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WATER BALANCE STUDY FOR A LIGNITE MINING AREA

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भारत के गुजरात राज्य में प्रस्तावित लिगनाइट खनन क्षेत्र के लिए एक जलभूवैज्ञानिकी अध्ययन कार्यान्वित किया गया। जल सन्तुलन अध्ययन के लिए प्रस्तावित खादसलिया लिगनाइट खान के रामदसिया जलविभाजक, जिसका क्षेत्रफल 31.92 वर्ग किलोमीटर है तथा जो भावनगर जिले की भावनगर तथा घोघा तहसीलों के दस गाँवों में फैला हुआ है, को प्रभावकारी क्षेत्र माना गया है। अध्ययन वाले क्षेत्र में एक भी परिवर्त्ती (चिरस्थायी) नदी या प्रमुख सतह जलक्षेत्र नहीं है। इस क्षेत्र में पानी का मुख्य स्रोत मानसून की वर्षा ही है जो जून महीने से अक्टूबर महीने के बीच होती है। पिछले बाइस वर्षों के दौरान औसत वार्षिक वर्षा 567 मिलीमीटर पाई गई है। सामान्यत: भूतल जल की गहराई सतह से 2 से 10 मीटर की सीमा में पाई गई है। वाटर टेबुल का क्षेत्रीय ढलान सतह के ढलान का अनुसरण करता है तथा मुख्यत: यह पश्चिम से पूरब की दिशा में 1 में 300 से 1 में 150 के मृदु ढलान की सीमा में है। चूँकि वर्षा ही पुन:भरण का मुख्य स्रोत है, अत: खुदाई किये गये कुँओं में जलसतह में अधिकतम बदलाव मानसून के ठीक पहले तथा मानसून के ठीक बाद की समयावधि में होता है। इस क्षेत्र के लिये प्रतिनिधिक रूप से औसत बदलाव 1.5 मीटर तक का लिया जा सकता है। इस क्षेत्र में कुल अवक्षेपण का 15% से 18% तक का अन्त:स्पन्दन होता है।

रामदसिया जलविभाजक (वाटरशेड) के लिये भूतल जल की माँग 2.967 मिलियन क्यूबिक मीटर है जबकि उपलब्धता 3.35 मिलियन क्यूबिक मीटर है। इससे यह पता चलता है कि जलविभाजक के लिये भूतल जल की माँग की स्थिति लगभग 90% है, जो कि ''डार्क'' श्रेणी के अंतर्गत आता है। इस क्षेत्र में लम्बे समयान्तराल में भूतल जल का स्तर यह बतलाता है कि विगत कुछ वर्षों के दौरान हुई कम वर्षा के कारण जल का स्तर लगातार कम हो रहा है। यह भी देखा गया है कि भारी सतही परिसरण का केवल कुछ भाग (कुल वर्षा का 40%) का ही जलप्रवाह के रूप में भण्डारण होता है, तथा वर्षा के पानी का शेष बड़ा भाग बरबाद हो जाता है। अतएव भूजल के पुन:भरण की उपयुक्त तकनीक का उपयोग करके इस महत्वपूर्ण भाग का भूमि में भण्डारण किया जाना चाहिये।

INTRODUCTION

The proposed Khadsaliya lignite mining project is located at Khadsaliya village of Bhavnagar district in Gujarat state in India. The total leasehold area is 171 ha. The expected life of the proposed mine will be about 17 to 18 years with an average lignite production of 0.40 Mt per annum. Surface elevation from the mean sea level of the leasehold area varies from 27 m in the SE to 66 m in NW. The lignite seam with maximum thickiness is 9.15 m occurs at depths varying from 28.65 to 67.71 m. As per the geology of the area, the open pit mine will be excavated in benches below groundwater level. Exploitation of lignite in this open pit may influence the surface and groundwater resources in and around the mine. Hydrological regime, especially water balance of any area, is controlled by various factors like, topography and drainage, climate, geology and soil characteristics, aquifer characteristics and groundwater conditions, water recharge and potential, and water quality (Coates, 1981). A study of these aspects and the factors, which tend to influence or alter various parameters are prerequisite for the understanding of the hydro-geological impact of the mining project on the region concerned (Strack, 1998). With this in view, a water balance study has been carried out for the proposed mining area.

Khadsaliya lignite block falls under Ramdasiya watershed. A watershed or drainage basin or catchments area is an area of ground in which any falling drop of water will ultimately drain in the same stream or river (Chaulya et al. 2000). The watershed is demarcated based on drainage network and topography of the area. If any effect on the surface water is envisaged due to the proposed lignite mine that will influence only the Ramdasiya watershed or catchments area in terms of change in drainage pattern and quantity of water resource. Therefore, for water balance and hydrological study of Khadsaliya lignite mine, Ramdasiya watershed has been considered as an influencing zone.

