J. Ind. Geophys. Union (2003)
Vol.7, No.2, pp.105-113

Geo-Electrical data analysis to demarcate groundwater pockets and recharge zones in Champavathi River Basin, Vizianagaram District, Andhra Pradesh

P.Jagadeeswara Rao, B.Suryaprakasa Rao, M.Jagannadha Rao[1] and P.Harikrishna

Department of Geo-Engineering, Andhra University, Visakhapatnam – 530 003

[1]Deparement of Geology, Andhra University, Visakhapatnam - 530 003

ABSTRACT

Investigations have been made for groundwater exploration and artificial recharge for groundwater augmentation in Champavathi River Basin area (CRB), Vizianagaram District of Andhra Pradesh following the concept of watershed. The basin has a drainage area of about 1410.87 sq.km. The area comes under the Eastern Ghat Mobile Belt (EGMB) consisting of Precambrian formations of high grade metamorphic rocks, constituting khondalites, charnockites, quartzites, migmatites and calc-granulites.

Groundwater potential zones and recharge pockets have been identified based on hydro-geological data and geo-electrical data. Based on these studies groundwater potential of the area is categorised as good, medium and poor. Over 80 wells have been monitored to assess and 48 Vertical Electrical Soundings (VES) have been carried out. The primary parameters r and h and the Dar Zarrouk parameters T, S, and λ are determined to demarcate groundwater potential zones and artificial recharge sites. Vertical geo-electrical sections and spatial distribution of secondary parameters are constructed. The areas with 1.0 and less than 1.5 anisotropy are considered for groundwater potential zones and for recharge pockets. This range of anisotropy indicates high porosity and permeability.

INTRODUCTION

Scarcity of groundwater is a major problem in hard rock terrain of Eastern Ghats of which Champavathi river basin is a part. Suitable exploration technique and thorough geological knowledge are essential to delineate groundwater aquifers. It is essential to find out suitable locations for recharging structures in hard rock terrain as rain fall is erratic or even may fail sometimes. Radhakrishna (1998) suggested harvesting of rain water from rooftops and storing it in tanks for water conservation in hard rock terrain. He also suggested steps for storing rainwater in large underground cisterns at vantage points. Vasudev, Murthy & Nagamalleswara Rao (2002) suggested check dams and recharge pits in a micro watershed of the Champavathi river basin. In the present study, attempts have been made to delineate groundwater potential zones and recharge pockets on the basis of the geo-electrical results, geological and hydro geological conditions using the concept of watershed.

The Champavathi River Basin (CRB) is located in Vizianagaram District of Andhra Pradesh bounded by 18^0 0' – 18^0 28' 30" N. Lat and 83^0 2' 30" – 83^0 36' 15" E Long. The river originates at an altitude of 1200 m above msl in Andra hilly area and joins the Bay of Bengal near the village, Konada (Lat 18^0 2' N and Long 83^0 34' 20" E). The river has four main tributaries namely Eduvampula Gedda, Chitta Gedda, Pothula Gedda and Gadi Gedda and has a drainage area of about 1410.875 sq.kms (Fig.1). The CRB is in the physiographic province of northern Eastern Ghats. Physiographically, the area is divisible into 1) Hilly terrain (Madugulakondas) 2) Vizianagaram plains with isolated hillocks and 3) Coastal plains.

Champavathi River is a non-perennial and medium category watershed (Rao 1979). It flows through rain fed cultivated areas.

GEOLOGY

The general stratigraphic succession of geological formations occurring in the study area is given in Table 1. Geological formations and their structural features are shown in Fig.2.

Table 1. Stratigraphic succession of geological formations in Champavathi River Basin.

Age	Formations	Lithology
Recent soils	Alluvium	Soils, sands, silts and clays.
	Younger intrusives	Pegmatite's and quartz veins
		Porphyroblastic charnockite
		Porphyritic granite gneiss
		Garnet biotite gneiss
Archaeans	Migmatites	Migmatised quartzites
		Cordierite biotite gneiss
		Migmatised sillimanite gneiss
	Older intrusives	Quartzo feldspathic gneiss
	Charnockitic suite	Charnockites
		Pyroxene granulites
	Khondalitic suite	Garnet sillimanite gneiss
		Quartzites
		Calc-silicate rocks with or
		Without manganese

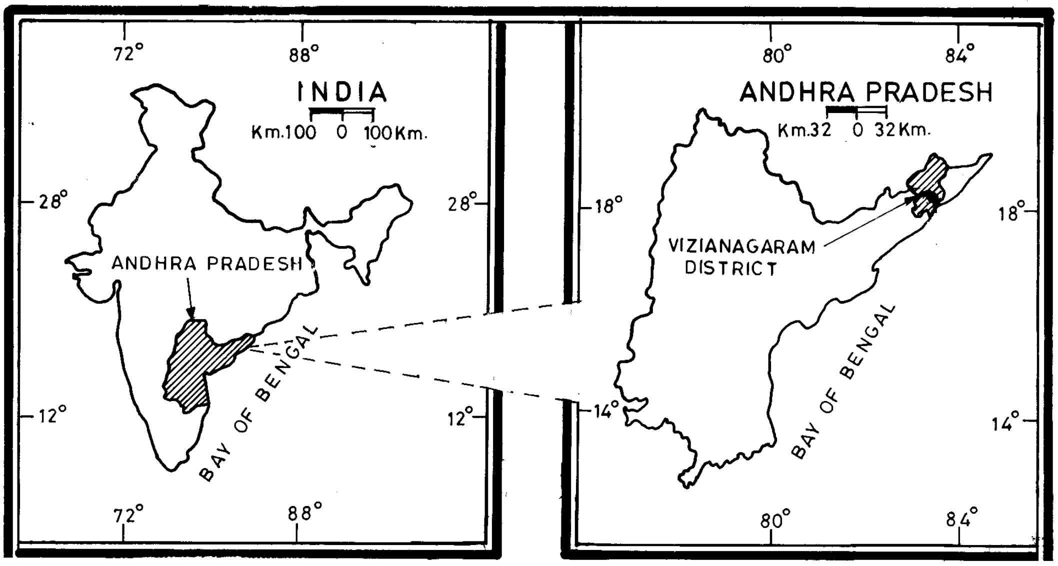

Figure 1. Location map of the study area.

