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III. GEOLOGY

Hydrogeomorphology

GEOMORPHOLOGICAL STUDIES FOR EXPLORATION OF GROUND WATER IN RAJASTHAN DESERT

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In this article, the significance of geomorphology in location and exploration of the ground water potential zones in the Rajasthan desert has been discussed. The ground water zones i.e., aquifers occurring under different geomorphological settings have been classified into two major groups viz., (*i*) shallow aquifers and (*ii*) deep aquifers. The deep aquifers have been further divided into two subgroups (*a*) moderately deep aquifers (*b*) very deep aquifers. The shallow aquifers have developed in the younger alluvial plains, along the buried courses of the drainage channels and intermontane basins. Moderately deep aquifers mostly occur under rocky/gravelly and buried pediments. The dominant geomorphic factors which have favoured the development of the potential aquifers under these geomorphological settings are; type and extent of drainage pattern, thickness of alluvial and aeolian materials, presence and extent of structurally weak zone, and presence or absence of concealed structure. These geomorphic features also control the subsurface flow direction, geochemical zonation and gradient of the aquifers. Very deep aquifers have been encountered under the coarse grained, grity and friable sandstone formations. These aquifers are not controlled by geomorphic features but have either fossil waters or their sources of recharge are far away.

Keywords: Aquifers; Buried Courses of Drainage Channels; Static Water Level; Artificial Recharge; Intermontane Basins; Interdune Plains.

INTRODUCTION

RAJASTHAN desert has scanty water resources due to low and erratic rainfall. The average annual rainfall of this region is 7.5cm, to 45cm, about 90 per cent of which occurs in 2-6 showers during the period of monsoon from June to September. As a result, possibilities of developing surface water resources are meagre. Out of the total precipitation, 65.75 per cent is utilised for cropping, deep drainage etc; 1.91 per cent goes out as run off. Out of the total run off, only 44.56 per cent is being utilised at present and the rest is lost during its course upto Rann of Kutch. Most of the precipitation is stored within the region in the form of ground water. Major portion of the region is covered with thick blanket of blown sand and sand dunes which obscure quick study of the concealed geological features. Hence, for exploring ground water, various expensive and time consuming indirect methods have to be adopted. For the benefit of the people, it is of paramount importance that one or more techniques costing less time and money, for locating ground water resources, should be developed and adopted.

The main source of groundwater is "precipitation within the region", which enters in the subsurface formations in two ways :

(*i*) *Direct percolation or through surface drainage.* It has been experimentally established that during normal rainfall year, there is not adequate precipitation which would directly percolate into the subsurface formations. During such period, evaporation and evapotranspiration losses exceed the normal average precipitation.

(*ii*) *Surface runoff through existing or prior drainage channels.* Development of the drainage channels is entirely governed by the morphological features which in turn depend on the lithological type, its fabrics and climatic conditions responsible for the development of various physico-chemical reactions of several weathering agencies. The drainage channels conspicuously and clearly manifest in the aerial photographs in three dimentional perspective and can be very precisely demarcated and mapped.

The above clearly suggest that preliminary delineation and mapping of the geomorphological units for any region in their correct perspective along with their mutual relationships with other parameters can provide rapid and valuable clues on the groundwater potential zones.

Discussion

The ground water potential zones that are aquifer encountered in different geomorphological settings of this region, can be divided into two major groups : (*i*) shallow acquifers; and (*ii*) deep aquifers. *Shallow acquifers* : These are generally developed in the older and younger alluvial plains, inter-dunal plains, piedmont plains, pediments and inter-montane basins and are directly dependent for their recharge on the drainage pattern, magnitude and type of water bearing alluvial material. These are mostly situated in the Central Luni basin covering Jalore and Pali district, southern portions of Jodhpur and Barmer districts. The following are the controlling factors for the development of such aquifers :

(*i*) Presence and extent of drainage patterns.

(*ii*) Presence and magnitude of a proper aquifer.

(*iii*) Thickness of the alluvial material.

(*iv*) Presence and extent of structurally weak zones which would act as a good conduit for water movement.

(*v*) Presence or absence of formations which would release salts to deteriorate the quality of water, like carbonate pan, gypsum bed, gruss zone etc.