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Hydrological region in the broader sense covers both surface water and groundwater (Maidment, 1993). Water is mostly in dynamic state with movement from one zone to another vertically and horizontally (Freeze & Cherry, 1979). An understanding of the hydrological aspects on a regional scale is advisable while planning for any management strategy. Assessment of surface and groundwater resources is necessary to know the availability with respect to the demand in the area. For an estimation of the water balance of the region, it is also necessary to have an idea about the hydrological status of the region (Marsity, 1986). Based on all the analysis, a management and conservation strategy has got to be formulated for the area.

The broad objectives of the study were to assess the surface and groundwater resources in the region, study the water balance status of the Ramdasiya watershed, analyse the physicochemical properties of surface and groundwater to evaluate its portability and formulate a water management strategy for the region. Detail of the study is comprehensively described in the paper.

METHODOLOGY

To fulfill the above objectives, following methodologies have been adopted:

- Supporting data regarding drainage pattern, geology, mining details, rainfall, ground and surface water resources, water balance status and other details of the study area have been collected from various agencies like River Measurement Division, Bhavnagar; Salt Control Division, Bhavnagar; Gujarat Heavy Chemicals Limited, Bhavnagar; District Census Department, Bhavnagar; Public Works Department, Bhavnagar; Min Mac Consultancy Pvt. Ltd., New Delhi; B. C. Misra & Associates International Consultants, New Delhi; National Remote Sensing Agency, Ahmedabad and others.

- Rainfall pattern and its intensity has been analysed to evaluate the runoff characteristics. Long term groundwater levels were collected and analysed for pre and post-monsoon water level fluctuations, and establishing a correlation of rainfall with water level fluctuations following Adamovski & Homory (1983), weeks & Boughton (1987) and Soliman et al. 1997).

- Geological structure and stratigraphical succession has been analysed from borehole data and geological cross-sections of the mine as per the methodology described by Karaguzal et al. (1999), (Chaulya et al. (2000) and Chakraborty et al. (2001).

- Aquifer parameters have been determined by pumping test in the study area and groundwater assessment has been carried out based on field study and supporting data to estimate the availability of groundwater and requirement of pump capacity based on following references Rao & Rao (1985), Brawson & Istok, (1992), Kresic (1997), Singh et al. (1999), Bell & Maud (2000) and Umar & Ahmad (2001).

- Water resource potential of the area has been calculated based on rainfall, runoff, evaporation, infiltration, drainage, land use, soil characteristics, geology, geomorphology, terrain features, slope, lineament density, etc. The references followed for this purpose were Bradon (1986), Lyle (1987) Karanth (1990), Tolman (1993), Abu-Taleb (1999) and Feng et al. (2000).

- Water balance study has been carried out based on analysis of water resource availability and demand in the study area following Brawner (1986), Basu & Basu (1999), Berger (2000) and Reddy et al. (2000).

- Analysis for water quality and soil quality has been carried out as per the standard method (Down & Stocks, 1977; Dominico & Schwart, 1990; AWWA, 1992; Lee et al., 2001).

- Finally, water management strategy has been formulated based on techno-economical feasibility of the area following the experience of various case studies (ASCE, 1972; Aral, 1995; Abu-Taleb, 1999; El Quali et al., 1999; Graniel et al., 1999; Yang et al., 1999; Farah et al., 2000; Reddy et al., 2000).

LOCATION OF THE STUDY SITE

Ramdasiya watershed has been considered as an influencing zone for the water balance study around the Khadsaliya lignite mine. The watershed area lies between 21° 32'59" to 21° 34 57" N latitude and 72° 10' 12" to 71° 15' 55" E longitude. The area falls in Bhavnagar and Ghogha Tahsils of Bhavnagar district in Gujarat state. The area is bounded by Maleswari watershed (total catchment area is 95.19 sq. km and designed discharge capacity is 1558.56 cumecs) in the north, Gulf of Khambat in the east, a local stream in the south and Jasapara watershed in the west. The study area falls in the southeast peninsular corner region of Gujarat, known as Kathiawar or Saurashtra. Figure 1 shows the location map of the Ramdasiya watershed. Ramdasiya watershed covers part or full of ten villages, namely, Nathugarh, Morchand, Kareda, Padwa, Bhadbhediya, Khadsaliya, Alapar, Sanodar, Hathab and Thalsar (Figure 2). The total area of the Ramdasiya watershed is 31.92 sq. km.

