

An Improved Methodology For Identification of Ground Water Potential Zones in a Typical Khondalitic Terrain

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Abstract

Integrated studies for evaluation of ground water potential in a typical khondalitic (garneti ferrous sillimanite gneiss) terrain is accomplished by proposing an improved methodology involving numerical weights and ratings assigned to various geophysical and geomorphic parameters leading to a computation of ground water potential Index (GWPI) of a given site. It is found that the GWPI of any site should be 35 and above in order to have 75% success rate of wells in a given khondalitic terrain with a yield norm of 8000 litres per hour (LPH) per well. This methodology is an improved one in the sense that the weights are tested for their validity unlike in the earlier methods proposed for similar purposes. These studies indicate that the ground water potential zones are located on gently sloping uplands covered by either shallow buried pediplains or washplains situated between the lineaments or streams. In addition, the potential areas should have basement depths either between 20-30 m or 40-45 m with an aquifer resistivity range 25-65 ohm m. Aquifers in the low lying areas near streams have been kaolinised and acting as barriers to accumulate ground water in the flat-upland areas.

Keywords: Ground water potential index, Improved methodology, weight, Khondalitic terrain.

Introduction

Nearly 65% of the total land area of India and 80% of peninsular India are occupied by hard rocks (Pathak, 1984) of which granite gneises, khondalites and basalts are the major rock types. Tens of thousands of bore wells drilled every year in these formations, either dry or with poor yield, are reported because of inadequate scientific approach. Citing of high yielding bore wells in these hard rock terrains for agricultural purposes, particularly meeting the stipulations of government financial institutions is every difficult as a bore well scheme will be financed only when it meets 75% success rate with a yield norm of 8000 LPH per a well. In the present paper an improved methodology is developed to identify the potential sites in a typical khondalitic (garnetiferrous sillimanite gneiss) terrain in such a way that the success rate of an area is 75% with a yield norm of 8000 LPH per well.

Description of the study area and definition of the problem

The study area selected is Kandivalas River sub-basin (KRSB) situated in northern parts of Eastern Ghats of India near Cheepurupally town of Vizianagaram district of Andhra Pradesh (Fig.1). It lies between north latitudes of 18° 9' 45" and 18° 19' and east longitudes of 83° 32' and 83° 39' 43" covering an area of 123.8 km². In general the area is covered by thick soil cover of 1 to 2 m depth followed by weathered and fractured

khondalitic suite of rocks and then basement of granite gneiss. The area is highly disturbed due to folding and faulting. The topography of the area is undulating. At all locations between khondalitic hills, there is a high slope at foothill region and gentle slope towards valley. Frequently small plateaus are also observed. Quartz mounds and veins are associated with the hills as well as plateaus. Though the average annual rainfall is around 1000 mm, in the absence of assured surface water supply, the agriculture is mainly dependent upon rains and small tanks in the monsoon season and open wells in the post monsoon season. Since these open wells are also becoming dry in summer season, farmers are increasingly depending on bore wells penetrated upto fractured formations, which are found to be sustainable for longer periods. Government is financing these bore well schemes provided they meet above-mentioned norms for success rate and yield of the well.

In order to investigate such bore well sites in the Kandivalas river sub-basin, a number of vertical electrical soundings (VES) were conducted at hydrogeologically favourable locations for high yielding wells. 42 wells were drilled out of which only 27 were successful putting—success rate only up to 64%. With a view, to increase the success rate a methodology is developed in this paper using various weights and ratings after thorough analysis of seven parameters namely, (1) first layer resistivity (F), (2) aquifer resistivity (A), (3) basement resistivity (B), (4) depth to electrical basement (H), (5) geomorphic Unit (M), (6) lineament control (L), and (7) topographic slope (S) at each bore well site. While first four parameters are obtained from the computer interpretation of the VES data, fifth and sixth parameters are derived from the visual interpretation of the