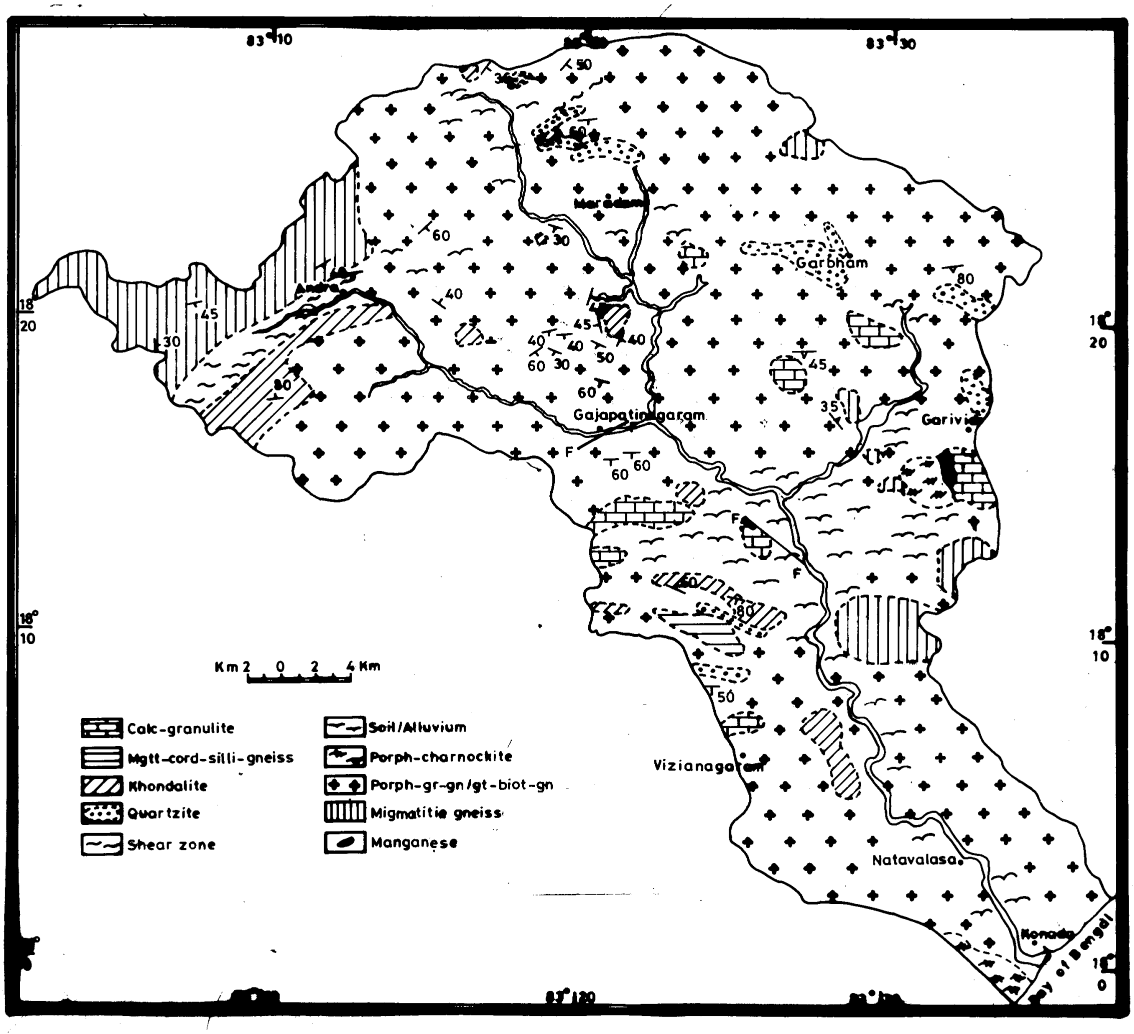

Figure 2. Geology of the study area.

The upper catchment of the river basin is covered by porphyritic granite gneiss and the lower catchment by garnet biotite gneiss. West of Andra, huge hill ranges consist of khondalite rocks having strike direction of east west and dipping 80^0 NE. Khondalites are best exposed west of Pathamunginapalle, south of Nellimarla, east of Nelivada, east of Ramabhadrapuram, south of Kayllam having strike of NE-SE and dipping 40^0 SW. The trend of the hill ranges and strike of the foliation of the khondalite is NE-SW. At places, the strike varies from NNE-SSW to ENE-WSW. Near Gajapathinagaram, the strike of the formation is NE-SW with dip of 50^0 SW. A fault in NE-SW passes through this area.

Calc-silicate rocks form low hillocks in northwest of Ambativalasa and are associated with manganese ore bodies. They occur as elongated E-W outcrops and have very good foliation, which is considered to be of bedding that strikes NW-SE and EW. These are invariably tight folded and have well developed cleavage with characteristic ribbed weathering. Quartzite is present as alternate bands within khondalite rock at places. Quarzites occur as bands parallel to the strike of the foliation of the Khondalites. Migmatite outcrops are exposed west of Andra village. Most of these hill ranges have strike direction of NE-SW and dip 30^0 to 40^0 E. In this area, a shear zone separated the khondalite suite of rocks from Migmatite gneiss. An intrusive charnockite massif is located near Pedabantupalle.

