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Appraisal of the Quality of Ground Waters in the Arid Zone of Rajasthan and Kutch

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Abstract. A survey and analyses of waters of arid zones of Western Rajasthan and Kutch have been presented. The data on physico-chemical characteristics of about 2000 ground water samples indicate that according to International Standards of drinking water as devised by WHO, 9 per cent waters in Rajasthan and 19 per cent in Kutch conform to permissible limits (TDS < 500 mg/l) and are suitable for drinking. Considering 2000 mg/l TDS, as maximum permissible level, 46 per cent of available waters in Western Rajasthan and 71 per cent in Kutch are potable. 38 and 57 per cent of waters have electrical conductivity less than 2250 micromhos/cm in Rajasthan and Kutch respectively.

Salinity and toxicological studies of brackish waters and their remedial measures are also discussed. A tentative correlation between prevailing water-borne diseases, kidney diseases and fluorosis and dissolved solids in waters of Western Rajasthan has also been shown. The waters have been classified into various suitability classes depending upon their composition.

Introduction

The Western Rajasthan, part of the Thar desert, is mostly covered by wind blown sand and sand dunes. The area has suffered extreme climatic oscillations in the past. From historic evidence[1] it is deduced that the present desert area was well wooded and marshy. Within a few thousand years, the climate has turned from mild humid to arid. The investigations[2] have shown that presence of large scale dust in air over the area due to wind erosion is one of the important cause for the divergence in the upper levels of air, which is responsible for absence of rain over the area.

The hydrogeological survey[3] of 0.31 million sq km area of Rajasthan has been completed by Central Ground Water Board (CGWB) in 1979. The hydrological map of India prepared by the Board depicts the occurrence, availability, movement and quality of water, etc. (with 41 parameters) as available in the sub-surface formations in the country, Based on hydrogeological surveys of Rajasthan, the Board identified the areas suitable for well construction.

The five districts of Western Rajasthan-Barmer, Jaisalmer, Bikaner, Jodhpur and Ganganagar falling in arid zone, have an area of 0.13 million sq km as against the total area of 0.19 million sq km of the Thar desert in the Indian territory. It is a

water deficit area having acute problem of saline ground waters. If all sources of water are taken into account, the total reserve comes to 310 billion cu. m, which is just equal to 4 years of the annual average precipitation. This estimate of ground water is an approximation computed from preliminary surveys of smaller areas in and around Lathi basin and Barunda limestone. Aquifers in general are limited in thickness and depth. There is hardly any recharge as average annual precipitation rarely exceeds 300 mm for the whole arid track. Quantitative assessments[4,5] of the ground water resources in Western Rajasthan have been carried out by the CGWB with the help of United Nations Development Programme during 1967—1974. The major objectives of the programme were to investigate and evaluate ground water potentials and ground water quality and to make appraisals of the technical and economical feasibility of ground water development by undertaking ground water resources explorations and evaluation in future.

UN technical team has concluded[4,5] that :

(a) Spread over an area of 41,000 sq km the reserve can yield 50 MCM (Million Cubic Metre) of water every year from the desert area of North and West Rajasthan surveys.

(b) The aquifer which is thick, extensive, near-shore deposit sand-stone formation in the Lathi area is estimated to contain 28,640 MCM of fresh water.

(c) In parts of Jaisalmer district in the Lathi-Chandan-Bhairawa track covering 518 sq km of area, studies reveal that the ground water resources potential is of a high order and that it can sustain medium to large scale development. The present rate of ground water development is around 2 MCM per year and it is estimated that the ground water from these formations can be withdrawn at the rate of 58 MCM per year for 200 years. Based on this study 42 high capacity tube wells can be constructed in this area.

(d) The team has also founded that in Lathi area the wells will have to be drilled to a depth of more than 150 metres.

(e) In Bikaner basin it was found that Palana sand-stones occurring in the depth span of 170 metres could sustain a development of ground water of the order of 50 MCM.

(f) In Luni basin it was found that another 9 MCM of fresh water was available from the quaternary alluvium for development purposes.

(g) In the district of Jodhpur water balance studies around Barunda have helped the identification of large fresh ground water storage in the limestone formations. The estimated safe yield of fresh ground water in the limestone has been worked out to be of the order of 24.5 MCM per year and the draft is normally about 12.4 MCM per year. There is thus a clear scope for further development for 12.1 MCM per year through series of production wells.

(h) Considering 3000 mg/l of total dissolved solids in ground waters as recommended by ICMR for the areas where alternative drinking water sources are not available, 60 MCM of water from Bikaner and Luni basin can be subjected to development through tube wells.