PHYSIOGRAPHY

The present physiographic setup of the region is a combined result of denudation and deposition process. Being the coastal area, the general topography is characterised by coastal plan and undulating uplands with

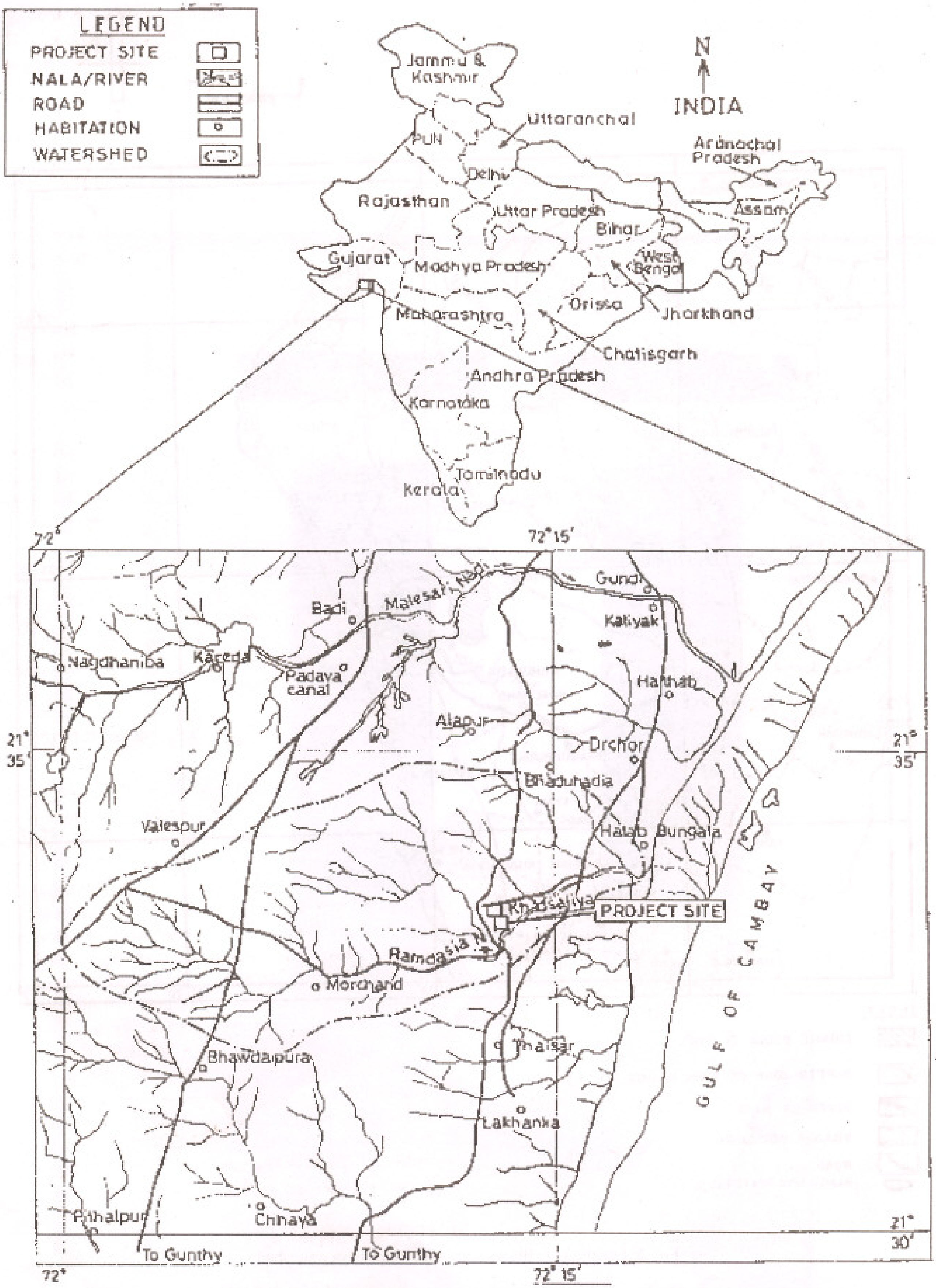

Fig. 1 : Location map of the study site

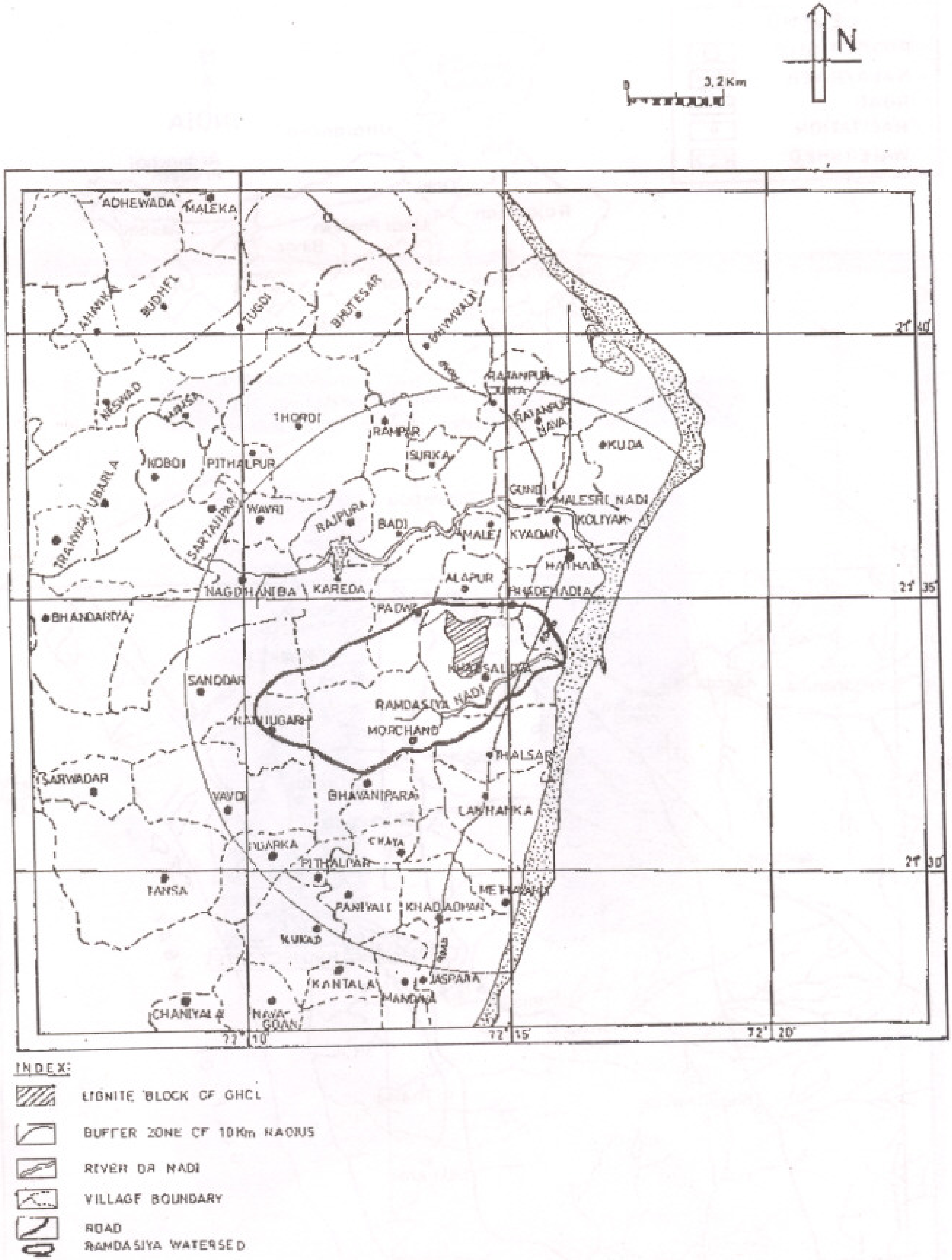

Fig. 2 : Location of villages within the Ramdasiya watershed

or without scruls. The overall topography (of the entire area) is gently undulating. The general slope of the area is from west to east. There is a good network of roads in the area.

DRAINAGE

The drainage pattern of the area is sub-dendritic to dendritic and the drainage density is medium. The drainage direction of the area is mostly west to north-east. There are no perennial rivers or major surface bodies within the proposed lignite field or mining lease area. The only river, which is of significance within the lignite mining area of Khadsaliya block, is Ramdasiya River, which is passing across the southern portion of the lignite block flowing eastwards and entering Gulf of Cambay. The river remains dry during most of the period except monsoon season. Total area of the Ramdasiya catchment is 31.92 sq. km having a maximum designed discharge capacity of 434.25 cumecs. Figure 3 shows the drainage pattern of the Ramdasiya watershed.

CLIMATE

The region experiences very hot summer and very low rainfall during monsoon. In general, any year can be divided into three seasons, namely, (i) Monsoon season, late June to October; (ii) Winter season, November to February; and (iii) Summer season, March to June. The rainy period is hot and humid. Most of vegetative growth occurs during monsoon. The post-monsoon period is hotter with very high day temperature. Usually, most of the vegetation dries out during this period. Winter is mild and lasts for about three-and-a half months. During this season, the standing dry plants also disappear and the ground looks almost barren. The summer is too dry and hot, month of May being the hottest month. Winds are strong during summer and monsoon seasons. The relative humidity reaches over 94% during monsoon and rest of the year is comparatively dry.