NATURE OF AQUIFER

Groundwater in the study area occurs under phreatic and semi-confined conditions, the hydro-geological regime of the area is influenced by the Champavathi river. Out of the 80 observation wells inventoried covering the entire area, 18 are in hilly terrain, 57 in Vizianagaram plains and 5 in coastal plains. However, a limited number of wells reflecting the terrain conditions in all the three physiographic zones are summarized (Table 2). The static water levels in pre-monsoon and post-monsoon range from 12.10 to 1.72 m bgl and 6.6 to 1.15 m bgl in the area respectively.

The top layer consists of red soil/ sandy loam and laterite soils with a total thickness of 2-10 m. This layer is underlain by weathered zone inturn underlain by hard rock at many places. But in a few places the weathered zone is followed by fractured zone. These zones together have the thickness of about 50 - 80 m has been inferred from the well inventory and soundings. The highest water table fluctuation is observed in hilly terrain and medium to the lowest in Vizianagaram plains and coastal plains. Various landforms formed by the river in the area influence the occurrence, distribution and fluctuations of the water table.

ANALYSIS OF GEO-ELECTRICAL DATA AND RESULTS

Schlumberger method of electrical resistivity technique has been adopted to delineate the subsurface lithological configuration, aquifer characteristics and depth to bedrock.

In this study, 48 VES (Vertical Electrical Soundings) have been carried out to cover the area (Fig.3) and maximum electrode separation (AB/2) is restricted to 100 m. This has been decided based on well inventory data which shows that the rock is as shallow as 20 - 50 m below ground level. A few soundings are conducted up to 120 – 150 m in Khondalite pockets. The soundings cover the major physiogrpahic units hilly terrain, Vizianagaram plains and coastal plains of the basin.

Field curves are matched with theoretical curves prepared by Orellana & Mooney (1966) using two and three layer master curves and auxiliary charts. In general A, K, H, HA and KH type curves are obtained representing three to four layer subsurface set-up .

Interpretation of resistivity data

The resistivity results (ρ,h) are represented in three profiles, which are reckoned as A-A', B-B' and C-C'. These profiles covering three physiographic units are summarized below.

Subsurface geo-electrical section along A-A'

The top soil layer has a resistivity of 7 to 163 ohm m with a thickness of 3 to 5 m. This layer consists of red soil and sandy soil at different sounding locations. Sandy soil resistivity is in the order of 151 to 163 ohm m and its thickness is 3 m at sounding 13 (Pathamunginapalle). The depth of weathered rock extends up to 10 m at sounding numbers 21 and 22 and it increases towards the sounding 9 and 13. Maximum thickness of weathered zone is expected at sounding 13 (Fig.4). The khondalite and migmatite gneiss are overlaid by weathered zone. Fracture zone is expected up to 100 m at sounding location 13. The nature of sounding curve is the criterion to demarcate the fractured zone in the hard rock area. This is qualitatively considered based on the deviation of last segment of the curve from 45° angle. In some cases the occurrence of fractured zone is indicated by the type curves AK and HK.

Subsurface geo-electrical section along B-B'

The vertical geo-electrical section along B-B' is shown in Fig.5. The resistivity of top soil layer varies from 10 to 104 ohm m and the thickness from 2 to 10 m. In this profile, the top layer consists of red soil. Sand pockets are overlaid by red soil at Lingalavalasa Agraharam and Budarayavalasa villages. In the