Geological survey of India[6] has also revealed sufficient deposits of waters in about 1000 sq km area in Barmer and Jaisalmer districts. The water discharge capacity of

the source available in the Lathi zone of Jaisalmer district is estimated to be 1 lakh litres per hour. The capacity of sources in Bikaner is about 50,000 litres per hour. More attention have been paid to the ground water resources of Western Rajasthan to develop arid and semi arid regions and various organisations[7–11] engaged in these studies are carrying out intensive exploration of the deeper aquifers followed by some hydrological techniques.

The radiometric carbon dating[12] on ground water samples in the Lathi basin has shown an age of 6000-9000 years for this water. The carbon-14 dating of ground water from Lathi-Chandan-Bhairawa area was also carried out[4] by TIFR, Bombay and the age of ground water from Bhairawa test-wells has been found to be 7000-8000 years and in Ajasar test-wells, 8000-17,000 years.

The Kutch district of Gujarat falling in the arid zone has an area of about 38,500 sq km and its extreme western region is full of thorny bushes. The northern region is the low lying area called Rann. There is practically no vegetation and potable water resources are scarce in this region. Scanty rainfall, reoccurring draughts, and absence of perennial rivers have hindered the development of the district.

Rajasthan State and Kutch district have limited perennial rivers to develop major irrigation schemes. Even after taking into consideration the ultimate benefit which will be available after the completion of Chambal Project and Rajasthan Canal Project the percentage of irrigation in the Rajasthan will be only 15 per cent of the available cultivable land in the state. The minor irrigation projects have only so far been executed by maximum utilisation of local resources by construction of open wells and tube wells, which contribute about two third of the total irrigation in the state. The CGWB and Rajasthan Ground Water Board (now known as Rajasthan Ground Water Department) after hydrogeological and geophysical surveys of Western Rajasthan undertook construction of 339 tube wells[13] (Barmer, 41; Jaisalmer, 82; Bikaner, 92; Jodhpur, 107 and Ganganagar, 17) and 666 open wells[14] (Barmer, 52; Jaisalmer, 19; Bikaner, 7 and Jodhpur, 588) during 1956-72.

In the present investigation an appraisal of the quality of ground waters for drinking and irrigation in the arid zone of Rajasthan and Kutch is presented. The Defence Laboratory, Jodhpur has carried out a detailed survey and the physico-chemical, toxicological, and desalination studies[15–17] on brackish waters of Thar desert during the last 20 years. The review article discusses the detailed studies on about 2000 ground water samples covering five districts of Western Rajasthan (Barmer, Jaisalmer, Bikaner, Ganganagar and Jodhpur) and one district of Gujarat (Kutch) falling in arid zone. Salinity and toxicological studies on brackish waters and their remedial measures including assessment of quality and quantity of water, and desalting kits, etc., developed by this laboratory are also discussed. The waters have been classified into various suitability classes considering electrical conductivity, sodium content, salinity and hardness, etc., for appraisal of water quality for irrigation.

Physico-chemical Studies

Collection of samples — The Survey of India map was taken as major guide. The means of transport was jeep, or camel where jeep could not negotiate the area due

to sand-dunes. The water samples (about 1600) from Western Rajasthan and Kutch (400) were collected in polythene bottles and brought to the Laboratory for examination and analysed. During collection of samples other data, namely, ambient temperature, temperature of water, depth of well, length of water column, diameter of well, and taste of water were also recorded.

Yield of wells — The discharge capacity of 85 representative open wells of arid area of Rajasthan used by the Services (TDS < 2000 mg/l) was also determined[18]. The mechanical bailer[18] developed by this laboratory was used for the study.

Physico-chemical analysis — The water samples were submitted to physico-chemical analysis[15-17] and the following were noted : *pH*; electrical conductivity; anions—chloride, bicarbonate, carbonate (volumetrically) and sulphate (gravimetrically); cations—calcium, magnesium (volumetrically using EDTA), sodium and potassium (using flame photometer); TDS and hardness as calcium carbonate (total, temporary and permanent). The Ca/Mg, Cl/SO_4, Cl/TDS and SO_4/TDS ratios have also been calculated and reported.

Toxicological Studies

Besides the normal chemical constituents, ten toxic metals and ions—*As*, *Ba*, *Cd*, *Cr*, *Pb*, *Se*, *Ag*, *CN*, *F* and NO_3 were also estimated in 200 ground water samples collected from forward areas and other important locations used by the Services. A survey of water-borne diseases, kidney diseases and fluorosis has been carried out[17] in the Military Hospitals at Jodhpur and Bikaner to examine whether a correlation exists between prevailing diseases and dissolved solids in waters of Western Rajasthan.

During the survey the stagnant brackish waters have been found smelling with H_2S. The shallow water sources have been reported to be contaminated with guinea-worm. Microbiological studies on these samples were carried out in the laboratory. Studies on random 400 water samples from drinking water supply were also carried out in order to study the frequent outbreaks of water-borne diseases in Army areas. Bacteriological studies of these water samples were mainly done for examination of coliform group of organisms using a new, rapid method developed by this laboratory[19].