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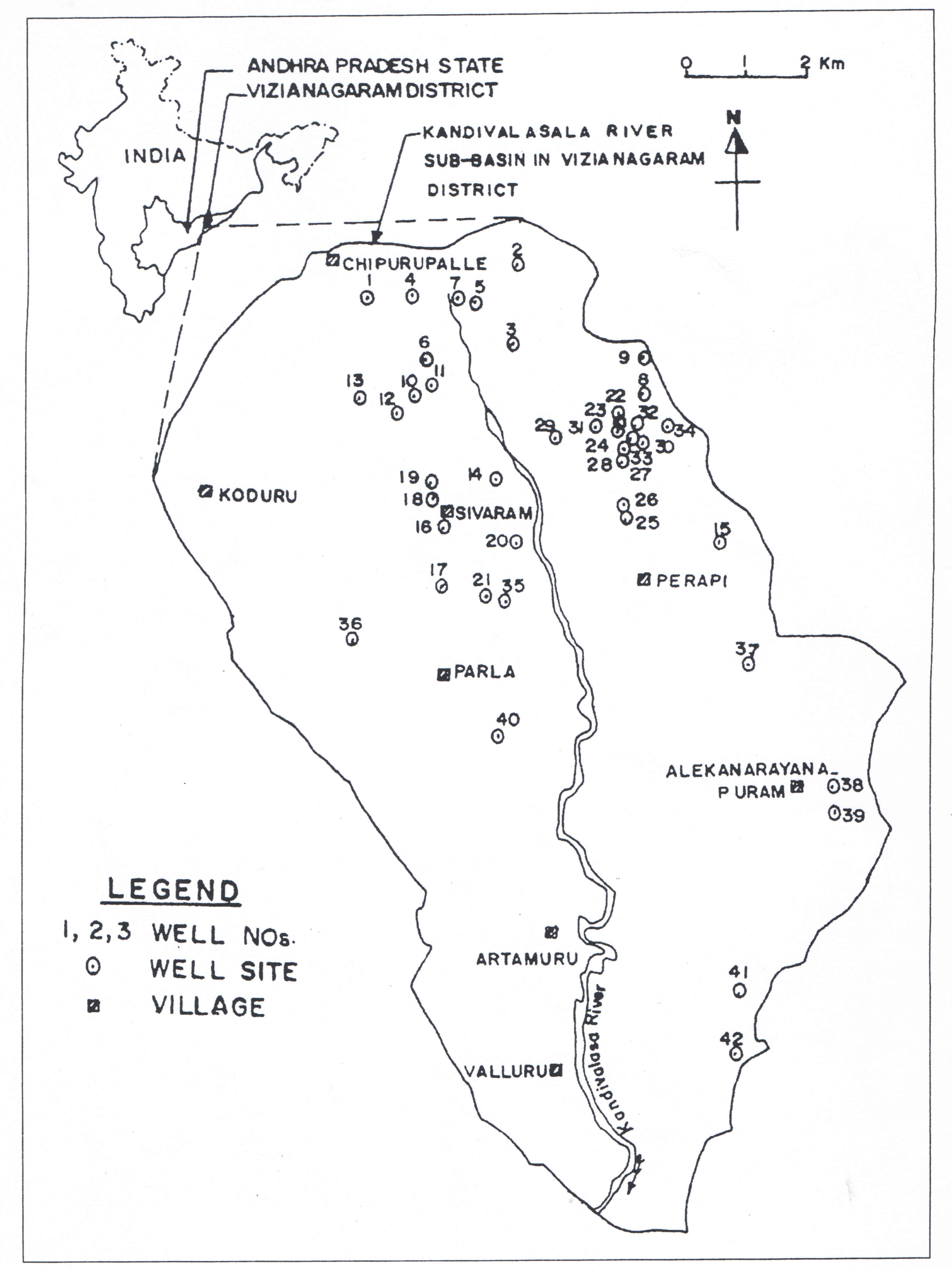


Fig. 1 Location Map of Study Area

Table 1: Geophysical and geomorphic parameters of successful and failed wells in Kandivalasa river sub-basin

