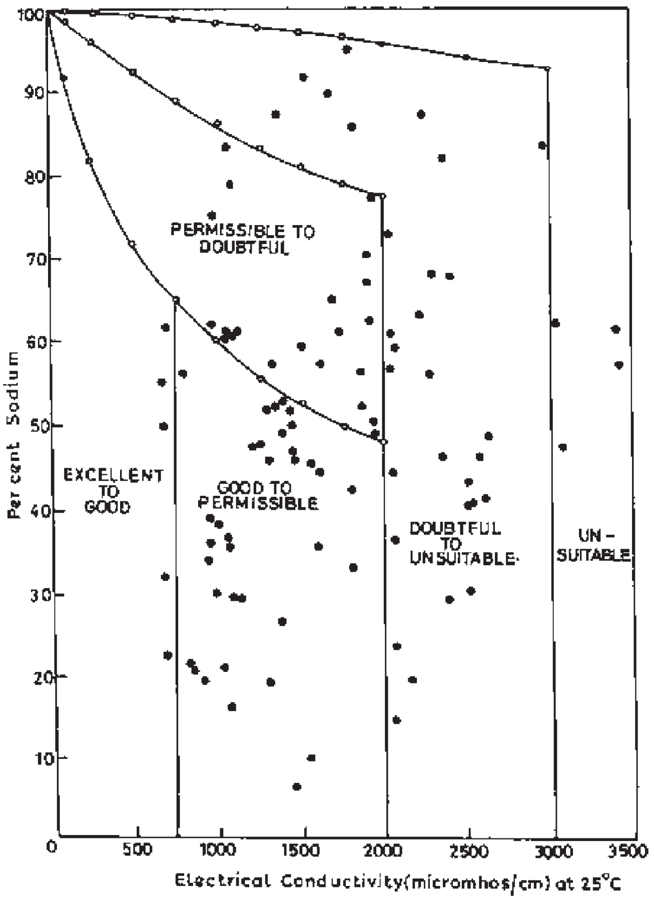

Fig. 9 Specific conductance and percent sodium relationship for irrigation waters

isolated patches located in the north-western and south-eastern parts of the region. Generally, the massive limestone and quartzite areas are demarcated as poor zones whereas the areas underlain with shale have moderate to good potential.

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References

Crawford AR, Compston W (1973) The age of the Cuddapah and Kurnool systems, southern India. J Geol Soc Aust 19(4):453–464

Dutt NVBS (1966) Note on the flux grade limestone and dolomite in Kurnool Cuddapah and Anantapur Districts Andhra Pradesh. Ind Mineral 20(2):173–179

Gowd SS, Sudheer AS, Srinvasulu S, Sreedevi PD (1998) Remote sensing analysis to delineate ground water potential zones of Peddavanka watershed Anantapur (Dist) Andhra Pradesh. Geogr Rev Ind 60(2):145–154

Janardhana Raju N, Reddy TVK (1998) Fracture pattern and electrical resistivity studies for groundwater exploration. Environ Geol 34(3):175–182

Janardhana Raju N, Reddy TVK, Nayudu PT, Kotaiah B (1994) Estimation of aquifer parameters and groundwater balance of the upper Gunjanaeru River basin Cuddapah district Andhra Pradesh. Bhu-Jalnews, Faridabad 9(3):11–15

King W (1872) Kadapah and Kurnool formations in the Madras Presidency. Mem Geol Surv India 8

Krishna M, Srinivas G (1995) Role of geological and geomorphological factors in groundwater exploration: a study through remote sensing technique. Int J Remote Sensing 16:2595–2618

Krishnan MS (1968) Geology of India and Burma. Higginbothams (pvt) Ltd., Madras, 536 pp

Krishnaswamy VS (1981) Geological and mineral map of Cuddapah basin. Geol Surv India, Calcutta

Lokesh KN, Narayana SK (1996) Geomorphological and hydrogeochemical studies of Pangala River basin (D.K), Karnataka. Hydrol J 19(1):33–43

Murthy YGK, Setti TLN, Rajurkar ST, Meoli SH, Nagaraja Rao BK, Ramalingaswami G, Madan Mohan B, Ravindra Babu R (1979) Salient features of the revised geological map of the Cuddapah Basin. Third Workshop on Status and Problems in Indian Peninsular shield. Indian Inst Peninsular Geology, Hyderabad

Narayanaswami S (1966) Tectonics of the Cuddapah basin. (7): 33–50

Palanivel S, Ganesh A, Vasanthakumaran T (1996) Geohydrological evaluation of upper Agniar and Vellar basins Tamilnadu: an integrated approach using remote sensing, geophysical and well inventory data. J Ind Soc Remote Sensing 24(3):153–168

Pandey SM, Mathur SB, Singh RB (2002) Groundwater resource development and exploration in Shahabad block of Baran district, Rajasthan. In: Thangarajan M, Singh VS, Rai SN (eds) Sustainable development and management of groundwater resources in semi-arid region with special reference to hard rocks, pp 65–73

Pascoe EH (1950) Manual of the geology of India, 3rd edn. pp 355–366

Raju KCB, Rao GVK, Kumar BJ (1989) Analytical aspects of remote sensing techniques for groundwater prospecting in hard rocks. Proc of the 6th Asian Conference on Remote Sensing, pp 127–132

Sarfaraz A, Nagi DC (1999) Hydrogeomorphological mapping for groundwater prospecting using IRS-IA LISS II images. A case study of eastern Orissa an area between the Baitrani and Subarnrekha River. J Appl Hydrol XII(4):39–45

Scheidegger AE (1973) Hydrogeomorphology. J Hydrol 20(2):193–215

Sreedevi PD, Srinivasulu S, Kesava Raju K (2001) Delineation of ground water potential zones and electrical resistivity studies for water exploration. Environ Geol 40(9):1252–1264

Srinivas Rao Y, Krishna Reddy TV, Nayudu PT (1997) Hydrogeomorphological studies by remote sensing application in Niva River basin Chittoor Andhra Pradesh. J Ind Soc Remote Sensing 25(3):187–194

Stephen Mabee B, Kenneth Hardcastle C, Donald Wise U (1994) A method of collecting and analyzing lineaments for regional-scale fractured-bedrock aquifer studies. Groundwater 32(6):884–894

Vaidyanadhan R (1962) Effects of uplift and structure on drainage in the southern part of the Cuddapah Basin. J Geol Soc Ind 3:70–85

Vaidyanadhan R (1967) An outline of the geomorphic history of India south of N. lat18°. Proc. Seminar on Geomorphological Studies in India, pp 121–130

Vaidyanadhan R, Ramana Rao KLV, Pradhasarathi YJ (1971) Lineaments and their importance in landform studies. J Geol Soc Ind 12(3):299–302

Wadia DN (1957) Geology of India, 3rd edn. McMillan and Co., Ltd., London

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