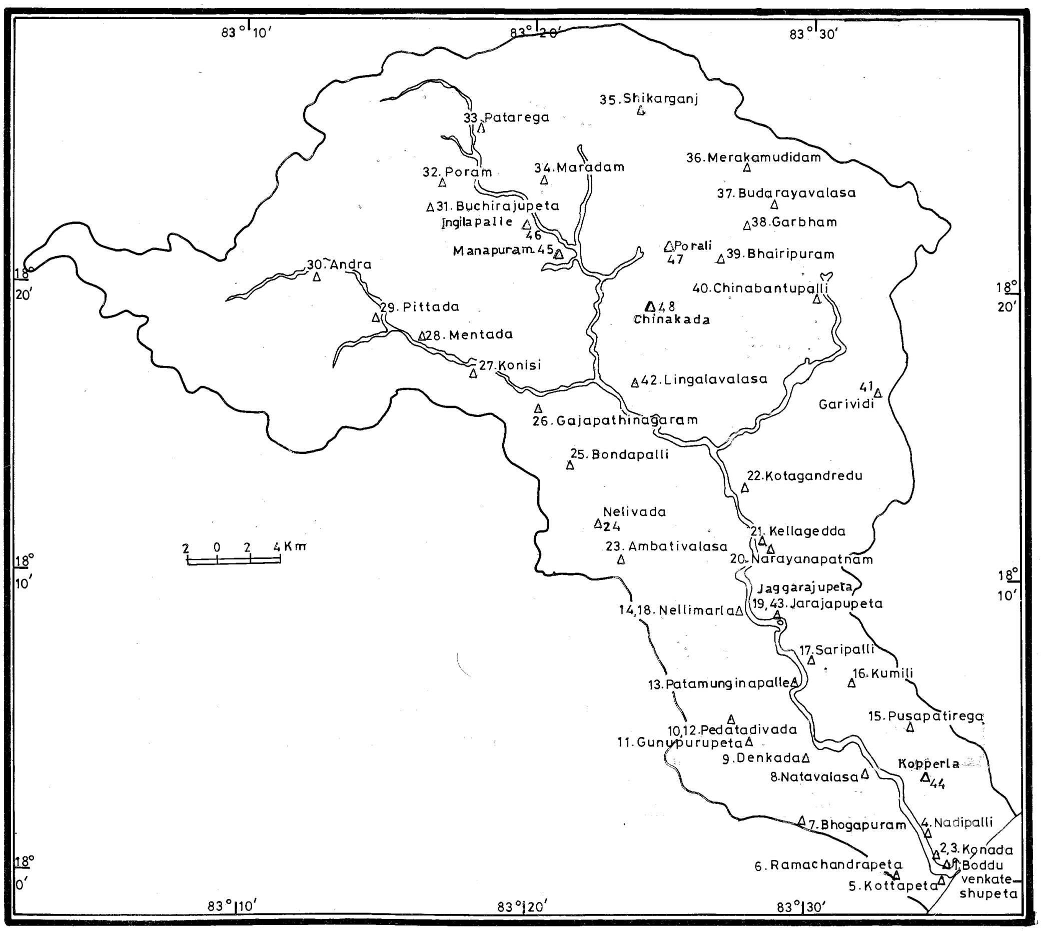

Figure 3. Vertical electrical sounding locations in the study area

Table 2. Well inventory data.

Physiographic division	Name of the village	Depth to water table (m) (Premonsoon)	Depth to water table (m) (Post-monsoon)	Fluctuation (m)	Lithology
Hilly terrain (18 wells)	Andra	8	3.65	4.35	Redkankar, Weathered khondalite
	Denkada	6.8	6.2	0.6	Sandy clay, weathered garnet biotite gneiss
Vizianagaram plains (57wells)	Gajapathinagaram	8.5	4.85	3.65	Weathered garnet biotite gneiss
	Bondapalle	8.35	5.9	2.45	Unconsolidated calcium carbonate, weathered khondalite
	Garividi	5.8	1.8	4	Weathered calc-silicate
Coastal plains (5 wells)	Konada	1.72	1.35	0.37	Sand dunes, sandyclay, weathered garnet biotite gneiss
	Natavalasa	7.4	5.2	2.2	Redkankar, weathered garnet biotite gneiss

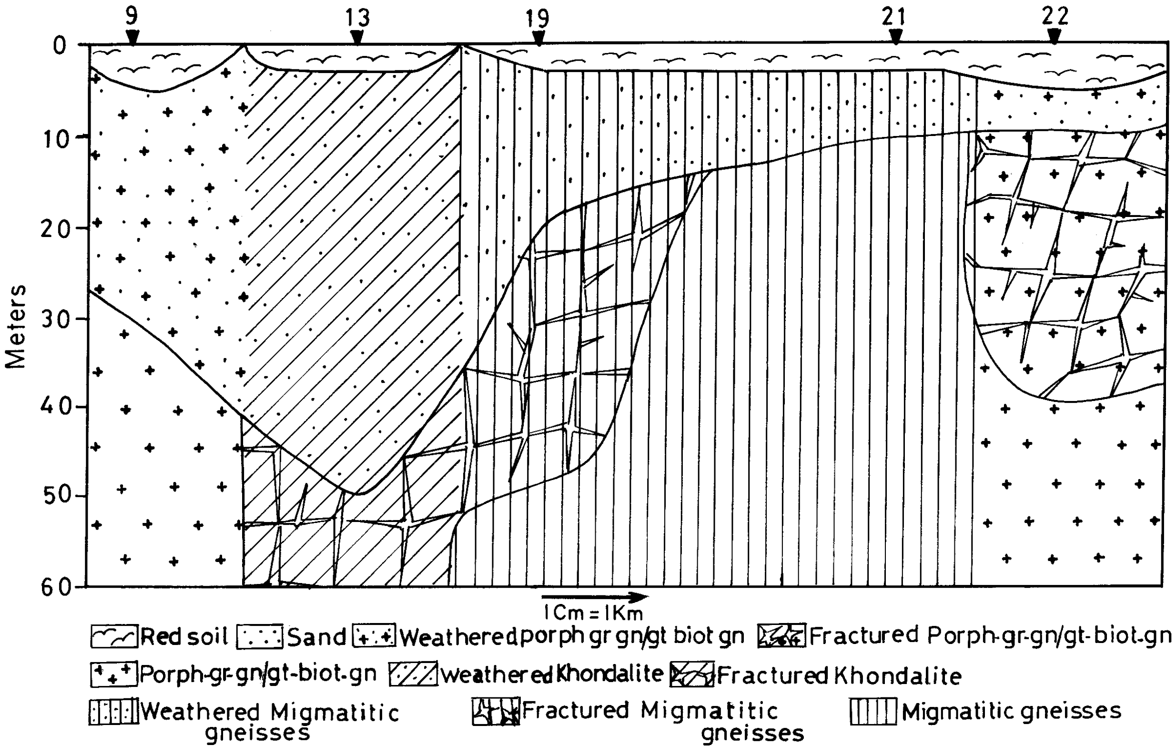

Figure 4. Subsurface geo-electrical section A-A'