		•			Geomorphic unit	Lineament Control	Topograp hic slope	Discharge (lph)	Status
1	34.90	10.27	292.97	18.76	BPPS	BL	NL	510	F
2	78.70	27.78	119.68	32.57	BPPM	OL	NL	4550	F
3	85.02	19.49	59.40	24.94	BPPM	BL	N	4550	F
4	33.64	21.96	223.35	22.48	WP	NL*	NL	3640	F
5	116.44	43.06	3314.00	29.22	WP	BL	NL	27270	S
6	30.82	12.89	188.43	16.30	P	BL	. NL	18180	S
7	38.00	24.70	999.00	44.20	WP	NL*	NL	7950	S
8	680.90	160.99	993.00	38.15	BPPM	OL	VGS	2270	F
9	93.38	64.97	669.15	61.35	WP	NL*	VGS	7950	S
10	26.84	8.89	1107.10	21.65	BPPM	BL	VGS	7950	S
11	28.43	13.54	76.28	20.10	BPPM	BL	NL	25450	S
12	84.75	71.36	152.90	38.82	BPPM	NL*	VGS	3410	F
13	300.00	30.00	9999.00	49.20	WP	NL*	NL	2720	F
14	26.66	56.73	923.00	42.10	WP	BL	NL.	11360	S
15	104.20	23.07	1006.50	49.85	BPPM	BL	VGS	11360	S
16	117.06	22.55	73.50	23.13	WP	NL*	VGS	7950	S
17	82.91	14.96	457.39	35.41	RH	NL*	VGS	18180	S
18	39.60	13.96	1000.62	39.49	BPPM	BL	VGS	450	F
19	34.74	14.23	1009.27	29.03	BPPM	BL	VGS	7950	S
20	40.00	57.00	999.00	27.00	BPPM	BL	NL	12270	S
21	46.43	21.76	999.0	35.39	BPPS	NL*	VGS	510	F
22	51.09	21.77	145.4	21.43	BPPM	BL	VGS	15910	S
23	59.36	20.57	185.75	22.85	BPPS	BL	VGS	18180	S
24	66.16	34.97	1003.91	32.10	BPPS	BL	VGS	20450	S
25	175.24	34.0	10032.2	26.91	BPPS	BL	VGS	10450	S
26	65.58	10.44	4045.75	18.0	BPPS	BL	VGS	10910	S
27	2639.3	28.0	143.34	22.86	BPPS	BL	VGS	13640	S
28	2950.4	30.46	756.3	35.03	BPPS	BL	VGS	18100	S
29	1057.5	30.79	1725.0	27.39	BPPS	BL	NL	450	F
30	144.7	25.7	923.0	36.8	BPPS	NL*	VGS	15910	S
31	35.5	11.93	3492.2	19.92	BPPS	OL	VGS	3640	F
32	188.65	32.13	105.4	34.73	BPPS	OL	VGS	9090	S
33	40.64	13.75	75.06	15.7	BPPS	BL	VGS	3640	F
34	64.0	25.6	160.0	28.0	BPPM	BL	VGS	11360	S
35	53.6	27.12	259.85	22.58	BPPM	BL	VGS	3640	F
36	27.95	21.98	558.73	23.87	BPPS	NL*	VGS	2270	F
37	47.86	20.13	982.36	44.31	BPPS	OL	VGS	3640	F
38	49.3	32.61	931.36	33.82	BPPM	NL*	GS	9900	S
39	85.6	28.37	67.04	29.05	BPPS	BL	MS	11910	S
40	57.62	18.31	209.4	21.67	BPPS	NL*	NL	22730	S
41	486.84	20.67	9852.02	43.46	BPPS	BL	NL	13640	S
42	42.6	9.66	71.51	21.26	BPPS	BL	VSS	18180	S

BPPS: Shallow Buried Weathered Pediplain

P: Pediment

BL: Between the Lineament OL: On the Lineament VSS: Very Steep Slope

BPPM: Moderately Buried Weathered Pediplain

RH: Residual Hill

NL*: Near the Lineament VG: Very Gently Slope

WP: Wash Plain
GS: Gently Slope
NL: Nearly Level
MS: Moderate Slope

Landsat satellite imagery of the study area. Seventh parameter is calculated from the topographic data of the study area. Values of all these parameters are listed in Table.1.

Earlier work on methods involving numerical weights and ratings

Dee et al. (1973) have developed a methodology called Environmental Evaluation System (EES) for conducting environmental impact analysis of large water resources development projects. The EES provides a method of assigning a rating to each parameter and it is multiplied by a weight depending on its relative importance. The environmental impact is obtained by taking difference of sums of products of weights with ratings over all the parameters calculated before and after the project.

