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Relationship Among Reference Evapotranspiration Models for Arid Region of Rajasthan

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Abstract: There are many methods for estimation of reference evapotranspiration (ET_O). These methods have been developed for specific sites, and need to be tested for other regions before their application. Several researchers have compared the results obtained from different evapotranspiration methods. However, no single existing method is universally applicable under all climatic conditions. Application of many of these methods is restricted because of large amount of data required. There has always been a need to estimate ET using limited meteorological data, whatsoever is available. Keeping in view the above difficulty, a study was undertaken to develop interrelationships among frequently used models for estimation of reference ET. Several standard models, namely Blaney-Criddle, Radiation, modified Penman and most recently developed Penman-Monteith and others have been used to develop interrelationships. About 30 years of weekly meteorological data of Jodhpur (Rajasthan) have been used to develop the interrelationships. Such interrelationships could be used as an additional tool to convert ET_O estimated by one method to another method. Interrelationships between different models of ET_O are also useful for comparing the performance of different models. The present paper provides an opportunity to select a method of using limited available data under arid zone conditions.

Key words: Reference evapotranspiration, methods, relationship, arid, Rajasthan.

Estimation of evapotranspiration (ET) is of great importance for the management of water resources, and for solving many theoretical problems in the field of hydrology and meteorology. In the planning of irrigation project, ET data are used as the basis for estimating the acreage of various crops, or combination of crops that can be irrigated with a given quantity of water available. Direct measurement of ET requires special instruments to measure various physical parameters associated with it. Methods of direct measurement are often expensive and demanding in terms of accuracy of measurement. Due to difficulty in accurate field measurements, ET is commonly computed from weather data. There are many methods reported by Wilson (1974), Doorrenbos and Pruitt (1977), Subramanya (1984), Michael (1986), Mavi (1986), Singh (1989), NIH (1989), etc., for estimation of ET_O. Several workers, viz., McGuiness and Bordne (1972), Jensen (1974), Hargreaves and Samani (1985), Al-Sha'lan and Salih (1987), Rao *et al.* (1988), Mohan (1991) and Amatya *et al.* (1995) have compared different ET methods. However, no single existing method using meteorological data is universally adaptable under all climatic conditions. Therefore, use of a specific method is limited by the conditions in which they had been developed. Large data requirement also limits the application of many of these methods, as all the necessary meteorological data are not always available. Under such condition, use of a specific method becomes very difficult and application of an alternate method (for which data are easily available) may not yield results with desired accuracy. An attempt has been made in this study to develop interrelationships among the frequently used methods for estimation of ET_0 and provide easy conversion procedures for different methods.

Materials and Methods

Study area

The study has been conducted for Jodhpur station of arid western Rajasthan, popularly known as Thar Desert, which covers about 6.4% of the country's total geographical area. This region is characterized by low (10 to 40 cm) and erratic (CV >50%) rainfall. The water available from various sources, such as surface water and ground water, are not sufficient even for drinking purposes. Looking to low irrigation potential available and limited water resources it is necessary to adopt conservation measures for management of water resources. One must also estimate precisely the amount of water required for crop production and other uses.

Evapotranspiration methods: A brief overview

Some of the frequently used empirical methods for estimation of ET_0 are (i) Blaney-Criddle, (ii) Radiation, (iii) Penman, (iv) Pan evaporation, (v) Hargreaves, and (vi) Thornthwaite. All these methods have got limitations and cannot be used universally in general and for arid areas in particular.

The principal limitation of Penman approach is the lack of sufficient measurements of various climatic parameters at most of the locations. The Blaney- Criddle method should be applied for periods of one month or longer. It has serious limitation of representing consumptive use for period shorter than one month, because it considers temperature as the only variable (Doorrenbos and Pruitt, 1977). The pan evaporation method needs empirical coefficients to estimate reference crop evapotranspiration from ET. The radiation method shows good results in humid climate where the aerodynamic term is relatively small, but its performance under arid conditions is erratic and it tends to underestimate ET (Allen *et al.*, 1998).