Studies of Water Quality for Irrigation

The mean composition of TDS, *pH*, CO_3, HCO_3, *Cl*, SO_4, *Ca*, *Mg*, *Na* and *K* have been calculated for ground waters of Barmer, Jaisalmer, Bikaner, Ganganagar, Jodhpur and Kutch districts. The waters have been classified into various suitability classes for conductivity, hardness, sodium percent and TDS, *Cl* and SO_4 range, which are useful for classifying waters for irrigation.

The other useful value sodium absorption ratio[20] (SAR), which is an index of alkalinity hazard has also been calculated for Kutch district.

Results and Discussion

The drinking water standards as recommended by WHO[21], USPHS[22] and ICMR[23] are given in Table 1. The maximum and minimum values of the various physico-chemical

properties and constituents (*pH*, conductivity, TDS, hardness, *Cl*, SO_4, CO_3, HCO_3, *Ca* and *Mg*) of 2000 water samples studied and other general information (depth of well, etc.) are presented in Table 2. The corresponding values for the tap water at Jodhpur and sea water near Bombay are also given for the purpose of comparison. It is seen from Table 2 that the TDS of water samples varies between 98 and 29,564 mg/l, chloride from 7 to 12,737 mg/l, sulphate from traces to 6066 mg/l, bicarbonate from nil to 2340 mg/l in Western Rajasthan, while in Kutch TDS varied from 48 to 75,292 mg/l, chloride from 19 to 34,830 mg/l, sulphate from nil to 3642 mg/l and bicarbonate from 7 to 956 mg/l. The average conductivity in Western Rajasthan and Kutch comes to 5080 and 4399 micromhos/cm at 25°C respectively.

Table 1. Drinking water standards.

Sl. No.	Constituents	WHO		USPHS		ICMR	
		Max. acceptable (mg/l)	Max. allowable (mg/l)	Limits not to be exceeded (mg/l)	Cause for rejection (mg/l)	Highest desirable level (mg/l)	Max. permissible level (mg/l)
1	TDS	500	1500	500	—	500	1500*
2	Chloride (*Cl*)	200	600	250	—	200	1000
3	Sulphate (SO_4)	200	400	250	—	200	400
4	Lead (*Pb*)	—	0.05	—	0.05	—	0.1
5	Selenium (*Se*)	—	0.01	—	0.10	—	0.01
6	Arsenic (*As*)	—	0.05	0.01	0.05	—	0.05
7	Chromium (Cr^{+6})	—	0.05	—	0.05	—	—
8	Cyanide (*CN*)	—	0.20	0.01	0.02	—	0.05
9	Cadmium (*Cd*)	—	0.01	—	0.01	—	0.01
10	Barium (*Ba*)	—	1	—	1	—	—
11	Silver (*Ag*)	—	—	—	0.05	—	—
12	Nitrate (NO_3)	10	45	45	—	20	**
13	Fluoride (*F*)	0.8–1.0	1.0–1.5	0.7–1.2	1.4–2.4	1.0	1.5

*Dissolved solids relaxable upto 3000 mg/l in cases where alternate sources are not available within reach.

**More information is required to prescribe a value but in no circumstances should the level exceed 100 mg/l.

In Table 3 are given districtwise the percentage frequency of samples containing different ranges of TDS, chloride (as *Cl* and *NaCl*) and sulphate. It may be seen from Table 3 that in Western Rajasthan 27 per cent of ground waters contain TDS within 1000 mg/l, but the maximum percentage (53 per cent) of samples lies within 1001-5000 mg/l. Beyond 10,000 mg/l TDS, the frequency is only four per cent. In Kutch 40 per cent samples lie within 0-1000 mg/l TDS and maximum percentage of samples (71 per cent) are within 0-2000 mg/l. Salinity has been expressed as chloride and sodium chloride and the maximum percentage (52 per cent) of samples have chlorides within 0-1000 mg/l (as *NaCl*) in Western Rajasthan while in Kutch the figure is 74 per cent.

Table 2. Physico-chemical characteristics of ground waters of Jaisalmer, Barmer, Bikaner, Ganganagar, Jodhpur, Kutch districts, Jodhpur water and sea water.