Aller et al. (1987) have proposed a system called DRASTIC to evaluate ground water pollution potential using hydrogeologic parameters by assigning various weights and ratings depending upon their relative importance. The pollution potential of an area, called DRASTIC index, is calculated by taking the sum of products of weights with ratings over all the parameters. The higher the DRASTIC index the greater the ground water pollution potential. Kalinski et al. (1994) have utilised the same technique to determine the incidence of OVC contamination of municipal wells in Nebraska, USA. Rosen (1994) has applied DRASTIC methodology to Swedish conditions and found that the weights and ratings adopted therein give it some advantageous statistical properties.

Venkateswara Rao and Briz-Kishore (1991) have developed a methodology for locating potential aquifers in a typical semi-arid region in India by using resistivity and hydrogeologic parameters. This methodology also uses the technique of assigning weights and ratings for various parameters for calculating the ground water potential index which is a sum of product of weights and ratings over all the parameters. But this methodology differs from DRASTIC in assigning ratings. In this method ratings are assigned purely on scientific analysis of the various parameters as detailed in the subsequent sections of this paper.

In the present paper, essentially the same methodology is used but weights are tested for their validity unlike in earlier methods and also some parameters are changed to improve the system. Therefore, it is called an improved methodology over the earlier method published by the author (Venkateswara Rao and Briz Kishore, 1991)

Methodology and discussion of results

The method involves four steps. The first step is to select the parameters and to assign weights to the parameters. The second step is to analyze the existing data for each parameter and assign ratings for various ranges of a given parameter. The third step is to compute the ground water potential Index (GWPI) using the weights and ratings and to test the correlation between success rate and GWPI. Final Step is to validate the weights. The entire procedure is described in the following sections.

Step (A): Selection of parameters and assigning weights

Parameter selection is based on available data that are quantitatively or qualitatively developed with a subjective understanding of the physical field conditions that are indicative of ground water potential. The merit of these parameters lies in the fact that they are based on readily available or easily measured information before expensive test drilling operations are undertaken. For instance, the seven parameters listed in Table 4 constitute most of the information that is required before recommending a site for drilling. The highest weight '5' is given to the depth to electrical basement (H), which is considered to be most important parameter as it is indicative of the total weathered, and fractured thickness that is required for storage of ground water. A weight '3' is given to the aquifer resistivity (A), which is considered as the next important parameter as it is indicative of the water bearing nature of the substratum. First layer resistivity (F), Basement resistivity (B) and Geomorphic Unit (M) are assigned a weight of 'l'each as their influence is least but significant in deciding the ground water potential which will be explained in latter sections. Similarly topographic slope (s) and lineament control (L) can play more significant role than F, B and M in deciding the ground water potential and hence a medium weight of '2' is givento these parameters.

Step (B): Assigning ratings

The data of seven parameters for all the 42 wells along with yields are given in Table 1. In Table 2 first layer resistivity, aquifer resistivity, basement resistivity and depth to basement are divided into different class intervals, while in Table 3, parameters such as geomorphic unit and lineament control are described according to location of the well site. Percentage of successful wells to the total number of 42 wells falling in each of the interclass and locations are also shown in Tables 2 and 3. Looking at the success percentage, rating is assigned to the class intervals as well as locations of various parameters which is indicated in Table 4 and is discussed below:

First layer resistivity (F)

Characteristics of the topsoil like its state of weathering; consolidation, grain size and its moisture content affect the infiltration of rainwater into the ground. Resistivity of first layer to some extent represents these characteristics, which have an influence on the ground water recharge. From Table 2 it can be observed that the low resistivity of the top layer of the order of 50-ohm m or less is an indication of low potential area with a silty clay mantle that does not permit free infiltration while high resistivity of the order of 200 ohm-m and above is indicative

of dry weathered layer or high slope area where groundwater is not available. Hence these two ranges are given lowest rating '1'. Highest rating '3' is given to the most successful range of 100-200 ohm-m which is found to be observed in the areas covered with quartz gravels on the surface and quartzisation in the subsurface layers resulting in plentiful well yields. Rating '2' is given to the moderate successful range of 50-100 ohm-m.