(*vi*) Presence of sand dunes or sand cover on the piedmont plains or pediments or drainage channels which would act as good reservoirs for groundwater accumulation.

(*vii*) Presence or absence of concealed structure which would restrict the subsurface flow of ground water and develop a subsurface reservoir over an underlying relatively impervious formations.

It is not only that the geomorphological features and the controlling factors are responsible for the development of potential aquifers but these also govern their subsurface flow directions and geochemical zonation and gradient.

Chatterji (1964) has worked out the various types of quifers depending on the geomorphological features of the central Luni basin. The water potentials established by him in various types of aquifers situated under different geomorphological settings are shown in Table I.

TABLE I

Ground water exploitation zones

S. No.	Class of zone	Total No. of zones	Total area in sq. km.	Ratio of the total area (Percentage)	Ground water reserve in million cubic* meters	
					Total	in 100 sq. km.
1.	Plain tract	9	316.0	2.82	10.2	3.2
2.	River tract	11	1297.3	11.71	17.2	1.3
3.	Inter-dune areas	4	179.1	1.57	6.7	3.8
4.	Inter-montane areas	6	562.0	5.01	8.3	1.4
5.	Foot hills	9	106.2	0.96	0.41	0.3
6.	Unexploited					
	(a) Hills	—	290.0	2.58	—	—
	(b) Rest, including water-table tracts covering a few hectares	3	8441.2	75.35	—	—
	Total	42	11188.8	100.0	42.81	

*The water reserves have been calculated on the basis of the formula given by Talman (1937).

According to Chatterjee (1964) the static water level is the least in case of alluvial plains near river tracts and maximum in the case of inter-dunal plains. Average discharge potential is maximum in case of alluvial aquifers situated in the piedmont plains. The total soluble salt contents are the least in the intermontane basin aquifers. Considering this value of total salt contents as standard, the total soluble salt contents of various other types of aquifer have been statistically analysed and are shown in Table II.

It is quite apparent from data in Table II that the total soluble salt contents in the case of intermontane and foot-hill areas are not significantly different. In the basin, 16.4 per cent of the area has no salt hazard, 25.4 per cent has slight, 34.3 per cent has medium and 21.3 per cent area has high salt hazard. 2.6 per cent of the area is under hills.

From Table III, it is quite apparent that a relationship exists between depth of static water level and total soluble salt contents in the case of plain tract ($p < 0.001$, $r = -0.47$); while in other cases the relationship does not hold good. Except in interdunal areas, in all other types of water potential zones, the relationship between the static water level and total soluble salt is negatively correlated, indicating that there is a regular salt concentration in interdunal areas.

In Table IV, a comparison of the behaviour of static water level and total soluble salts of different types of water potential zones in the entire region

TABLE II

*Statistical analysis of total soluble salt contents in different types of water potential zones**

S. N.	Comparison between inter-montane area and	't' value	'p' value
1.	River tract	7.265	< 0.001
2.	Plain tract	24.722	< 0.001
3.	Foot hills	0.56	Not significant
4.	Interdune area	30.80	< 0.001

TABLE III

Statistical relationship between static water level and total soluble salt in different types of water potential zones

S. No.	Group	'r' value	't' value	'p' value
1.	Inter-montane area	− 0.009	0.005	< 0.500
2.	River tract	− 0.16	1.303	< 0.100
3.	Plain tract	− 0.47	3.305	< 0.001
4.	Foot hills	− 0.20	0.56	< 0.500
5.	Inter dune area	− 0.37	1.213	< 0.200

TABLE IV

Significant levels of correlation co-efficients of static water level and total soluble salts in different types of water potential zones

S. No.	Group	'Z' value	SD = 1/ $n-3$	In comparison to entire region	
				't' value	'p' value
1.	Intermontane area	0.050	0.02	1.2	0.0400
2.	River tract	0.161	0.01	1.6	0.200
3.	Plain tract	0.51	0.04	0.7	0.500
4.	Foot hills	0.205	0.14	4.4	0.001
5.	Interdunal areas	0.380	0.14	1.2	0.200

*The following standard statistical abbreviations have been used in the tables 2, 3 and 4
't' = student's 't' Z = Fisher's "Z" (transformed value or 'r') p = Probability level
r = Coefficient of correlation SD = Standard Deviation n = Number of pairs or observations or sample size.