Sl. No.	Details	Max. limit (Min. limit)						Tap water from Jodhpur	Sea water from Bombay
		Jaisalmer	Barmer	Bikaner	Ganganagar	Jodhpur	Kutch		
1	Depth (meters)	123(3)	105(2.2)	127.5(3)	61.5(1.65)	105(3)	52.5(0.6)	—	—
2	*pH*	8.94(7)	8.7(7.2)	9.0(6.5)	8.6(7.0)	8.5(7.2)	8.6(7.0)	7.8	—
3	(i) Conductivity (micromhos/cm at 25°C)	36300(254)	34200(320)	48500(567)	35652(260)	17900(218)	83104(111)	—	—
	(ii) Average conductivity	4928	5781	5491	4904	3935	4399	—	—
4	TDS (mg/l)	29568(160)	26140(200)	29140(430)	29016(98)	11914(154)	75292(48)	188	41408
5	Hardness as $CaCO_3$ (mg/l)								
	(i) Total	4358(18)	8095(18.5)	5984(26.6)	5422(13)	2540(60)	16400(46)	98	6776
	(ii) Temporary	4215(7)	2196(Nil)	5556(19)	959(2)	835(44)	8701(2)	11	45
	(iii) Permanent	4032(4)	2896(9.2)	3813(9)	5310(Nil)	2480(10)	15530(44)	87	6731
6	Chloride (Cl^-), mg/l	11978(14)	12361(26)	9911(31)	12737(7)	5620(26)	34830(19)	18	20068
7	Sulphae (SO_4^{--}) mg/l	4039(12)	3349(Nil)	4252(Traces)	6066(11)	1020(Nil)	3642(Nil)	Nil	2827
8	Bicarbonate (HCO_3^-) mg/l	1193(78)	1730(Nil)	2013(84)	1683(122)	2390(128)	956(70)	160	—
9	Carbonate (CO_3^{--}) mg/l	118(Nil)	168(Nil)	120(Nil)	56(Nil)	190(Nil)	81(Nil)	Nil	—
10	Calcium (Ca^{++}) mg/l	815(2)	804(5)	1168(3.2)	918(5)	558(8)	1945(5)	28	400
11	Magnesium (Mg^{++}) mg/l	612(1)	467(3.2)	627(1)	743(Nil)	383(6)	2818(2)	7	1403

Table 3. Percentage frequency of ground waters of Jaisalmer, Barmer, Bikaner, Ganganagar, Jodhpur and Kutch having different TDS, chloride, and sulphate range.

Sl. No.	District	Jaisalmer (%)	Barmer (%)	Bikaner (%)	Ganganagar (%)	Jodhpur (%)	Kutch (%)
1	TDS range (mg/l)						
	0 – 500	18	4	1	11	10	19
	0 – 1000	35	18	16	34	33	40
	0 – 2000	47	32	37	50	62	71
	2001 – 5000	37	41	41	35	27	20
	5001 – 10000	10	23	23	12	9	6
	Above 10000	6	4	5	3	2	3
2	Cl^- range (mg/l)						
	0 – 250	34	22	16	51	31	40
	0 – 600	49	18	25	17	31	25
	Above 600	17	60	59	32	38	35
3	*Cl* range as *NaCl* (mg/l)						
	0 – 1000	49	38	43	68	62	74
	1001 – 5000	40	46	39	25	34	22
	5001 – 10000	6	13	17	6	4	3
	Above 10000	5	3	1	1	—	1
4	SO_4 range (mg/l)						
	0 – 250	56	60	46	50	76	71
	0 – 400	16	17	42	24	8	21
	Above 400	28	23	12	26	16	8

The ground waters have generally high hardness from the potability point of view. Waters containing 121-180 mg/l hardness may be considered as hard, and those containing above 180 mg/l of hardness as very hard[24]. Table 4 presents this data as per the US Geological Survey classification[25]. It may be mentioned here that in USA, public water supplies have been made[25] of water having hardness (expressed as $CaCO_3$) from less than 10 to about 1800 mg/l. Such amounts of hardness are considered to be of no

Table 4. Percentage frequency of ground waters having different degrees of total hardness classified according to US geological system.

Class	Total Hardness as $CaCO_3$ (mg/l)	Degree of hardness	% Frequency					
			Jaisalmer	Barmer	Bikaner	Ganganagar	Jodhpur	Kutch
1	0–55	Soft	2	0.7	1.6	2	Nil	2.5
2	56–100	Slightly hard	5.6	3.5	2.8	8	1.8	3.5
3	101–200	Moderately hard	15.7	12.1	9.5	9.5	5	13.3
4	201–500	Very hard	44.6	40.5	34	31.5	64.1	36

sanitary significance but above 160-200 mg/l the usefulness of such waters for domestic and industrial purposes is limited. Looking into Table 4, a few samples, one per cent in Western Rajasthan and 2.5 per cent in Kutch, are soft and the rest either hard (slightly or moderately) or very hard. The maximum frequency of very hard water is found to be 43 per cent in Western Rajasthan and 36 per cent in Kutch.