RAINFALL

The rainfall recorded at Bhavnagar meteorological station for the period 1979-2000. The rainfall does not show any cyclic occurrence. There are wide and erratic variations. Monthly variation of average rainfall during last twenty-two years (1979-2000) is depicted in Figure 4. It can be observed that the monsoon season is spread over the five months of June to October. The average annual rainfall for the year 1979 to 2000 was 567.2mm (Fig. 5).

LAND USE

Detailed breakup of land use pattern in the Ramdasiya watershed is given in Table 1 and illustrated in Figure 6. A

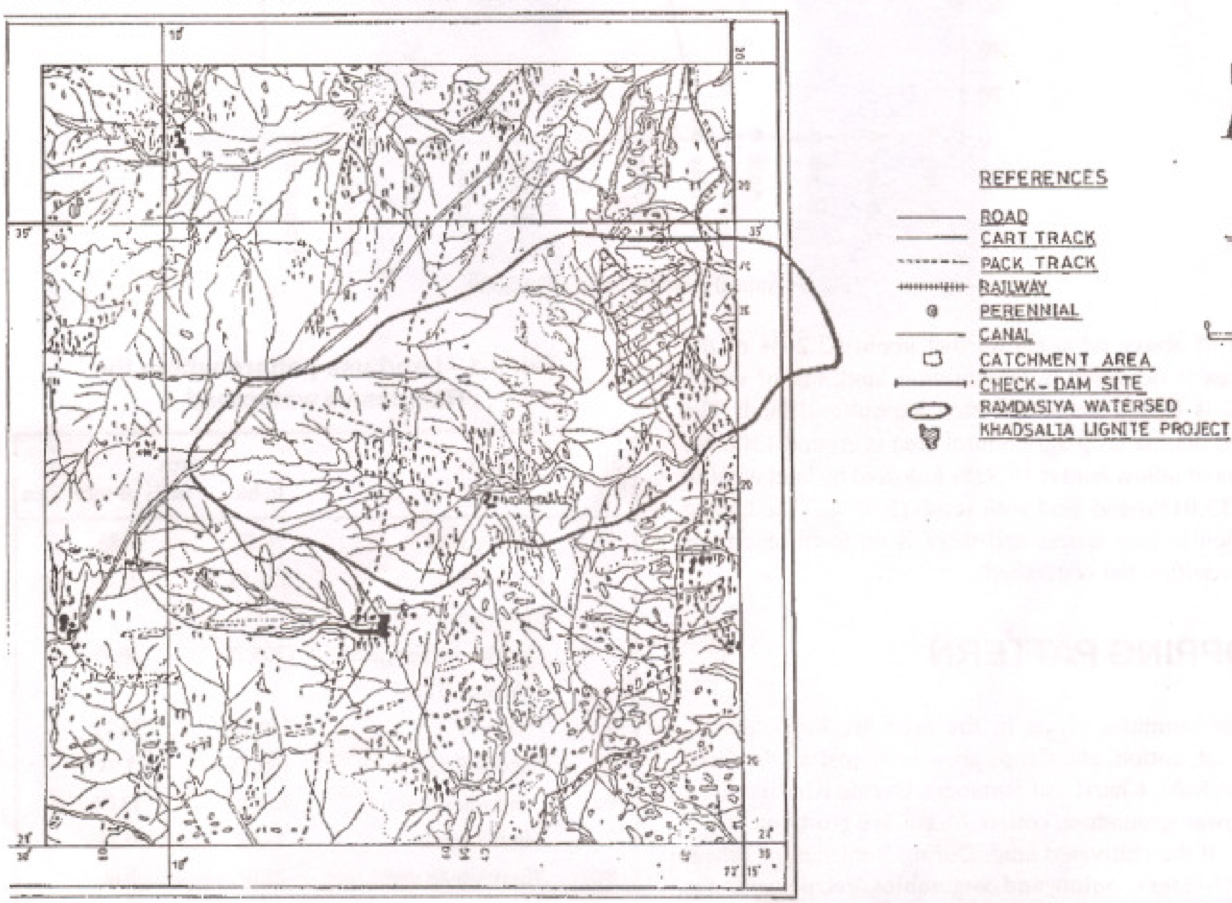

Fig. 3 : Drainage network of Ramdasiya watershed

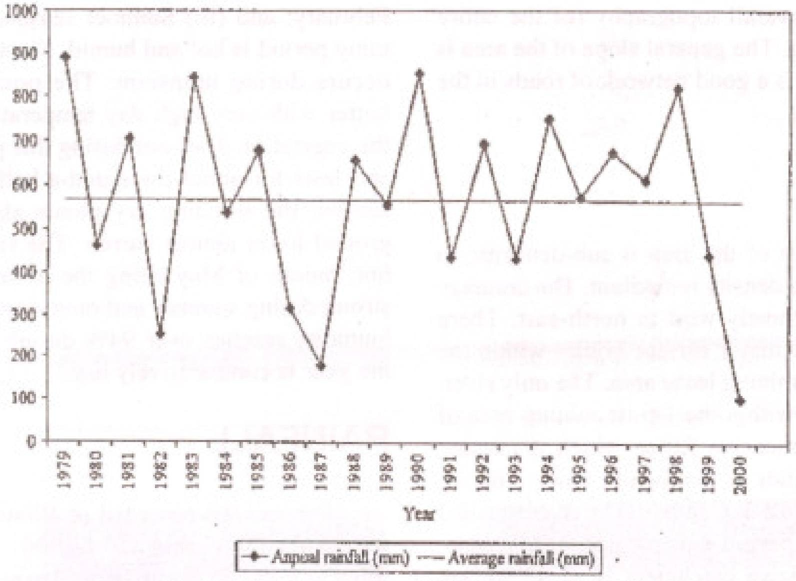

Fig. 4 : Monthly average rainfall during 1979-2000

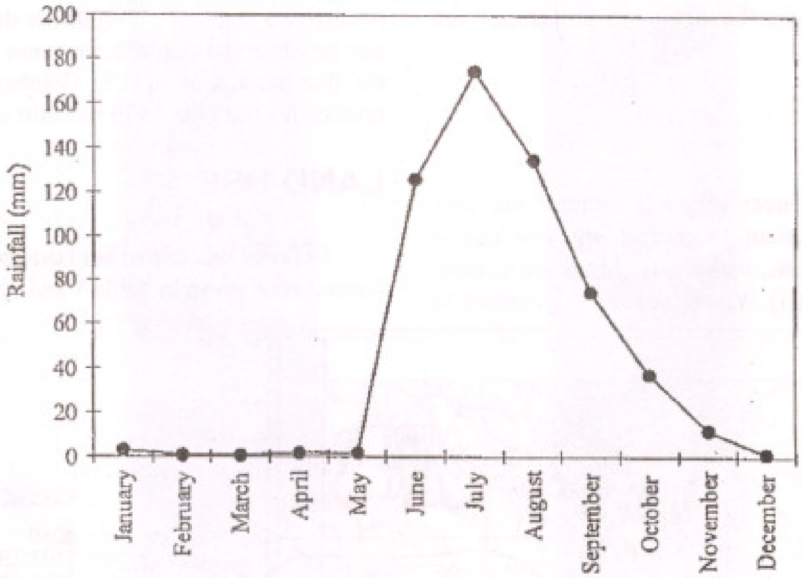

Fig. 5 : Annual rainfall during 1979-2000

perusal of above table shows that about 62.20% of the total area is occupied by agricultural land, out of which 40.91% is falling under irrigated agricultural land. The irrigated double crop agricultural area is around 1306 ha. The area of fallow land is 16.92% followed by land without scrub (13.01%) and land with scrub (5.98%). The human habitation is very sparse and there is no town or city or industry within the watershed.

CROPPING PATTERN

The common crops in the area are bajri, jowar, groundnut, cotton, etc. Crops grow in almost all the three seasons (Rabi, Kharif and Summer). During Kharif season bajri, jowar, groundnut, cotton, til, etc. are grown on major portion of the cultivated land. During Rabi season, wheat jowar (fodder), onion and vegetables get priority for cultivation. However, the data from

Table 1 - Land use pattern within the Ramdasiya watershed

Sl. No.	Laud use	Area In ha	Area In % of total area
1	Built up land	26.59	0.83
2	Kharif (Rainfall) agricultural land	679.48	21.29
3	Double crop (irrigated) agricultural land	1305.78	40.91
4	Fallow land	540.10	16.92
5	Land with scrub	190.73	5.98
6	Land without scrub	415.39	13.01
7	Mining waste	11.92	0.37
8	Stony waste/sheet rock	22.01	0.69
	Total	3192.00	100.00