The Thornthwaite formula gives a reasonably good estimate of reference crop evapotranspiration in temperate, continental climate of North America where it was developed. Thornthwaite method is not expected to give good estimate for arid and semi-arid areas (Chang, 1968). The other limitation of the formulae is that temperature alone is not a good indicator of energy available for reference crop evapotranspiration.

Hargreaves based his method on data from grass lysimeter in Latin America. Hargreaves method has no adjustment factor for site-specific conditions of elevation and humidity. On the basis of different drawbacks of various models, it can be said that none of the existing methods using meteorological data is universally applicable under all the climatic conditions

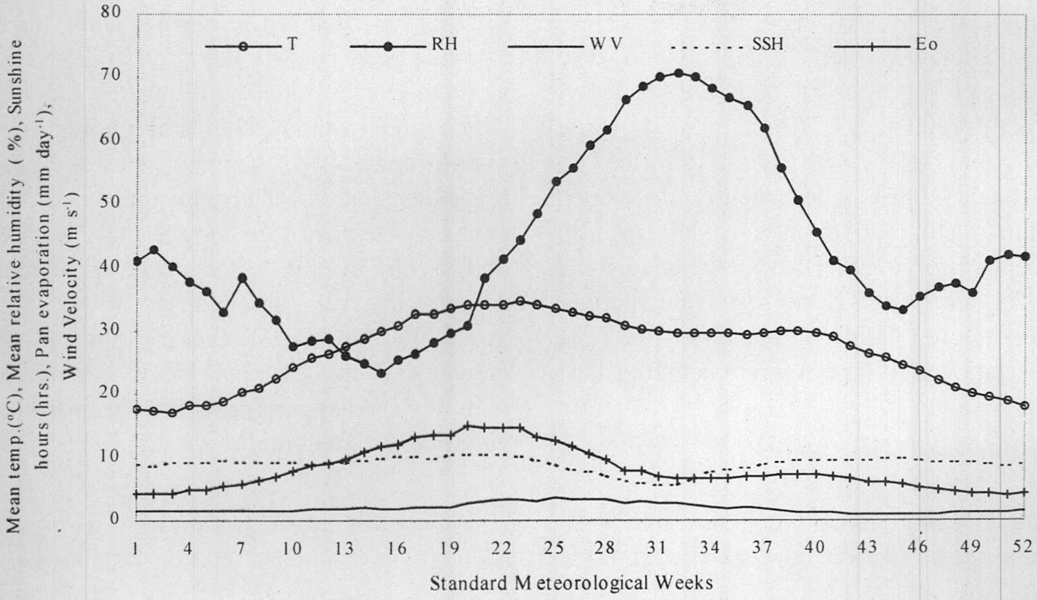

Fig. 1. Trend of meteorological parameters for Jodhpur.

for estimation of ET_O. An analysis of the performance of various methods reveals the need for formulating interrelationships among different methods of ET_O estimation.

Estimation of reference evapotranspiration

The ET rate from a reference surface, not short of water, is called the ET_O. The FAO expert consultation on revision of FAO methodologies for crop water requirement has defined reference surface as "A hypothetical reference crop with an assumed height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23" (Allen *et al*., 1998). The reference surface closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. The ET_O concept is used to study the evaporative demand of atmosphere independent of crop type, crop development and management practices. As water is abundantly available at reference evaporating surface, soil factors do not affect ET_O.

The weekly records of climatic parameters i.e., temperature, humidity, wind velocity, sunshine hours, pan evaporation, radiation, etc., for Jodhpur (located at 26°18′N latitude and 73°01′E longitude at 224 m MSL) have been obtained for 30 years (1967-1999, except 1970, 1975, 1976) from IMD, Pune. These data have been averaged on weekly basis to obtain mean value of each parameter (Fig. 1). Seven frequently used standard methods have been selected to calculate the value of ET_O by using normal climatic parameters. These methods are Blaney-Criddle (BLC), Radiation (RAD), modified Penman

(MPM), pan evaporation (PAN), Christiansen (CHN), Thornthwaite (THW) and Penman-Monteith (PM) method. The details of first four methods are presented by Doorrenbos and Pruitt, (1977), while CHN and THW methods are described in Michael (1986). The recently developed Penman-Monteith method is described in Allen *et al.* (1998). The methods selected for estimation of ET_O are based on radiation, temperature, their combinations, multiple correlation and pan evaporation approaches.