Aquifer resistivity (A)

After examining the VES data, the aquifer layer is identified in such a way that it is either the second layer or the third layer depending upon the respective layer thickness and resistivity conducive to bear the water. It can be inferred from Table 2 that aquifer resistivity less than 15 ohm - m is indicative of highly weathered formations which are mostly kaolinised and resistivity greater than 65 ohm-m are associated with basement characteristics as these ranges have the least success rate and

therefore least rating '1' is given. Highest rating is given to the range of 25-65 ohm-m, which is representative of a potential aquifer, as the highest percentage of success is observed in this range. Rating '2' is given to the moderate successful range of 15-25 Ohm-m.

Basement resistivity (B)

From Tables 1 and 2 it can be observed that at a majority of the successful well points the basement resistivities are very high. Almost all the unsuccessful well locations show a lower range of basement resistivity of less than 400 ohm-m. Reduced basement resistivity is an indication of mildly weathered basement. Thus higher range of basement resistivities are given rating '3' lower range is given '1' and medium range is given '2'

Table 2: Percentage of successful wells in various ranges of geophysical parameters

First Layer Resistivity (ohm-m)

	0-50	50-10	100-150	150-2	>200
No of Successful Wells	9	9	3	3	3
No. of Failed Wells	8	4	0	0	3
Percent Success	52.9	69.2	100	100	50

Aquifer Resistivity (Ohm-m)

	5-15	15-25	25-35	35-45	45-55	55-65	>65
No.of Successful Wells	7	7	9	1	0	3	0
No.of Failed Wells	5	4	4	0	0	0	2
Percent Success	58.3	63.6	69.2	100	0	100	0

Basement Resistivity (Ohm-m)

	<400	400-800	>800
No. of Successful Wells	9	2	16
No. of Failed Wells	8	0	7
Percent Success	53	100	69.56

Depth to Electrical Basement (m)

	<20	20-25	25-30	30-35	35-40	40-45	45-50	>50
No. of Successful Wells	2	8	6	3	3	3	1	
No. of Failed Wells	2	8	6	3	3	3	1	1
Percent Success	33.3	72.7	100	60	42.8	100	33.3	50

Depth to electrical basement (H)

From Table 2, the percentage of successful wells with respect to total subsurface thickness 'H' reveals not one but two ranges of optimum values. One is 20-30 m range and the other is 40-45 m range both showing a near cent-percent success rate in well yield. Therefore rating '3' is given for these ranges. Less than 20 m overall thickness is obviously inadequate to hold a reasonable quantity of ground water leading to very low percent of success rate in this range, while greater than 45 m of weathered and fractured depth is an indication of intense weathering leading to kaolinisation of the aquifers. Therefore these very low success rate ranges (< 20 m and >45 m) are given rating '1'. A moderate success rate is observed in the range of 30-40 m therefore rating '2' is assigned for this range.

Geomorphic unit (M)

The percentage of successful wells with respect to geomorphic unit is shown in Table 3, which reveals that the maximum success rate of 71% is seen in wash plains followed by the shallow buried weathered pediplains (BPPS) with a success rate of 63%. BPPS having greater areal coverage with a flat upland topographic position in the basin is considered

as the most groundwater potential area. Therefore, these two geomorphic units have been assigned the rating '3'. The moderately buried weathered pediplain (BPPM) with a least success rate of 57% have small fractured and large kaolinised zones compared to BPPS, therefore BPPM is given a least rating of '1'. There is no sufficient data for rocky pediments and residual hills, which are generally devoid of water except under special circumstances as they were found in the present case study. Hence, a rating '2' is given to them.