($Z = 0.107$; $SD = 0.003$) is shown. It appears that all the tracts have their own distinctive patterns of their relationship and the individual variations are such as to baffle any attempt to give a composite picture of the whole region by any generalised statement of this relationship.

Chatterji (1966) has further shown that the potentials of aquifer situated on the piedmont plains are directly related to the joint pattern and deposition of sand on them. The results of his studies around Israna hill, composed of Jalore granite are shown in Table V.

TABLE V

Hydrogeological observations around Israna hills

No. of wells	Lithology of acquifer	Physiographic setting of wells	Approximate discharge per well in 1 p.h.	Static water level (in metres) &		Total soluble salt (in ppm)
				Observed	Variation after rains	
1	Granite	Sand deposit	8,000	14.3	1.3	1,328
2	B-Glown Sand	Upper piedmont	1,500	15.9	No	6,400
7	Granite	Sand deposit	1,500	15.9	3.0	538
4	Granite	Upper piedmont	5,500	11.0	1.6	717
12	Granite	Sand deposit	100	4.3	1.0	934
Nill	Granite	Hill	Nil	—	—	—
5	Granite	Sand deposit	5,500	23.2	1.5	1,376
7	Granite	Sand deposit	16,500	16.8	1.5	2,880

Ghose *et al.* (1966) have established the correlations between the landforms of Sojat area and availability of subsurface water. They have concluded from this study that the flood plains have more water potentials and the source of subsurface water is from the subterranean flow of the Sukri river. The river Sukri originates from a Catchment in the Aravalli ranges, where rainfall is higher but there is a very little run-off. Most of the water flows underground along the river bed and contributes to ground water reserves or flood plains The pidemont plain is an erosional feature situated at a higher level than the flood plain and there is no possibility of subsurface water flow in this unit. The older alluvial plains, due to presence of *kankar* pan below the alluvial material have less water potential and ground water is generally assceiated around small nullahs or present and prior drainage channels. As these are further away from the Sukri river, subsurface flow does not reach there. As a result, water in such aquifers is more mineralised.

Pandey *et al.* (1968) have shown the influence of geomorphic features on water resources in the areas around Jodhpur. They have indicated that the drainage basins in different geomorphological units have different geomorphic properties. The relationship of number of streams and total length of streams with different order in basins are different. The structure and resistance of the rock type are the principal governing factors for the variation of drainage patterns. They have inferred that younger alluvial plains, lower piedmont zones and inter-montane valleys are the best situations for the development of the ground water potentials. The depth to water table in the younger alluvial plains, specially along the master streams is shallow and varies from 5m to 17m. The depth to water table in inter-montane valleys varies from 14m to 44m and 8m to 25m respectively.

The rocky flat plains with the shallow soil cover and inter dunal plains (rocky with shallow soil cover) are the poor hosts of ground water. Hence, they concluded that water may be found along the channels, at the end of the channels and in the bed of the channels.

Ghose and Singh (1973, 1974, 1975) have worked out influences of prior stream channels on ground water potentials in the vast alluvial and interdunal plains in the Jodhpur district. These studies revelaed that buried course of the prior drainage channels in real sense preserve and regulate the flow of ground water in the area. Moreover, in addition to these prior channels, the flood plains along the Mitri river are considered to be water potential aquifers. Saha (1953) has reported water potential zones near Samdari on river Luni bed have developed due to the presence of a concealed ridge below sand cover on the Malani rhyolite basement.

Chatterji (1963) has indicated that in the plain tracts where the channels have been suffocated due to piling up of blown sand are the water potential areas because the water of the channels is directly discharged into the deposited sand which have good storage capacity.

Taylor *et al.* (1955) have indicated that in the plain tract of Pali area, which is composed of Jalore granite with a very shallow soil cover, the development of water potentials zones are dependent on the presence and magnitude of the gruss formation; which is again dependent upon the physiography and the presence of drainage.