Results and Discussion

ET_O using above methods have been estimated for Jodhpur on weekly basis. Table 1 presents estimation of ET_O by seven different methods. The results show that estimated ET_O has less variation in different methods except from Thornthwaite's model, which underestimates ET_O in winter and over-estimates it in summer. The obvious reason is that the Thornthwaite's method considers temperature as the only index of ET. The average temperature in winter is generally very low and is quite high in summer. The role of other meteorological parameters like wind velocity, relative humidity and temperature cause a significant variation in magnitude of ET.

Amatya *et al.* (1995) and Tyagi *et al.* (2000) have developed relationship between

Table 1. Reference-evapotranspiration at Jodhpur as calculated through different models (mm day^{-1})

Week No.	PM	MPM	BLC	RAD	CHN	THW	PAN
1	3.09	3.72	3.72	4.04	3.20	1.00	2.37
2	3.15	3.79	3.61	3.97	3.25	0.92	2.41
3	3.12	3.95	3.99	4.12	3.17	0.88	2.46
4	3.34	4.16	3.96	4.29	3.34	1.09	2.74
5	3.77	4.64	4.36	4.98	3.63	1.05	2.80
6	3.98	4.94	4.61	5.22	3.73	1.20	3.07
7	4.09	5.44	4.68	5.14	3.97	1.53	3.34
8	4.31	5.55	4.91	5.32	4.13	1.75	3.58
9	5.01	6.26	5.44	6.28	4.72	2.62	3.76
10	5.28	6.42	6.02	6.64	4.92	3.41	4.22
11	5.68	6.71	6.06	6.60	5.37	4.21	4.64
12	5.72	6.93	6.21	6.76	5.41	4.49	4.79
13	6.53	7.53	7.06	7.76	6.18	5.52	5.11
14	7.13	8.02	7.93	8.11	6.63	6.37	5.66
15	7.12	8.17	7.80	8.31	6.70	7.42	5.98
16	7.38	8.40	8.05	8.47	6.92	8.21	6.26
17	8.04	9.02	8.92	8.77	7.53	9.90	6.85
18	8.29	9.50	8.99	8.90	8.02	10.85	6.98
19	8.41	10.07	9.29	9.17	8.19	12.05	7.17
20	9.32	10.47	9.83	9.40	8.85	12.83	7.76

Table 1. Contd...

Week No.	PM	MPM	BLC	RAD	CHN	THW	PAN
21	9.34	11.00	9.47	9.22	9.02	12.80	7.87
22	9.32	10.91	9.88	9.12	9.27	12.75	7.87
23	9.48	10.93	9.91	8.99	9.49	13.53	7.92
24	8.65	9.81	8.98	8.42	9.08	12.68	7.34
25	8.51	9.62	8.52	7.96	9.29	11.81	7.08
26	7.73	8.84	7.55	7.20	9.13	11.50	6.75
27	7.17	8.06	7.11	6.83	8.84	10.60	6.13
28	6.71	7.96	6.65	6.41	8.68	10.20	5.72
29	5.81	6.79	5.76	5.56	8.11	9.17	4.86
30	5.66	6.75	5.65	5.40	8.18	8.52	4.77
31	5.21	6.34	4.97	4.97	7.74	7.81	4.37
32	5.08	6.48	4.84	4.88	7.62	7.48	4.11
33	5.21	6.73	5.11	5.30	7.41	7.39	4.17
34	5.50	7.16	5.18	5.82	7.21	7.60	4.33
35	5.19	6.81	5.16	5.56	6.78	6.76	4.23
36	5.32	6.88	5.26	5.78	6.91	6.64	4.43
37	5.44	6.90	5.70	6.13	6.60	6.91	4.47
38	5.67	6.69	6.13	6.48	6.60	7.00	4.54
39	5.54	6.61	6.18	6.71	6.17	6.98	4.46
40	4.77	5.76	5.82	5.96	5.52	6.62	4.36
41	4.55	5.58	5.46	6.00	5.26	6.07	4.16
42	4.41	5.05	5.59	5.97	5.02	5.05	3.85
43	4.18	4.96	5.19	5.95	4.75	4.38	3.57
44	3.54	4.42	4.93	5.21	4.17	3.69	3.46
45	3.43	4.31	4.76	5.15	4.02	3.13	3.23
46	3.34	4.11	4.79	4.90	3.92	2.74	2.97
47	3.31	3.98	4.49	4.69	3.81	2.21	2.74
48	3.02	3.61	4.06	4.25	3.47	1.75	2.65
49	2.96	3.75	4.25	4.16	3.37	1.54	2.50
50	2.89	3.50	3.70	3.93	3.33	1.38	2.43
51	2.92	3.61	3.81	3.82	3.32	1.25	2.35
52	2.98	3.59	3.68	3.87	3.30	1.01	2.37