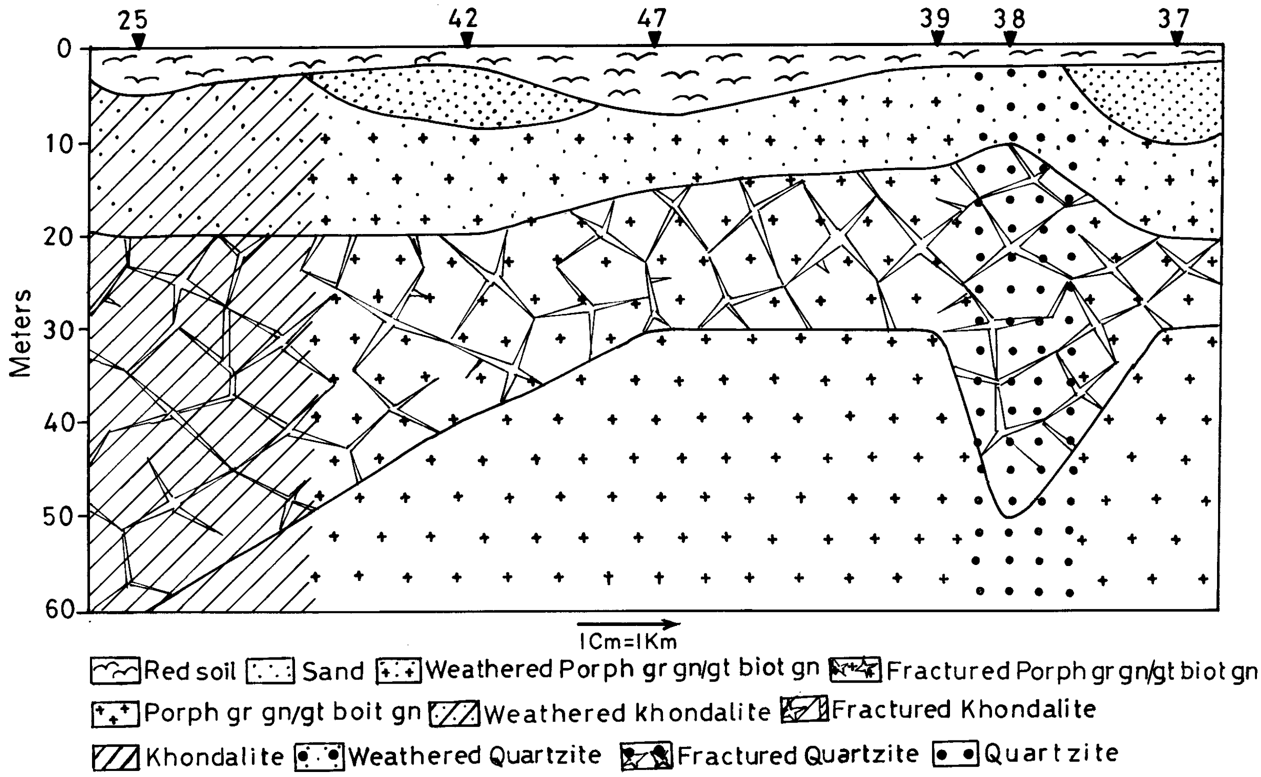

Figure 5. Subsurface geo-electrical section B-B'

sandy layer, resistivity varies from 19 to 41 ohm m with a thickness of 6 m at Lingalavalasa and 8 m at Budarayavalasa. Thereafter, the weathered rock has a thickness of 10-20 m. The resistivity varies from 8 to 27 ohm m. Weathered rock is underlain by hard rock with fractures. The fractured zone thickness extends from 30-60 m. Hard rock at shallow depth is expected in Chinakada and Bhairipuram villages with resistivity of 80-103 ohm m. Lithological units identified along this section are garnet biotite gneiss, porphyritic granite gneiss, khondalite, calc-silicate and quartzite.

Subsurface geo-electrical section along C-C'

Soil has 2.5 to 60 ohm m resistivity with 2 to 5 m thickness. The soil layer consists of three types of soils, sandy soil, red soil and laterite soil. Sandy soil has a resistivity of 3-12 ohm m with a thickness of 5 m at soundings 1 and 2 (Bodduvenkateshupeta and Konada). The red soil has resistivity of 13 - 20 ohm m and has a thickness of 5 m at Pusapatirega. The resistivity of the weathered zone is 8 - 45 ohm m. Weathered rock of the highest thickness of 50 m rock is expected at Nadipalle.

Fractured and massive hard rocks are garnet biotite gneiss and charnockite along this profile. These are underlain by weathered rock. Fracture zone at the sounding of Nadipalle is expected up to a depth of 100 meters (Fig.6).

Dar Zarrouk parameters for aquifer characteristics

Commonly a geo-electrical section constructed from the analysis of VES data does not coincide with the corresponding geological sections. Layers of different lithology or ages or both may have the same resistivity and they form a single geo-electrical layer. Anisotropy of the subsurface layers is another factor which would introduce errors in the estimates of true resistivity and depths in the interpretation of VES curves. Maillet (1947) introduced secondary resistivity parameters, transverse resistance (T) and longitudinal conductance (S) and coefficient of anisotropy (λ). The parameters are determined for the study area as they are significant in understanding the subsurface lithology.

The graphical procedures are discussed by Kalenov (1957), Kunetz (1966), Keller & Frischknecht (1966). The application of these parameters is discussed by Satya Kumar K (1979), Rama Rao (1980), Prakasa Rao (1983) and Venkateswara Rao (2002) in different geological conditions. The aquifer resistance (Average resistivity x Aquifer thickness) proposed by Venkateswara Rao (2002) has been used in the present study.