Under the prevailing conditions of saline water irrigated agriculture in Western Rajasthan, all the classification in vogue like residual sodium carbonate, Puris salt index ratio, conductivity, SAR or sodium per cent and US salinity diagram have great limitations. Saline ground waters of electrical conductivity from 2000-12,000 micromhos/cm (TDS 1.5 to 7 gm/l) are used for growing wheat like *Kharchia* variety and barley in arid and semi-arid regions of Rajasthan[23]. In view of the above fact the mean values of ground waters of Barmer, Jaisalmer, Bikaner, Ganganagar, Jodhpur and Kutch are given in Table 5. The data on conductivity and sodium per cent of samples are enumerated in Tables 6 and 7 respectively. The classification of water with respect to conductivity (C) given in Table 6 clearly indicates that the percentage of excellent water quality

Table 5. Mean composition and quality of ground waters of Jaisalmer, Barmer, Bikaner, Ganganagar, Jodhpur and Kutch.

Sl. No.	District	Jaisalmer	Barmer	Bikaner	Ganganagar	Jodhpur	Kutch
1	TDS	3030	3729	4201	2941	2285	2474
2	*pH*	7.8	7.9	7.7	7.7	7.7	7.6
3	CO_3	27	22	Nil	Nil	Nil	38
4	HCO_3	388	384	405	464	485	294
5	*Cl*	1125	1393	1558	775	780	971
6	SO_4	337	365	590	523	235	239
7	*Ca*	108	94	160	138	89	27
8	*Mg*	80	91	143	94	69	86
9	*Na*	577	934	1348	551	519	521
10	*K*	29	61	39	49	85	23

Concentrations are expressed in mg/l.

Table 6. Percentage frequency of groundwaters of Jaisalmer, Barmer, Bikaner, Ganganagar, Jodhpur and Kutch having different conductivity (C).

Sl. No.	Conductivity (micromhos/cm)	Jaisalmer (%)	Barmer (%)	Bikaner (%)	Ganganagar (%)	Jodhpur (%)	Kutch (%)
1	C1 0 - 250	--	—	—	—	—	—
2	C2 251 - 750	10	6	4	18	6	13
3	C3 751 - 2250	31	21	24	33	38	44
4	C4 2251 - 4000	15	16	23	17	26	20
5	C5 4001 - 6000	14	19	10	13	14	11
6	C6 6001 - 12000	22	25	22	12	9	8
7	C7 above 12000	8	13	17	7	7	4

Table 7. Percentage frequency of ground waters of Jaisalmer, Barmer, Bikaner, Ganganagar, Jodhpur and Kutch having different sodium content.

Sl. No.	Sodium (%)	Water class	Jaisalmer	Barmer	Bikaner	Ganganagar	Jodhpur	Kutch
1	< 20	Excellent	10	4	0.5	8	1.8	6
2	20-40	Good	13.5	11.5	9.5	25	20.2	20.5
3	40-60	Permissible	15	18.5	19	29.5	34.5	34
4	60-80	Doubtful	35.5	42	45.5	26	33.5	28.5
5	> 80	Unsuitable	26	24	25.5	11.5	10	11

for irrigation in Western Rajasthan and Kutch is nil. The percentage frequency of waters having permissible conductivity limit upto 2250 micromhos/cm is 38 per cent in Western Rajasthan and 57 per cent in Kutch. In Western Rajasthan the maximum percentage (51 per cent) of samples, which are being used for saline water tolerant crops have conductivity between 2251 and 12,000 micromhos/cm while in Kutch the maximum percentage (57 per cent) lies below 2250 micromhos/cm.

The sodium per cent of the water samples is calculated by the formula[20] :

$$\frac{Na \times 100}{Ca + Mg + Na + K}$$ (where concentration of cation is taken in meq/1).

The knowledge of composition of salts in these saline lands is important for their correct management and expeditious reclamation. The sodium ion in highly saline ground waters of Western Rajasthan enters the exchange complex of soil, particularly if the soil does not contain gypsum and increases the exchangeable sodium percentage of the soil. The soils then develop undesirable physical characters which persists even after the removal of excess salt[27-23]. The sodium imbalance in drinking water has also been studied[29] due to large number of life threatening diseases and the greater number of persons affected by this metal ion.

It is observed from Table 7 that sodium per cent of ground waters varies from 2 to 97 per cent in Western Rajasthan and from 3 to 95 per cent in Kutch. In Western Rajasthan, the maximum number of water samples (36.5 per cent) have 60-80 per cent sodium while in Kutch the maximum number of samples (34 per cent) have 40-60 sodium percentage range. The SAR value for Kutch waters have also been calculated and found to vary from 0.36 to 66.5 with the average value of 8.

WHO and ICMR have indicated *As*, *Ba*, *Cd*, *Cr*, *Pb*, *Se*, *Ag* and *CN* as toxic substances and *F* and NO_3 as health affecting substances in drinking water beyond the limits given in Table 1. The amount of these metals and ions was estimated in 200 representative water samples, having TDS < 2000 mg/l collected from important locations of Western Rajasthan. None of the natural waters have been found to be contaminated with toxic substances. However, fluoride and nitrate are present in all the water samples analysed. It is found that over 50 per cent waters analysed contain fluoride above permissible limit of 2 mg/l and thus are unfit for drinking. The maximum concentration of flouride was found to be 18 mg/l. The nitrates are also available in waters of Western Rajasthan and in some pockets these are present in alarming limits

causing severe concern to live-stock[30-31]. The maximum concentration of nitrate reported is 1772 mg/l in water having TDS 5485 mg/l.