different methods of ET using linear regression technique for specific locations. A similar attempt has been made in the present study to develop relationship for Jodhpur in arid western Rajasthan through linear regression (Table 2). Conversion from

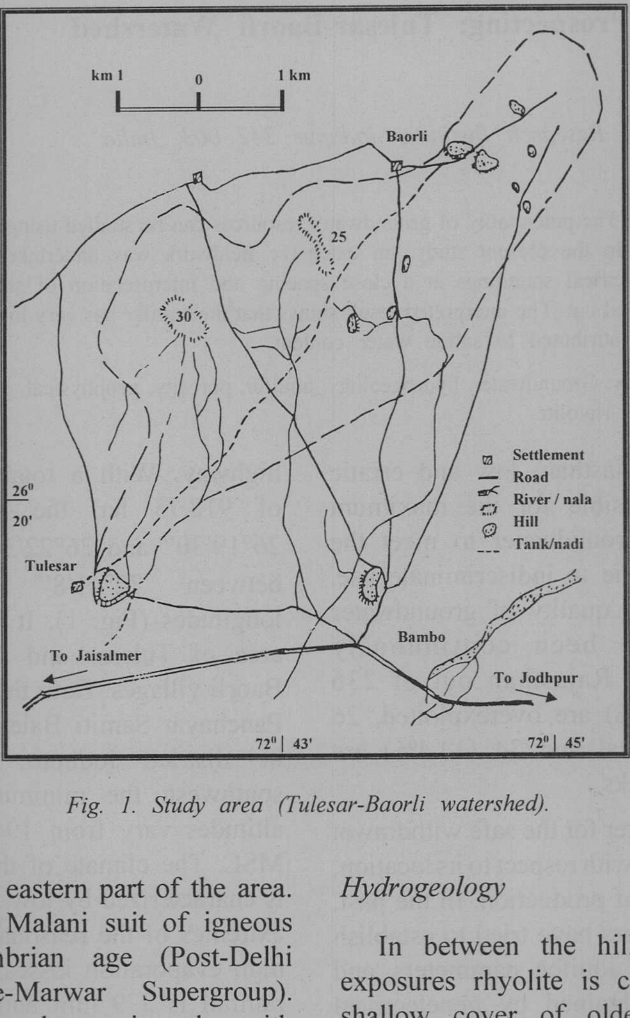

Fig. 1. Study area (Tulesar-Baorli watershed).

of hillocks in the eastern part of the area. These belong to Malani suit of igneous rock of Precambrian age (Post-Delhi Supergroup; Pre-Marwar Supergroup). Rhyolite is gray to brown in color with frequent phenocryst of quartz and feldspar in the hill-300 and the hill-252. Green rhyolite is also intruded as dyke in the eastern part of the hill. The rest of the area is covered with older alluvium, comprising of heterogeneous mixture of sand, silt and rhyolite fragments of different sizes with kankar as the chief constituent. The formation is semi-consolidated and should have undergone prolonged weathering under arid environment in recent and sub-recent times.