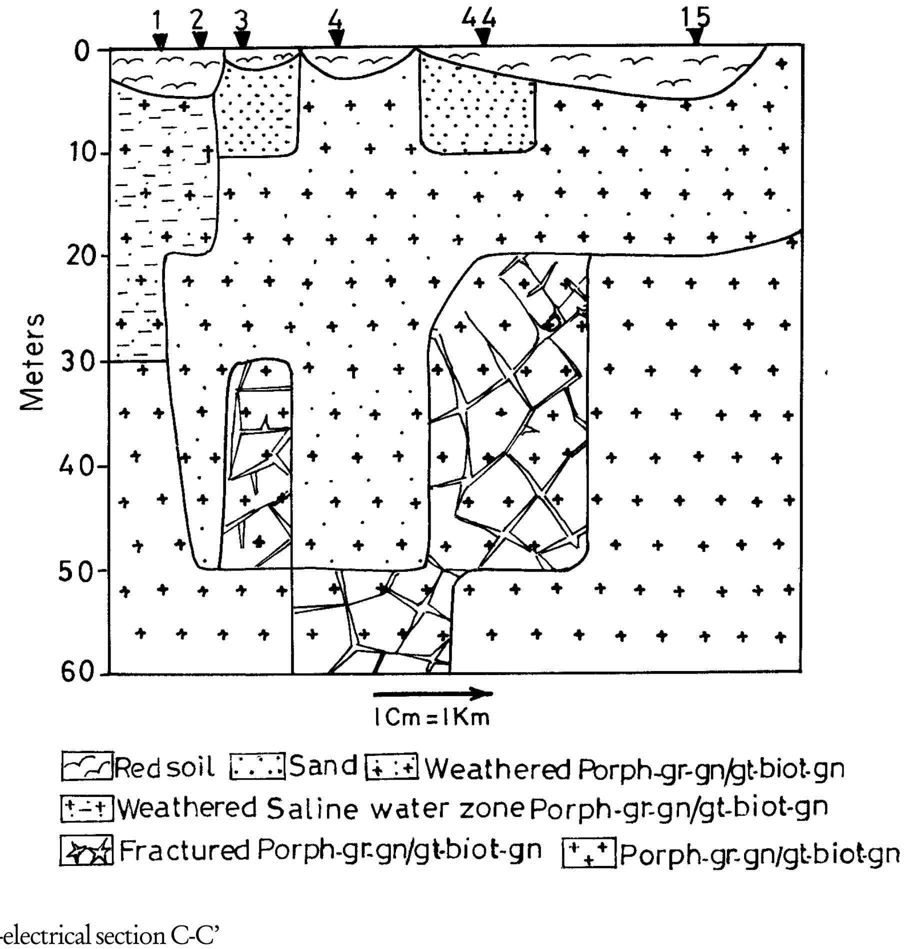

Figure 6. Subsurface geo-electrical section C-C'

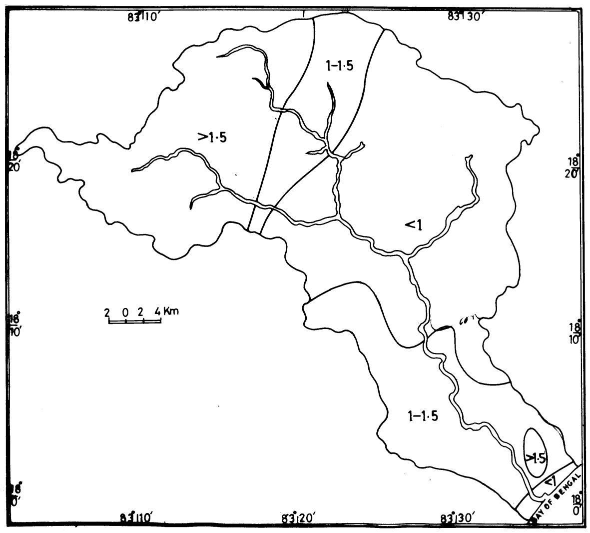

Figure 7. Variation of coefficient of anisotropy in the study area

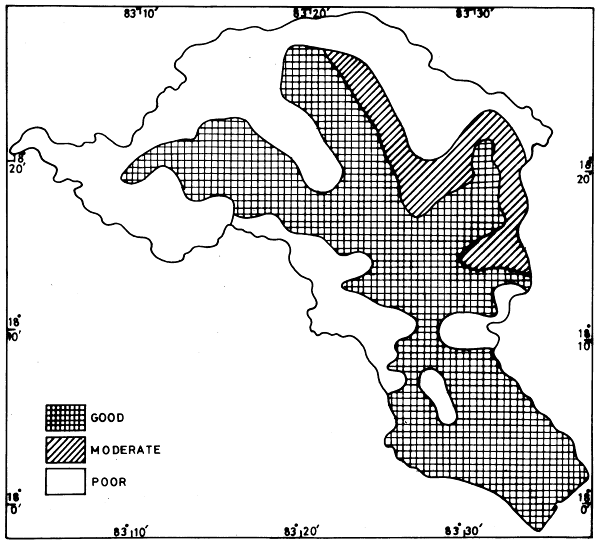

Figure 8. Groundwater potential zones in the study area

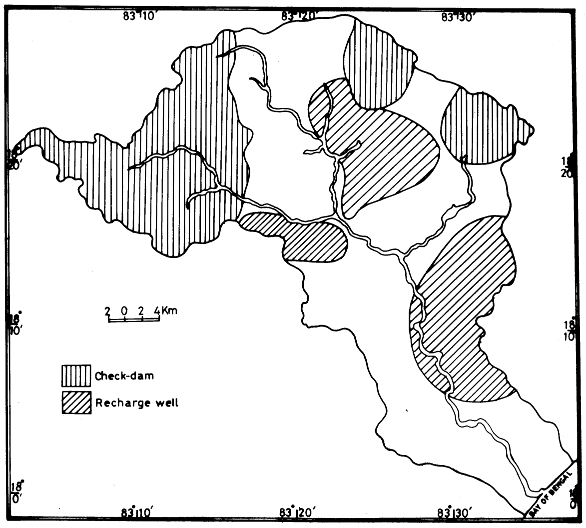

Figure 9. Areas of artificial recharge in the study area.