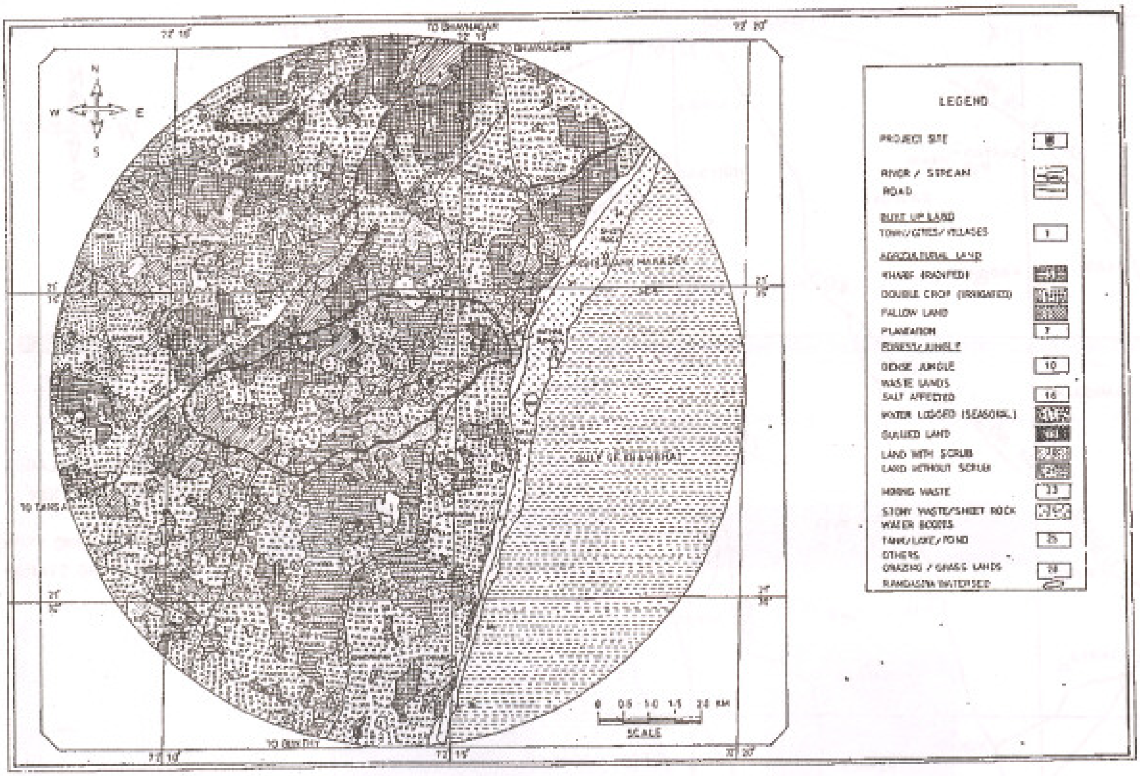

Fig. 6 : Land use pattern of the study area

Bhavnagar agriculture office shows that groundnut has acquired a monotonous pattern in summer season. The yield of the crops is low due to low rainfall and absence of sufficient level of provision for irrigation.

SOIL QUALITY

Results of analysis of two soil samples of Khadsaliya (S1) and Morechand (S2) villages are given in Table 2. The locations of soil sampling stations are shown in Figure 7. Type of soil is silty clay. The colour of the soil is usually pale yellow. The pH varies from 6.7 to 9.0 and organic matter ranges between 0.27% and 1.50%.

Table 2 : Soil quality of the study area

Sl. No.	Parameters	Unit	Khadsaliya (S1)	Morechand (S2)
1	pH value	-	6.7	9.0
2	Conductivity	Milli mhos/cm	1.54	0.107
3	Type of soil	-	Silty clay	Silty clay
4	Water holding capacity	% by mass	66	59
5	Bulk density	g/cc	1.186	1.28
6	Organic matter	% by mass	0.27	1.50
7	Potassium (as K_2O)	ppm	17.0	22.0
8	Phosphorus (as P_2O_5)	% by mass	0.007	0.006
9	Chloride (as Cl)	ppm	68.0	4.0
10	Nitrate (as N)	% by mass	0.15	0.19
11	Fluoride (as F)	ppm	0.14	0.60
12	Moisture	% by mass	4.65	3.36
13	Calcium (as CaO)	ppm	11.0	12.0
14	Sulphate (as SO_4)	ppm	36	9.0
15	Carbonate (as $CaCO_3$)	% by mass	1.8	2.7
16	Iron (as Fe_2O_3)	% by mass	Nil	0.4

NATURAL VEGETATION

Broadly, dry deciduous type natural vegetation is common in the area. The area falls under tropical dry deciduous forest (thorn forest). Heavy grazing coupled with less rainfall has resulted in inferior quality thorn forest. Mostly the grassland areas are also degraded. Some of the common species found in the area are

a) Trees - Ambo, Amli, Baval, Bordi Gorad, Gundi, Limbo, Piplo, Timru, Vadlo, Khakhro, etc.

b) Shurbs and herbs - Akdo, Awal, Dharudi, Gokhru, Kardo, Katki, Viklo, Galo, Vevdi, etc.

c) Bamboo and grasses - Baru, Darabh, Dhodiu, Dhro, Ghaulu, Lapdu, Ratad, Rosha, etc.