Hydrogeology

In between the hills and the other exposures rhyolite is concealed under a shallow cover of older alluvium. The thickness of alluvium is more in the southern and eastern parts of the watershed. There is no well in the area, restricting direct observation of the hydrogeological parameters.

Survey of India topographical maps at 1:50,000 scale (45B/11 and 45B/15), aerial photographs of 1959 at 1:31680 scale and IRS LISS-II Geocoded FCC of 19th January 1995 were interpreted. The boundary of the project areas taken from cadastral map was at 1:6336 scale and enlarged to 1:5000 scale. Taking control points from topomaps and aerial photographs all important physical features were incorporated. Hydrogeological and geophysical investigations were carried out by making thirty geoelectrical (resistivity) soundings. The data were interpreted in two steps. In the first step, the initial layer parameters were obtained through partial curve matching technique using standard graph (Orellawa and Mooney, 1966). This initial model was then used to obtain the final layer parameters through inversion technique in the second step and correlated with the lithology.

Results and Discussion

Analysis of litholog data revealed that 3 m thick weathered rhyolite is present at a depth of 42 m, followed by hard and compact rhyolite (Table 1). Rhyolite in general being a poor host of ground water, should not have much water-bearing potential until and unless there is good fractured or/and weathered zone. Considering the nature of the rock here possibility of getting good quality water is remote.

Geophysical characteristics

With a view to gather further details on hydrogeological parameters, viz., nature of aquifer, expected quality of water, depth to basement, etc., 30 spots well distributed over the area under the project were examined by carrying out geophysical surveys using resistivity sounding technique (Fig. 2; Table 2). At spot 10 and 28 data were not interpretable.

By analyzing and interpreting resistivity sounding data, the subsurface was divided into a number of layers with varying thickness and resistivity values. Resistivity of rock is controlled by the rock type, compactness, porosity, presence or absence of water in the pore spaces, degree of salinity of formation water, presence or absence of clastic or other conductive material. Therefore, given the rock type, with the interpretation of resistivity data it is possible to know about the (i) possibility of encountering an aquifer, (ii) quality of formation water in terms of salinity and also (iii) depth to basement.

Table 1. Litholog of borewell drilled at village Tulesar

Depth range (m)	Thickness (m)	Lithological formation
0 - 7	7	Top soil chiefly clay with quartz pieces
7 - 21	14	Hard clay with gravel of quartz
21 - 27	6	Sandy clay
27 - 29	2	Medium to coarse grained sand with fragments of quartz
29 - 31	2	Light brown fine grained sand with fragments of quartz
31 - 38	7	Sandy clay with quartz pieces
38 - 41	3	Coarse gravel with rock fragments
41 - 42	1	Fine sand
42 - 45	3	Weathered and fractured rholite
45 - 50	5	Hard and compact rhyolite