Lineament control (L)

It is observed from the analysis (Table 1 and 3) of the lineament control that the wells located on lineaments are not giving good yields whereas wells located on the upland areas between the lineaments are yielding better discharges and hence rating '1' to the former case and rating '3' to the latter case are assigned. Wells cited in intermediate areas are giving moderate yields. Therefore rating '2' is assigned to this position. This phenomenon is explained from the fact that the lineaments in this basin are principally fault zones along which stream courses have developed. Underneath the streams, the subsurface formation of khondalite appears to have transformed itself

Table 3: Percent successful wells in various units of geomorphic variables

Geomorphic Unit

	Residual Hill (R.H.)	Rockey Pediment (P)	Moderately Buried Pediplain (BPPM)	Shallow Buried Pediplan (BPPS)	Wash Plain (WP)
No of Successful Wells	1	1	8	12	5
No. of Failed Wells	0	0	6	7	2
Percent Success	100	100	57.1	63.1	71.4

Lineament Control

	On the Lineament	Near the Lineament	Between the Lineament
No of Successful Wells	1	19	7
No. of Failed Wells	4	6	5
Percent Success	20	76	58.3

Topographic slope, percent

	0-1 Nearly Level (NL)	1-3 Very Gentle Slope (VGS)	Slope (GS)	5-10 Moderate Slope (MS)		15-35 Steep Slope (SS)	
No of Successful Wells	8	16	1	1	0	0	1
No. of Failed Wells	6	9	0	0	0	0	0
Percent Success	57.1	64 .	100	100	0	0	100

into kaolin due to constant contact with water and acting as a barrier preventing lateral movement of ground water forcing it to accumulate between the lineaments.

Topographic slope (S)

It can be found from Table 3 that the very gently sloping (1-3% slope) uplands are better than nearly flat low lands (0-1%) or much steeper hilly areas, from the viewpoint of well yields. This may be due to the fact that the partial or complete kaolinisation of potential water-bearing strata in the nearly flat low lands surrounding on either side of the river, while the aquifer in uplands with gentle slope has the suitable fractured formation for accumulation of water. Therefore rating '3' is assigned to the slope range 1-3% and rating '1' is assigned for slope range 0-1%. As there is no sufficient data on higher slope a medium rating of '2' is given to these ranges.

Step (C): Computation of ground water potential index (GWPI)

To evaluate the ground water potential of a given site ground water potential Index (GWPI) is proposed. GWPI is computed as the weighted sum of the seven variables descibel earlier given by the formula

$$GWPI = F_w F_R + A_w A_R + B_w B_R + H_w H_R + M_w M + L_w L_R + S_w S_R.$$

where the subscripts W and R stands for weight and rating respectively. Thus in the best hydrogeological situation where the rating is '3' (Table 4)) for all the parameters of varying weights of '1' to '5', the GWPI is 45 and the least possible