A survey of water-borne diseases, kidney diseases and fluorosis carried out to examine the possibility of a correlation between prevailing diseases and dissolved solids in waters of Western Rajasthan indicates that out of 3031 cases reported in Military Hospitals in Jodhpur and Bikaner during 1971-74, 82 per cent are due to water-borne diseases, 15 per cent due to kidney diseases and 3 per cent due to fluorosis and caries teeth.

The stagnant brackish waters smelling with H_2S, on bacteriological examination showed the presence of gram negative, non-sporulating, mezophilic type and highly motile bacteria. It was concluded from the detailed study that the type of sulphate reducing bacteria found in brackish water is *Desulphovibrio desulphuricans.* The bacterium has been reported for the first time from brackish waters of Western Rajasthan[32-33]. The preliminary studies[31] of microbiological reduction of gypsum to sulphide (75.5 per cent) on chemical oxidation yielded 16 per cent sulphur (gypsum, $CaSO_4 2H_2O$, contains 18.6 per cent fixed sulphur). Rajasthan with 100 million tons of gypsum may meet sulphur needs of the defence when the technique can be perfected.

Surface waters of the Western Rajasthan have been reported[35] to be contaminated with guinea-worm. Detailed laboratory studies confirm that the embryos of guinea-worm were generally present and the users of these water sources had a significant incidence of dracontiasis, a guinea-worm disease. This is also confirmed from the scrutiny of medical records at Military Hospitals in Jodhpur and Bikaner. WHO, reporting infection with guinea-worm in rural areas of India, has discussed the epidemiology, control and treatment of guinea-worm disease[36].

Microbiological studies on 400 random water samples from drinking water supply of Army areas have indicated the presence of coliform group of organisms. The bacteriological studies on *E. coli* in water have been carried out by a new culture medium and a rapid technique developed by this laboratory[19]. The test has been found useful by the services in locating the source of pollution during outbreaks of water-borne diseases.

The discharge capacity of 85 representative open wells of Western Rajasthan having TDS < 2000 mg/l has been determined by Dupit's formula[25] using a mechanical bailer[18] fitted jeep developed by this laboratory. The capacity of the wells has been found to vary from 0.6 to 1.6 m^3/hr/m drawdown. It is also found that the depth of the open wells generally lies between 30–140 m, dia between 1–2 m and water column between 2–4 m. The gadget is a useful device for drawing water from deep open wells of Western Rajasthan, where commercial water pumps fail due to great depths and submersible pumps do not work satisfactorily due to insufficient water column. The gadget using engine power of stationary jeep or a 4×4 vehicle is effective in drawing 5000, 3000 and 2000 litres of water in one hour from the dug wells having depth 30, 80 and 140 m respectively.

Based on the survey, and analyses of waters of Rajasthan desert and Kutch, the studies on desalination of brackish waters and development of suitable gadgets for the

assessment and removal of dissolved salts from water were undertaken. A plant for water desalting[37] with capacity of 10,000 litres of drinking water per 8 hour of operation, based on electrodialysis method has been developed by this laboratory. This model is being modified and a plant based on reverse osmosis method is also being developed. An emergency desalting kit for removal of dissolved solids from sea-water as well as brackish water and a desert desalting kit[38] for removal of dissolved solids and toxic substances from brackish waters have been successfully developed for defence needs.

A water testing field kit[39] for assessing chemical[10] and bacteriological quality[19] of water has been developed and is being introduced in Armed Forces and BSF services. The assessment of chemical quality is based on determination of total dissolved solids using a portable battery operated conductivity meter and visual-instant tests for chloride, fluoride, nitrate and nitrite determinations. The bacteriological examination is based on a new culture medium developed for testing *E coli* in water. The test takes about 10 hours for *E coli* free water and is concluded in 14–20 hours for contaminated waters.

Conclusion

1. Hydrogeological surveys[3] conducted by the UNDP have indicated that about 1500 tube wells of heavy and medium capacity could be immediately constructed to exploit the resource of about 260 MCM per year. This would help irrigating 61,000 hectare of crop land in this desert region.

2. The soil and water analytical data[3] obtained during the UNDP studies indicated the suitability of fresh groundwater in lime-stone formations of Barunda, Jodhpur (24.5 MCM per year) for agricultural purposes in selected areas.

3. Survey and analyses of waters of Western Rajasthan and Kutch indicate that 9 per cent waters are potable in Western Rajasthan and 19 per cent in Kutch considering drinking water standards of WHO/USPHS/ICMR.