Longitudinal unit conductance and Transverse unit resistance (S & T)

The longitudinal unit conductance values vary from 0.43 to 2.56 mhos in the study area. The qualitative use of this parameter is to demarcate changes in total thickness of low resistivity materials (Henriet.1976; Galin 1979; Rajesh Raghunath, Sreedhara Murty & Uday Shankar 2002). In the upper part of the river basin beyond Pittada and Arikathota, the longitudinal conductance is more than 2 mhos, in conformity with hilly terrain of the area. A similar patch is also seen towards north east corner of the basin. About sixty percent of the basin area has a range of 1 to 2 mhos range revealing rock at deeper depth. This in turn indicates potential groundwater pockets in the area. Transverse unit resistance (T) varies from 200 to 9000 ohm.m^2 in the basin. The higher values from 3000 to 9000 ohm.m^2 are mostly seen in the area where hard rock at shallow depth. The range from 600 to 1200 ohm.m^2 is also considered as a criterion for identification of aquifer zones.

Coefficient of anisotropy (λ)

The values of anisotropy ranges from 0.3 to 2.0 in the basin area (Fig.7). Generally, the co-efficient of anisotropy is 1 and does not exceed 2 in most of the geological conditions (Zohdy. Eaton & Mabey 1974). Compact rock at shallow depth increases the coefficient of anisotropy (Keller & Frischknecht 1966). Hence, these areas can be associated with low porosity and permeability. The areas with 1.0 and less than 1.5 anisotropy are considered for groundwater potential zones with high porosity and permeability. Geologically, these areas have with khondalite, migmatite, calc-silicate, and gneiss in the study area. These permeable zones of sufficient thickness are indicated in Vizianagaram plains and coastal plains. More than 2, 'λ' value indicates hard porphyritic granite gneiss and garnet biotite gneiss terrain of the basin.

Groundwater potential zones

The areas with less than 1.5 anisotropy value are considered as potential aquifers for groundwater exploitation. Medium aquifer resistance, and fracture zones identified from qualitative assessment of data, are also considered as potential zones of groundwater. The aquifer thickness of 15 to 30 m is considered mapping medium potential zones in the case of soil and weathered layers, and 30-60 m in the case of fracture zones as good potential zones. The potential zones are divided into good (50-150 ohm.m) and medium (150-250 ohm.m) potential zones based on the thickness of the aquifer. The aquifer zones with an aquifer thickness of 40 m or more is considered as good and 30 m as medium and less than 20 as poor including soil layer. Alluvial aquifers, fractured zone and valley fills with anisotropy value around 1 are recognised as good groundwater potential zones. The villages Marupalli, Manapuram, Chinakada, Saripalli and Natavalsa comes under this category.

The groundwater potential under category one are also identified in Vizianagaram plains, coastal plains and to the east of Bondapalle (Fig.8). The location of the villages with good groundwater potential indicates that the potential increases from north towards south in the basin. Medium potential zones are demarcated where anisotropy is 1.5. The villages comes under this category are Poram, Maradam, Garividi Bondapalli, in the norhern part of Gharbam, Bhairipuram, Garividi in the north eastern part and north and south of Kotagangrdu in the middle part of the basin. Thick and with low resistivity pockets demarcate the groundwater potential zone in hard rock terrains (Balakrishna et al. 1983; Patangay & Murali 1984; Balasubramanian, Sharma.& Sastri 1985). But very low 'S' values are not considered to demarcate potential zones in the study area, because they may indicate clay pockets in khondalitic terrain and seldom in the other rock terrains .

Areas for artificial recharge

As the study area is rain fed, recharge zones are demarcated based on soils, geological information, water table condition and geo-electrical results. Urbanization and industrialization in the area have increased groundwater mining, resulting in groundwater table depletion to an alarming level. Therefore, the recharge systems are essential to replenish groundwater table to avoid drought conditions. Vasudev, Murty & Nagamalleswara Rao (2002) have suggested check dams and recharge pits based on rain fall data and evaluated their function in a micro watershed of this study area. Without prior study of soil and water table this type of approach based on rainfall alone may not give appropriate results. Recharge systems based on only Remote sensing studies (Chourasia 2001; Ramalingam & Santha Kumar 2002) have been suggested, where depth of soil and aquifer thickness cannot be determined. But no studies are available based on geo-electrical and hydro geological conditions, which is a better approach to locate suitable zones for recharge structures. The zones subjected to artificial recharge must have deeper water level condition, otherwise artificial recharge would lead to water logging (Rajesh Raghunath, Sreedhara Murty & Uday Shankar 2002). The above methodology is applied in the present area to recommend zones for rock fill dams, check dams and contour bunding in the upper reaches, and infiltration wells at village, town and industry level for rain water harvesting (Fig.9). These recharging structures are in use in a few cities in Andhra Pradesh (Venkateswara Rao 2000).

The important consideration for recharging aquifer system in hard rock areas is soil porosity, permeability, soil thickness and low groundwater table. The areas with 1.0 and less than 1.5 anisotropy are considered for recharge pockets. This range indicates high porosity and permeability. Rock fill dams and checks dams are recommended for second order streams and contour bunds almost at foothill level. These are suggested to reduce sediment transport and silting of the downstream tanks, to arrest flash floods and to recharge underground reservoirs.

The water table in the present study area is as low as 6 to 12 m b.g.l. It ranges from 7 to 9 m from Maradam, and Buchirajupeta to Lingalavasa in the north with sandy loams as top soil. Rain water harvesting from roof tops through recharge wells is suggested for this area. The water table of 6 to 8 m with similar type of soils indicated in Kellagedda to Natavalsa area in the suthern part of the basin . Rock fill dams , check dams and countour bunds are suggested around Andra, Pittada, Mentada, Shikarganj and east of Garbham in the northern part of the basin, because of comparatively less soil thickness and shallow rock.