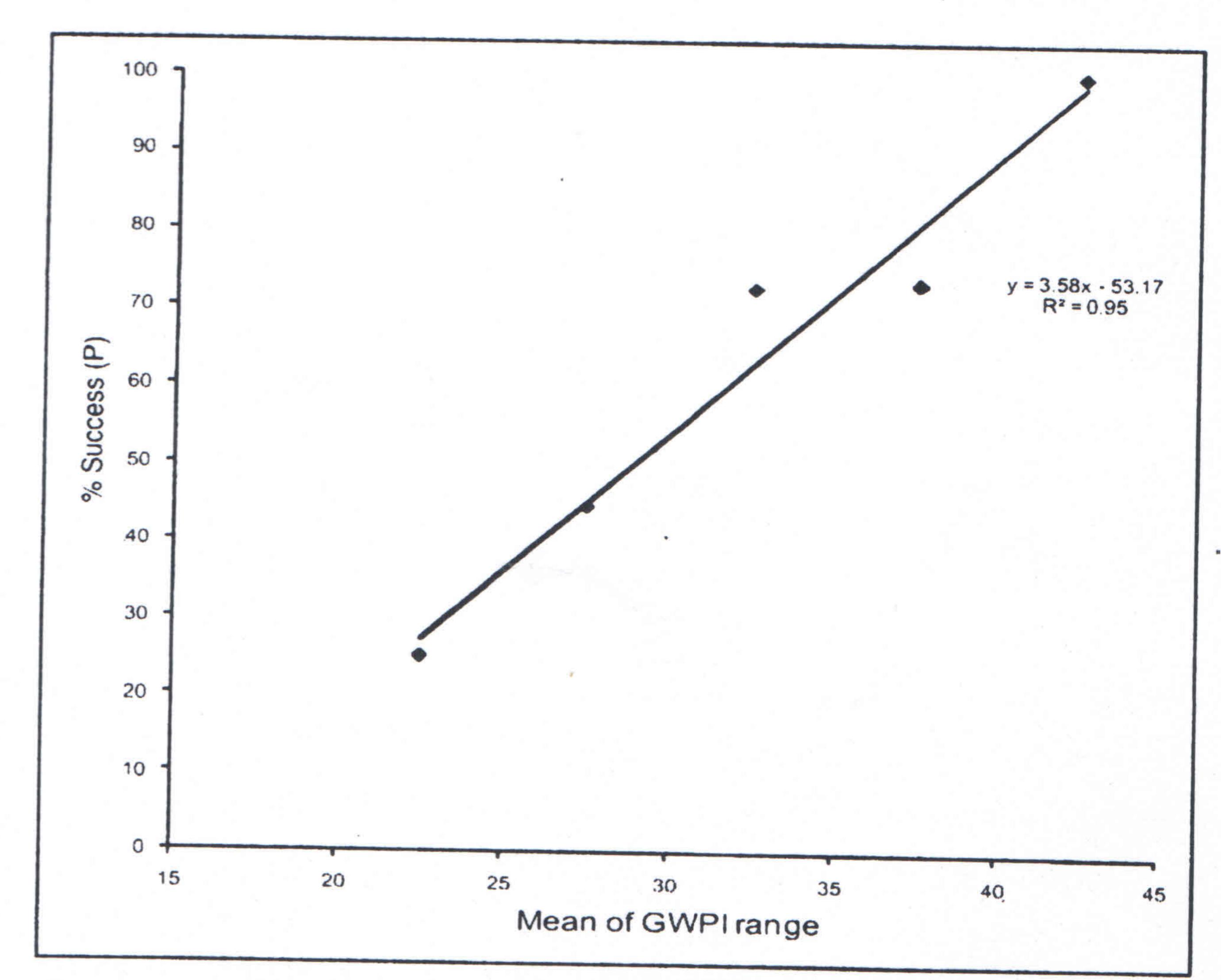


Fig. 2 Relation between GWPI and percent success of wells

value of GWPI is 15 where the rating is 1. The GWPI's for all the 42 wells are calculated by using the above formula and are presented in table 5. In order to assess the percentage of success of wells in a particular range of the index, the data in Table 5 is divided into 5 ranges as shown in Table 6. The success rate is found to increase with the increase in the range of ground water potential Index. To achieve the minimum success rate of 75% fixed up by the government financial institutes, a graph (Fig.2) is drawn between the 5 values of percent success (P) and the corresponding mean values (G) of the ranges of ground water potential index. From the figure it can be observed that a positive correlation exists between P and G and also it can

Table 4: Weights and ratings assigned to various ranges of parameters

Variable	Weight	Rating				
		1	2	3		
Geophysical Parameters 1. First Layer resistivity (F), Ohm-m	1	>200	50-100	100-200		
2. Aquifer resistivity (A), Ohm-m	3	<15 >65	15-25	25-65		
3. Basement resistivity (B), Ohm-m	1	<400	400-800	>800		
4. Depth to electrical basement (H),m	5	<20 >45	30-40	20-30 40-45		
Geomorphic Parameters 5. Geomorphic Unit (M)	1	BPPM	P&RH	WP & BPPS		
6. Lineament control (L)	2	On the Lineament	Near the Lineament	Between the Lineament		
7. Topographic slope(S), Percent	2	0-1	>3	1-3		

BPPM - Moderately buried weathered Pediplain

WP - Wash Plain

- Rocky Pediment

RH - Residual hill

BPPS - Shallow Buried Weathered Pediplain

Table 5. Ground water potential indices of successful and failed wells

Well No.	GWPI	Status
1	21	Failed
2	27	Failed
3	33	Failed
4	32	Failed
5	41	Success
6	20	Success
7	34	Success
8	26	Failed
9	31	Success
10	35	Success
11	29	Success
12	27	Failed
13	27	Failed
14	39	Success
15	30	Success
16	37	Success
17	29	Success
18	30	Failed
19	35	Success
20	37	Success
21	33	Failed
22	37	Success
23	39	Success
24	39	Success
25	45	Success
26	28	Success
27	41	Success
28	38	Success
29	39	Failed
30	38	Success
31	23	Failed
32	- 34	Success
33	25	Failed
34	40	Success
35	40	Failed
36	37	Failed
37	36	Failed
38	33	Success
39	40	
40	33	Success
41	36	Success
12		Success

be found that a GWPI of 35 is required for a site to get 75% success rate. A regression line is fitted between those five sets of values and it is found to be P = 3.58G - 53.2 (correlation coefficient =0.97) with 99% confidence level for Ψ^2 test.