4. The local inhabitants and Armed Forces located in the strategic desert area have to depend for drinking water and other needs on this scarce 9 per cent available water. This drinking water limit needs relaxation in view of the requirements of civil and defence personnel as adopted by other countries like USA[24,40] and Mexico[41], etc, where water with over 4000 mg/l TDS is used for drinking purposes. While surveying Western Rajasthan and Kutch, the survey teams came across several regions where potable water was not available and villagers were using brackish waters (TDS, 2500–4000 mg/l) for drinking since generations without any deleterious effects. In view of the above study this laboratory has recommended the maximum permissible limit of total dissolved solids in desert waters to be relaxed from 500 to 2000 mg/l. This recommendation is also in agreements with the ICMR recommendations[23] wherein TDS limit has been relaxed upto 3000 mg/l from 1500 mg/l maximum permissible level in areas where alternate sources are not available within reach. Considering 2000 mg/l as maximum permissible level of dissolved solids in water, 46 per cent available water of Western Rajasthan and 71 per cent in Kutch are potable. (Table 3).

5. Percentage frequency of TDS, chloride, hardness, conductivity and sodium percent are all in agreement with the conclusion that the brackishness in waters of these districts is in following decreasing order, Barmer > Bikaner > Jaisalmer > Jodhpur > Ganganagar.

6. Hydrochemical methods of explorations[42] for oil and gas formations are based on the determination of the saline composition of water. The saline content of waters as well as some single components, salts and ion can be used as indirect indications of the presence of petroleum.

7. The only river in this region is Luni which originates from the hills near Ajmer and merges in the Rann of Kutch. It remains practically dry except during monsoon season and hence cannot be used for irrigation. Irrigated agriculture thus can only be planned with the limited underground waters under good management.

8. The brackish water with conductivity range 2250 to 12,000 micromhos/cm can be satisfactorily used for growing *Kharchia* variety wheat, barley and other salt resistant crops.

9. The natural waters of the region are free from toxic elements but nitrate and fluoride are present in abundance in certain pockets and need careful control.

10. Microbiological studies and survey of Military Hospitals have shown a tentative correlation between prevailing diseases, dissolved solids, guinea-worm and *E coli* observed in waters. Detailed studies are required to establish the correlation.

11. Water resources maps demarkating brackish and potable zones based on survey of the waters of Western Rajasthan and Kutch have been found extremely useful by the Services.

12. Different types of kits and gadgets developed by the laboratory for assessing quality, quantity and demineralising brackish waters may find use in the civil sector also.

References

1. Wheeler, R. E. M., 'Five Thousand Years of Pakistan' (Roy. Ind. and Pak. Soc., London), 1950, 150; Arid Zone Research—VI. Plant Ecology, Reviews of Research (UNESCO), 1955, 25.
2. Twelve Years of Arid Zone Research (1959-71), Central Arid Zone Research Institute, Jodhpur, 1972, 6.
3. Baweja, B. K., 'Status of Ground Water Surveys and Exploration' (Central Ground Water Board, Ministry of Agriculture, Govt. of India, Faridabad), Haryana, 1980.
4. United Nations Development Programme, 'Ground Water Survey of the Jaisalmer (Lathi) Area, Rajasthan' (United Nations, New York), Technical Report, 1971.
5. United Nations Development Programme, 'Ground Water Surveys in Rajasthan and Gujarat, Technical Report No. DP/UN/IND-71-614/4 (United Nations, New York), 1976.
6. 'Resume of Work Carried out in the Western Region', G.S.I., 1971.
7. Proceedings of the 'Symposium on Ground Water Studies in Arid and Semi Arid Regions' held at University of Roorkee, Roorkee, 1966.
8. Report on the 'Winter School on the Development of Rajasthan Desert' held at CAZRI, Jodhpur, 1973.