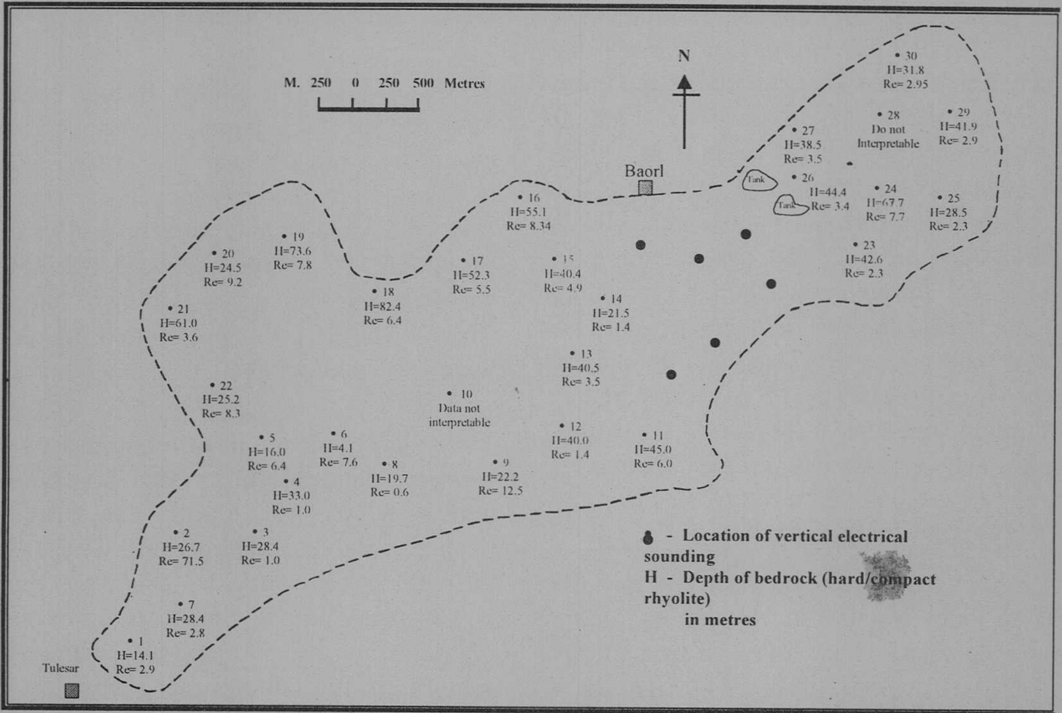

Fig. 2. Geoelectrical sounding parameters in watershed.

In the watershed overburden is older alluvium, followed by weathered rhyolite and then compact rhyolite forming the bedrock. Aquifer is made of alluvium and weathered rhyolite. The aquifer has very low resistivity, which is attributed to its saline water content. Additionally clay in the alluvium may be a cause for small resistivity. The resistivity of aquifer is almost in all cases <15 ohm-m and in more than 60% cases it is less than even 5 ohm-m. The depth to bedrock is very irregular as it usually happens in rhyolite terrain. In most of the areas it should be in the range of 40 to 60 m. In the southwestern part compact rhyolite can be expected at a depth of 25 to 30 m. In the northeastern part it should be encountered at a depth of about 35 to 45 m.

Groundwater resource potential

Groundwater reserves of the watershed have been estimated on the basis of thickness of saturated volume of aquifer. The nature of the basement in the area is quite irregular. Therefore, different zones of equal depth to bedrock were interpreted and delineated on the basis of geoelectrical survey. Since there was no well in the area, therefore the quantification of ground water was made through interpretation of geophysical data. The aquifer in the entire study area is older alluvium, comprising mainly sand, clay and kankar with very less effective porosity and it is underlain by weathered compact rhyolite. The ground water potential was estimated by considering 20 m water column and specific yield of entire aquifer system

Table 2. Interpreted values of resistivity and corresponding thickness of geoelectrical layer