CONCLUSIONS

Geological and geohydrological studies followed by geophysical studies made easy to locate feasible groundwater pockets like valley fills, weathered zones and fractured zones in the study area. The studies also helped to make possible to demarcate thick soil pockets followed by considerable thickness of aquifers as recharge pockets. A few weathered pockets which are located in Khondalite zone indicating low apparent resistively value ($<$ 10 ohm.m) are discarded for groundwater development due to clayey nature of the aquifer.

Geological structures like fractured zones and faults are confirmed by geo-electrical survey and suggested for bore wells to a depth of 70 to 80 m from the ground surface. These pockets are indicated by marginal T values from 600 to 1200 ohm m^2. The range of S values of 1.5 - 2.0 mhos is considered for open wells.

Extensive groundwater mining due to population, urbanization and industrialization results in the water table depletion to alarming levels and hence artificial recharge zones are identified based on soil thickness and permeability evaluated from apparent resistively values. Water table is also taken into account in the zones demarcation. Check dams are suggested on second order streams in the northern part of the basin. Check dams in the upper reaches of the basin will control the siltation to minor irrigation tanks below. Roof top recharge through shallow dug wells at village level and urban areas will control inundation in low-lying areas of the basin. The recharge structures would also improve the groundwater quantity and quality .

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Geo-Engineering for providing facility in carrying out resistivity survey. Authors also acknowledge the AICTE for utilizing the computer facility created under TAPTEC project. Critical and constructive review of the manuscript by the reviewers is greatly appreciated.

REFERENCES

Balakrishna, S., Subramanyam, K.,Gogte,B.S.& Venkatanarayana, B., 1983. Groundwater investigations in the union Territory of Dadra and Nagar Haveli, Geophys Res. Bull., 21, 347-359

Balasubramanian, A., Sharma,K..K. & Sastri,J.C.V., 1985. Geoelectrical and hydrogeochemical evaluation of coastal aquifers of Tambraparni basin, Tamil Nadu, Geophys. Res. Bull., 23, pp.203-209.

Balasubrahmanyan,M.N., 1978. Geochronology and geochemistry of Archaean tonalitic gneisses and granites of South Kanara district, Karnataka state, India, In Archaean geochemistry, pp.59-78, eds. Windley, B.N. & Nagvi, S.M. Elsevier..

Chourasia,L.P., 2001. Application of Geographic information system and Remote sensing for identification of Artificial recharge and groundwater exploration, Workshop W5 July 2001.

Galin, D.L., 1979. Use of Longitudinal conductance in vertical electrical sounding induced potential method for solving hydrogeologic problems, Vestrik Moskovskogo Univer., Geol., 34, 74-100.

Henriet, J.P.,1976. Direct application of the Dar-Zarrouk parameeters in ground water surveys, Geophys. Pros., 24, 344-353.

Kalenov, E.N., 1957. Interpretation of vertical electrical sounding curves. Mascow, Gostoptekhiz at, 412 p.

Kuentz, G., 1966. Principles of direct current resistivity prospecting. Berlin. Grebruder Bokrntraeger, 103p.

Keller, G.V. & Fischknechst, F.C., 1966. Electrical methods in geophysical prospecting, pergamon press, London.

Maillet, R., 1947. The fundamental equations of electrical prospecting, Geophysics,,2, 529-556.

Orellana, E. & Mooney, H.M., 1966, Master tables and curves for vertical electrical sounding over layered structures: Madrid Interciecia, 150 p 66 tables.Geophysics, 28, 99-110.

Patangay, N.S. & Murali, S., 1984. Geophysical Survey to locate groundwater resources for rural water supply, UNICEF course publication,CEG, O.U., Hyderabad.

Prakasa Rao, B.S., 1983. Studies on development of groundwater potential from palaeo channels. Ph.D thesis.

Radhakrishna, B.P., 1998. Groundwater: Wake-up before it is too late, Currt sci , 75 (6), 541-542 .

Rajesh Raghunath, Sreedhara Murty,T.R. & Uday Shankar, H.N., 2002. Electrical resistivity survey to demarcate potential sites for groundwater and artificial recharging in a part of Precambrian crystalline province of peninsular India, J.Appl. Hydro., 15 (2&3), 39-48.

Ramalingam, M. & Santhakumar,,A.R., 2002. Case study on Artificial recharge using Remote sensing and geographic information system, GIS Development (Internet browsing) (PLEASE GIVE ORIGINAL REFERENCE IN PLACEOF INTERNET BROWSING)

Rao, K.L., 1979. India's water wealth .Orient Longman, pp.267.

Satya Kumar, M.,1979. Geoelectrical and hydrogeological investigations on Miocene Rajahmundry sandstones of the lower Godavari valley, Andhra Pradesh, .Ph.D thesis.

Rama Rao, Ch., 1980, Geoelectrial investigation on some Gondwana sedimentary tracts for groundwater and related problems in West Godavari, Andhra Pradesh. Ph.D thesis.

Vasudev, K, Murty,. M.N. & Nagamalleswara Rao, B. 2002. Evaluation and monitoring of the Phool Bhag watershed,Viziyanagram,,Andhra Pradesj. J. Appl. Hydro., 15 (2&3), 100-103.

Venkateswara Rao, B., 2002, Geoelectrical data based statistical modeling for yield of Bore wells in a typical khondalitic terrain. J.Appl. Hydro., 15 (2&3), 1- 8.

Venkateswara Rao, V., 2000. Artificial recharge of groundwater : A book on Watershed Development published by Association of Hydrologists of India. Visakhapatnam.

Zohdy, A.A.R. Eaton.G.P. & Mabey, D.R., 1974, Application of surface Geophysics to groundwater investigations. Intechniques in water resources investigation. USGS, Book2, CDI, 116p.

(Accepted 2003 March 20. Received 2002 December 31; in original form 2002 October 4)