Ghose (1965) has discussed the genesis of desert plains in the central Luni basin and suggests that old and disorganised stream channels regulate the subterranean flow of water. Whenever there is any precipitation, water sinks immediately in the alluvial detritus and flows subterraneously. Since the passage of this subsurface water is very slow, most of this water is preserved underground in these old channels at Shallow depths. As such, the relics of these channels will form good prospecting and exploiting sites for ground water.

Verstappen *et al.* (1962) have worked out the inter-relationship between different land forms, the water potenials and the land use in Central Rajasthan. The results of this study indicate that the huge masses of usually fine grained sands piled both on the dissected sand dunes and on the parabolic/longitudinal dunes are capable of retention of considerable quantities of water. The older alluvial plains due to the presence of impervious layer of lime concretion, the precipitation falling within this unit does not infiltrate below the concretion layer and thus it cannot substantially contribute to the recharge of ground water resources. The younger alluvial plains due to the absence of *Kankar* pan is the most water potential unit and has the largest concentration of wells.

Chatterji (1964) has indicated that water is generally in sub-artesian conditions in the interdunal areas due to the presence of relatively impermeable layers within the dune deposited in different sequences of deposition.

Ghose *et al.* (1975, 1976) have observed in Merta and Degana tehsils of Nagpur district that the prior drainage channels are covered with thick alluvium and sand which are good accumulators of ground water and water occurs at 5m to 20m depth. Kidwai and Kapoor (1971) have also indicated that in Nagpur district ground water is generally associated with Quaternary formations which are associated with drainage of the region.

Roy *et al.* (1968) have worked out on the genesis of carbonate pan which is a characteristic geomorphic feature of arid zone of Rajasthan and have indicated that the presence of carbonate pan is one of the principal cause of mineralisation in shallow groundwater found in hard rock areas.

(*ii*) *Deep aquifers*

This group of aquifers can again be further sub-divided into two sub-groups viz., (*a*) moderately deep and (*b*) very deep. Such aquifers are generally situated on the piedmont plains of hard rock formations and in the rocky/gravelly pediments or limestone and sandstone burried pediments covered by colluvial and alluvial sediments and were sandstone or limestone forms concealed aquifer.

(*a*) *Moderately deep aquifers* : Such aquifers are generally located in Jhunjhunu, Sikar, Nagaur districts, northern part of Jodhpur and central part of Barmer districts and southern part of Churu district.

Recent investigations by Chatterji *et al.* (1976) have proved by geophysical methods the existence of enormous water resources in the sub-terranean sandstone aquifers below prior channels in Naradhna area near Nagpur. Similarly, Chatterji and Vangani (1976) have reported that in an inter-dunal area situated in proximity to eroded rocky area near Nagpur, where there is no channel of any type present sufficient recharge takes place in the interdunal areas in direct response to the precipitation. This is due to the presence of structurally weak zones in the eroded rocky areas. Similarly, Chatterji *et al.* (1970, 1971) have proved by geophysical methods in area around Rampura-Mathania and in Jodhpur city, where the subsurface bearing formations are sandstones, that under favourable morphological and drainage conditions, the recharge was effective. UNDP (1971*a*) has reported water occurrence of water potential on pediment surface of Vindhyan sandstone under aeolian and alluvial cover near Doli-Jhanwar-Pal area near Jodhpur.

This type of aquifer is generally either found in sandstone and limestone formations or in granites, phyllites, schists etc. In the sandstone and limestone formations the morphology and the existence of a drainage system has a direct relationship with the availability and hydrogeochemical zonations in ground water, whereas in other rock formations it is the presence of fractures, faults etc. either exposed in catchment areas or below drainage network which can act as a good conduit for water movement. Borunda limestone aquifer has its recharge source not within the area but is connected with a fault to river Luni which recharge the aquifer (UNDP, 1971*b*).

Singh *et al.* (1972), Ghose *et al.* (1976) have also observed that the sandstone and limestone buried pediments in noth-eastern and north-western parts of Jodhpur district and Nagaur tehsil have moderately deep potential aquifers. The precipitation infiltrates through the thin veneer of alluvial and aeolian sediments and weathered zones and is accumulated in hard strata in the form of ground water.