Location	Layer resistivity (Ohm-m)					Layer thickness (m)				
	R1	R2	R3	R4	R5	h1	h2	h3	h4	Total
Tulesar										
0.5 km NE	215	2.9	1121	–	–	3.1	61	–	–	64.1
1.3 km NE	90	13	1.5	3825	–	1.4	7.8	17.5	–	26.7
1.7 km NE	210	26	1.7	95	1.0	2.8	7.9	4.8	12.9	28.4
2.1 km NE	138	12	1.0	2022	–	3.8	14.9	14.3	–	33.0
2.2 km NE	202	14	6.4	–	–	4.7	11.3	–	–	16.0
2.6 km NE	15	0.2	3.7	7.6	–	1.6	0.5	1.9	–	4.0
1.0 km NE	208	2.0	26914	–	–	1.4	27	–	–	28.4
2.7 km NE	502	28	0.6	881	–	0.9	11	7.8	–	19.7
3.5 km ENE	321	23	7.6	12.3	–	1.3	3.3	17.6	–	22.2
4.5 km ENE	212	34	5.7	16.3		1.7	7.7	35.7	–	45.1
4.0 km ENE	265	21	1.4	225	52	0.7	19.6	1.5	11.9	40.4
4.2 km NE	272	26	3.5	31713	–	1.4	7.2	31.9	–	40.5
4.7 km NE	155	12	1.4	17	–	0.9	16.4	4.5	–	21.8
4.8 km ENE	156	13	4.9	1248	7228	1.2	7.4	39.5	20.1	68.2
5.0 km ENE	218	17	3.4	1710	–	3.5	18.4	3.2	–	55.1
4.1 km NE	385	21	5.5	4374	–	2.8	19.6	29.7	–	52.1
3.6 km NE	80	6.4	954	–	–	9.1	73.3		–	82.4
3.5 km NNE	208	7.8	4455	–	–	5.1	68.5	–	–	73.6
3.1 km NNE	574	22	9.2	1246	–	1.8	9.0	13.7	–	24.5
2.7 km NNE	173	87.	3.6	410	–	2.3	14.7	44	–	61.0
2.2 km NNE	2199	119	8.3	38506	–	1.5	11.4	12.3	–	25.2
1.6 km ESE	8	2.9	25	17995	–	3.3	34.6	4.7	Inf.	42.6
Baroli										
1.5 km E	7	1.9	7.7	1026	–	5.1	11.5	51.1	–	67.7
2.0 km E	54	8.1	2.1	11272		1.1	7.8	19.6	–	28.5
1.0 km ENE	13	3.4	5571	–	–	2.7	41.7	Inf.	–	
1.0 km NE	45	3.5	700	4824	–	2.5	36.0	11.3	–	49.8
1.7 km NE	Not interpreted									
2.2 km NE	7	2.7	1000	5399	–	8.8	33.1	8	-	49.9
1.9 km NNE	9	2.9	1087			3.2	28.1	–	–	31.3

as 2% (GWD, 1998). Thus, the estimated ground water potential of the project area, excluding the hills, is about 856 million gallons ($3.0\ 10^6\ m^3$) (Table 3).

Table 3. Groundwater potential of Tulesar-Baorli watershed

Description	Value
Area of watershed (a)	918.7 ha
Area of hills and upland (b)	62.7 ha
Net area considered for groundwater estimation (a - b)	856.0 ha
Saturated volume estimated	192.48 10^6 m^3
Specific yield	2%
Groundwater potential	3.85 10^6 m^3

Conclusion

Very low resistivity indicates the presence of saline aquifer. Moreover, due to either shallow bedrock or high clay content or both, only low discharges can be expected. Therefore, no part of the area can be recommended for any kind of ground water development program.

References

Abolfazli, H. 1996. Delineation of potential fresh groundwater zones through geoelectrical sounding data and its correlation with hydrogeological parameters in Jalore district, Rajasthan, India. *Ph.D. Thesis*, Banaras Hindu University, Varanasi, India.

CGWD 2000. Present status of groundwater resources of Rajasthan. *Bulletin, Central Ground Water Board,* Jaipur, 25 p.

Frohlich, R.K., Fisher, J.J. and Summerly, E. 1996. Electric hydraulic conductivity correlation in fractured crystalline bed rock, Central Landfill, Rhode Island, USA. *Journal of Applied Geophysics* 35: 249-259.

GWD 1998. *Assessment of Groundwater, Jodhpur District.* Ground Water Department Jodhpur, 80 p.

Henriet, J.P. 1976. Direct application of Dar-Zarrouk parameters in groundwater surveys. *Geophysical Prospects* 24: 344-353.

Mbonu, P.D.C., Ebeeniro, J.O., Ofoegbu, C.O. and Ekin, A.S. 1990. Geoelectrical sounding for the determination of aquifer characteristics in part of Umuahia area of Nigeria. *Geophysics* 56: 284-291.

Orellawa, E. and Mooney, H.M. 1966. Master table and curves for electrical sounding over layers structure. *Madrid:Interciencia* 125 p.

Yadav, G.S., Kumar, R. and Abolfazli, H. 1994. Estimation of hydraulic transmissivity from surface geoelectrical soundings. *Journal of Applied Hydrology* 7(1-4): 37-46.