9. International Symposium on 'Arid Zone Research and Development' organised by the Arid Zone Research Association of India (with the support of ICAR and UNESCO) held at CAZRI, Jodhpur, 1978, Abstracts.
10. Gupta, S. K. & Sharma P. (Ed.), 'Current Trends in Arid Zone Hydrology' (Today and Tomorrow Printers and Publishers, New Delhi), 1979, 373-78.
11. 'Workshop on Nuclear Techniques in Hydrology' organised by Isotopes in Industry Committee, Department of Atomic Energy, held at NGRI, Hyderabad, 1980.
12. Roy, A. A., Raju, D. V. N., Sikka, V. M., Misra, A. K., Tyagi, S. K. & Rao, G. V. K., 'Resources Studies of Ground Water Scope for Development of Ground Water Reserves in Lathi Basin, Jaisalmer, Barmer Districts, Rajasthan', Seminar on 'Water Resources of Rajasthan and Gujarat', 1971, Abstracts of papers, G. S. I., Western Region, Jaipur, 22.
13. Compilation of Tubewells Constructed in Different Districts of Rajasthan from 1956-57 to 1971-72, Govt. of Rajasthan, Rajasthan Gound Water Board, Jodhpur, 1972.
14. List of Open Wells Deepened by Boring in Different Districts of Rajasthan from 1956-57 to 1971-72, Govt. of Rajasthan, Rajasthan Ground Water Board, Jodhpur, 1972.
15. Gopal, R., Bhargava, T. N., Bhati, O. P., Tak, T. C., Ghosh, P. K., Rai, Sushila & Bhutra, Mankanwar, *Annals of Arid Zone.*, **19** (1980), 249.
16. Bhargava, T. N., Bhati, O. P., Mathur, C. P., Srivastava, J. L., Inder Singh & Sharma, R. N., 'Analysis of Waters of Kutch District, Gujarat', Report No. DL/TC/71/1, Defence Laboratory, Jodhpur, 1971.
17. Gopal, R., Bhargava, T. N., Bhati, O. P,, Tak, T. C., Ghosh, P. K., Rai, Sushila & Bhutra, Mankanwar, 'Salinity and Toxicological Studies of Water of Rajasthan Desert', *Def. Sci. J.* (In Press). Presented in 'Symposium on Toxicology in Defence Science' held at DRDE, Gwalior, 1980.
18. Gopal, R., Bhargava, T. N. & Bhati, O. P., *Curr. Agric.*, **1** (1977), 57.
19. Gopal, R., Bhargawa, T. N., Tak, T. C. & Bhutra, Mankanwar, 'A Rapid Method for Examination of Faecal Coliforms in Drinking Water' (Patent applied for).
20. US Salinity Laboratory Staff, 'Diagnosis and Improvement of Saline and Alkali Soils' (US Dept. of Agriculture), 1954, 160.
21. 'International Standards for Drinking Water' (WHO, 2nd Ed., Geneva), 1963.
22. 'Standard Methods for the Examination of Water and Waste Water', APHA-AWWA-WPCF, 14th Ed., 1976.
23. 'Manual of Standards of Quality for Drinking Water Supplies', ICMR, 1975, Special Report Series No. 44.
24. Charles, N. Durfor & Beecher, E., *Jour. AWWA* **56** (1964), 242.
25. Babbitt, H. E. & Donald, J. J., 'Water Supply Engineering', 5th Ed. (McGraw Hill & Co., London), 1955, 63, 391.
26. Gupta, R. K. & Ishwar Prakash (Ed.), 'Environmental Analysis of the Thar Desert' (English Book Depot, Dehradun), 1975, 187-90.
27. Kelley, W. P., 'Alkali Soils, their Formation, Properties and Reclamation' (Reinhold, New York), 1951.
28. Richards, L. A., (Ed.), U. S. D. A. (1954).
29. Russel, E. L., *Jour. AWWA.*, **62** (1970), 102.
30. Misra, S. K., *Scavenger*, **8** (1978).
31. 'Nitrate Poisoning in Livestock' (California Agriculture Experiment Station Extensive Service, Univesity of California), 1961.
32. Tak, T. C., Inder Singh, Sharma, R. N. & Nandy, A. N., *Labdev J. Sci. Technol.*, **9–B** (1971), 31.
33. Chaudhari, J. C. & Tak, T. C., *Sci. Cult.*, **33** (1967), 535.
34. Gopal, R. & Tak, T. C., *Curr. Agric.*, **1** (1977), 63–66.
35. Johnson, Sylvester & Singhavi, Aruna, *Trans. Isdt. Ucds.*, **2** (1977), 41–67.
36. Muller, R., Bulletin of the Word Health Organisation , **57** (1979), 683–689.
37. Sampooran Singh, Dwivedi, C. D., Purohit, A. D., Janweja, R. B., Prajapat, M. L., Bachlaus, M. K., Dave, U. K. & Khalsa, G. S., *Chemical Era.*, **12** (1976), 116-120.
38. Singh, Y. P., Singh, J., Das, G. & Gopal, R., *Def. Sci. J.* (In press).

39. Gopal, R., Vaswani, J., Bhargava, T. N., Bhati, O. P., Tak, T. C., Ghosh, P. K., Rai, Sushila & Bhutra, Mankanwar, 'Water Testing Field Kit', Report No. DLJ/TC/CHEM/79/7, Defence Laboratory, Jodhpur, 1979.
40. Nordell, E., 'Water Treatment for Industrial and other Uses', 2nd Ed. (Reinfold Publishing Corporation, New York), 1961, 17-217.
41. Dixey, F., 'A Practical Hand Book of Water Supply', 2nd Ed., (Thomos Murby & Co., London), 1950, 252.
42. Paul, A., Wilherspoon. & Willian, D. Ramsay, (Ed.), 'Geo-Chemical Methods of Prospecting and Exploration for Petroleum and Natural Gas' (University of California Press, Berkeley and Los Angeles, California), 1959, 237.