(*b*) *Very deep seated aquifers* : These types of aquifers are generally found in the sandstone formations which are coarse grained, gritty and friable. Such formations are encountered at greater depths below thick cover of dune sand and other formations in the Jaisalmer district, north of Barmer and Churu districts and Bikaner district. Such aquifers have a very little relationship to the surface morphological or the drainage features and generally have either fossil water or their source of recharges are far away from the aquifers, and may be in-confined conditions.

Though, however, some ground water accumulation takes place in the interdunal areas were favourable subsurface condition exist to develop perched situation (UNDP, 1971*c*). These ground water bodies develop in direct response to local precipitation, specially during the surplus rainfall year. This type of aquifer can be classified under moderate to very deep type.

However, aquifers in Tertiary sandstones around and south of Bikaner which are underlain by older alluvial plains have a direct relationship to the prior drainage channel existing near Kuchor, Hadda, Ratrio, Udasar, Girasar and Channeri villages. It has been seen, though this formation is widespread, the water potentialities lie only within the confines of the drainage system (Singh *et al.*, 1975). Sett (1958) has stated that the recharge to this aquifer is poor.

Also much work has been undertaken on similar lines in other countries regarding the factors responsible for the development of ground water potential bodies in various types of lithological formations. Langhein (1947), Dignman *et al.* (1954), Le Grand (1954), Langford Smith (1960) etc., have also studied and found that geomorphic features, development of which are governed by the lithology, fabric structure and climate; are the controlling factors for subsurface water flow, development of aquifer and mineralisation in ground water. Each investigator has also laid more emphasis on a drainage basin as a unit of investigation rather than any political boundary. However, due to appreciable variations in the precipitation, lithology and structure coupled with highly localised water potential zones, exploitation in arid areas is difficult.

Geomorphological studies not only facilitate locating potable water potential aquifers but are also essential prerequisites for rightly locating surface water resources. In selecting proper methods of artificial recharge to augment ground water resources, it helps in proper land use planning especially when irrigation with canal has to be adopted etc.

Moreover, when the canal irrigation is adopted in desertic areas, water percolation to the subsurface formation is at a much greater speed due to sandy terrain. Similar phenomenon has also been observed in the arid portions of Rajasthan. Hence, water is rising with an alarming speed of 0.3 metres per year in the Gang canal area and with 1.5 metres per year speed under Rajasthan and Ghaggar canal area. With this speed of rising water table within a period of 50 years or so, water table will be within 6 metres depth of the land surface; which is the critical limit for development of salinity and water logging in the sandy areas (UNDP/FAO, 1970).

To avert this situation, the best solution would be to take out this excess water by way of wells and bury it deep in the adjoining areas where water table is not rising, for utilising as a source of ground water now and later. This would again mean a comprehensive knowledge of the geomorphic features alongwith subsurface lithological formations which are of paramount importance for any such planning.

CONCLUSIONS

From the above discussion, it is apparent that a comprehensive knowledge of geomorphological features of the Indian desert would facilitate in locating and exploring ground water potential areas for the development of the region. Moreover, geomorphological studies would also help in many ways in land use planning and utilisation of excess seepage water under canal zones. Surface runoff, consumptive utilisation by crops, evaporation losses by vegetation and deep drainage are principally governed by soil types and land use which are dependent on the geomorphology of the area. However, it may be stated that natural parameters are so varied that any generalised investigation would not give proper economic returns. The geomorphological studies to be adopted as a tool have to be essentially coupled with exploratory drilling and pump testing to enable to arrive at proper conclusions with regard to the aquifers which are economically exploitable without quality hazards. It is aslo apparent that the development of water potential aquifers are localised in nature and are not widespread which is mainly due to the lithological formations and structures of the region. As a result, any study on regional basis or district basis will not be fruitful unless the detailed geomorphological mapping is undertaken for showing clearly all the controlling factors up to micro catchment unit levels. This would be only possible if the geomorphological mapping is undertaken at least on 1:50,000 scale with the help of the latest aerial photographs and adopting a basin as a unit of investigation. However, at 1 : 1 million scale, regional preliminary information and demarcations would be easily possible with the help of satellite photographs.

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