Step (D): Testing of weights

In order to examine whether the relativeness of the assigned weights to various parameters is correct or not a comparative analysis is made between four combinations of weights (Table. 7) by calculating correlation coefficients between P and G for all the four combinations. The highest correlation coefficient is obtained for the first combination, which provides adequate justification for the choice of weights in the present study. No attempt is made to examine all the possible combination of weights. For instance it is difficult to comprehend any logic in assigning weights like Fw = 5, Hw = 1 or Mw = 4 etc. As far as the ratings are concerned they are assigned purely on the success rate of a range or a described situation of the given parameter. As more and more feedback data obtained from the further drilling joins the system, the ranges may get refined and altered while assigning the rating.

Conclusions

An improved methodology is suggested for location of ground water potential aquifers in a typical khondalitic terrain by using a total of seven geophysical and geomorphic parameters assigned with various weights and ratings depending upon their relative importance. It is an improved methodology in the sense that the weights are tested for their validity unlike in the earlier methods proposed for similar purposes. The study

Table 6. Percent successful wells in various ranges of GWPI

Range of GWPI	20-25	25-30	30-35	35-40	40-45
Mean	22.5	27.5	32.5	37.5	42.5
No. of Successful Wells	1	4	8	11	3
No. of Failed Wells	3	5	3	4	0
Percent Success	25	44.44	72.72	73.3	100

Table 7: Correlation coefficients between GWPI and well success rate for different weights of parameters

Combination	Fw	A	B	H	M	L	Sw	Correlation Coefficients
	1	3	1	5	1	2	2	0.976
2	1	4	1	4	2	3	1	0.950
3	2	4	2	4	2	1	2	0.865
4	1	5	2	3	2	2	2	0.430
5	1	4	1	5	2	2	2	0.423

indicate that the ground water potential zones are located on gently sloping uplands covered by shallow buried pediplains and wash plains situated between the lineaments or streams. In addition, the potential areas should have the basement depths either between 20-30 m or 40-45m with an aquifer resistivity range of 25-65 ohm m. Aquifers in the low lying areas near streams have become kaolinised and acting as barriers to accumulate ground water in the flat upland areas. GWPI is computed to indicate the relative ground water potential of a given site and is found to be 35 to achieve 75% success with a yield norm of 8000 LPH.

References

- Aller, L., Lehr, J.H., Peetty, R. and Bennett, T. 1987 Drastic: a standardised system to evaluate ground water pollution potential using hydrogeolgic setting, Journal of Geological Society of India, Vol. 21, pp.23-37.
- Dee, N., Baker J., Drobny, N., Duke, K., Whitman, I. and Fahringer, D. 1973 An environmental evaluation system for water resources planning, Water *Resources Research*, Vol.9, No.3, pp. 523-535.

- Kalinski, R.J., Kelly, W.E., Bogardi, I., Ehrman. R.L. and Yamamoto, P.D.1994. Correlation between drastic vulnerabilities and incidents of VOC contamination of municipal wells in Nebraska, *Ground Water*, Vol.32, No.1, pp. 31-34.
- Pathak, B.K. 1984 Hydrogeological surveys and ground water resource evaluation in the hard rock areas of India, *Procs. of International Workshop on Rural Hydrogeology and Hydraulics in Fissured Basement Zones*, Roorkee, pp. 14-15.
- Rosen, L. 1994 A study of the drastic methodology with emphasis on Swedish conditions, *Ground Water*, Vol. 32, No. 2, pp. 278-285
- Venkateswara Rao, B. and Briz-Kishore, B.H. 1991 A methodology for locating potential aquifers in a typical semi-arid region in India using resistivity and hydrogeologic parameters. *Geoexploration*. Vol. 27, pp. 55-64.