POPULATION

As mentioned earlier, part of ten villages fall in the Ramdasiya watershed covering total area of 31.92 sq. km. However, as per settlement map of the area, it has been observed that out of these ten villages, only five villages are having settlement within the Ramdasiya watershed. Population of the five villages is indicated in Table 3 and total population in the watershed is 13,647. Therefore, population density of the study area becomes 428 persons per square kilometre.

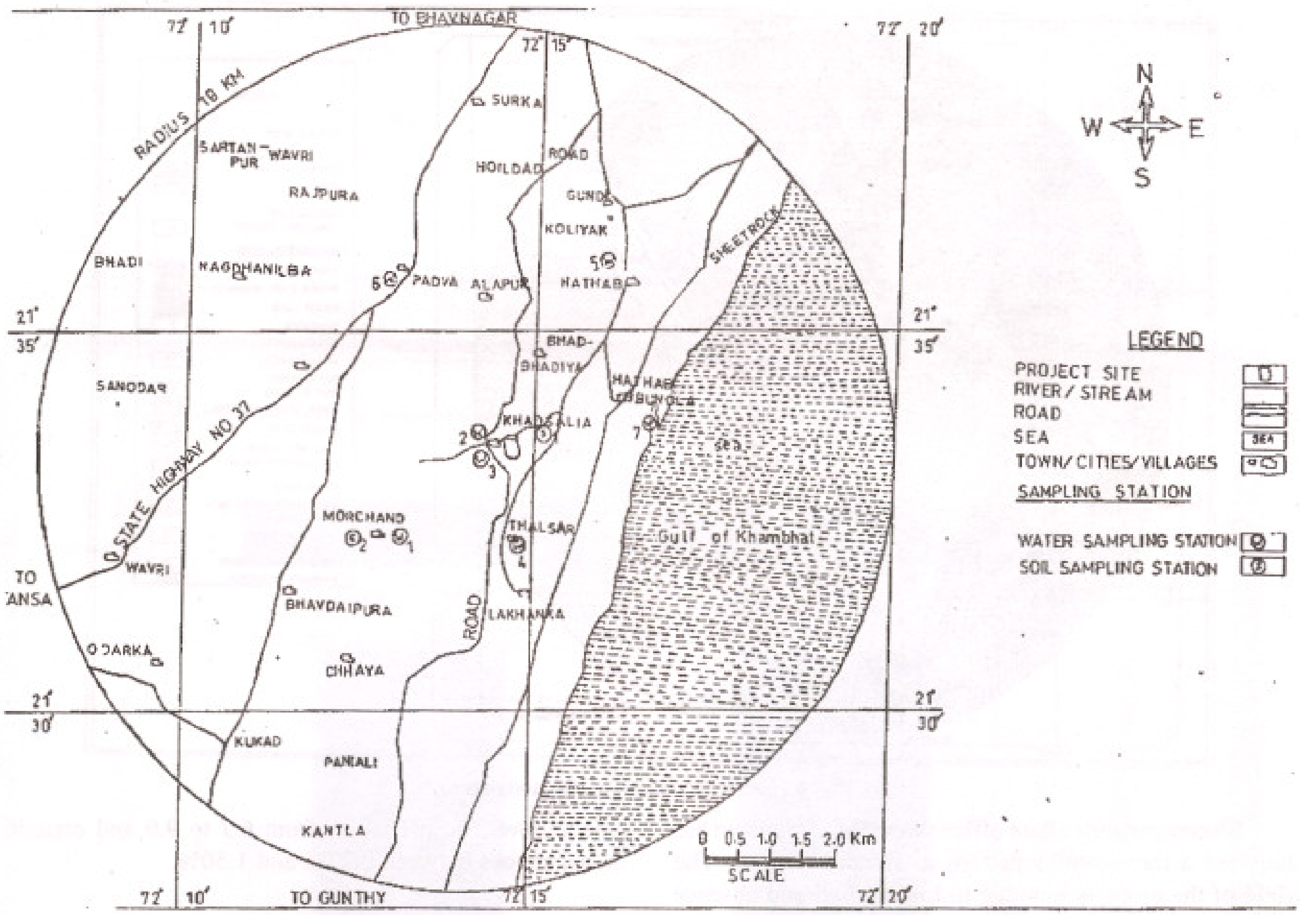

Fig. 7 : Location of soil and water sampling point

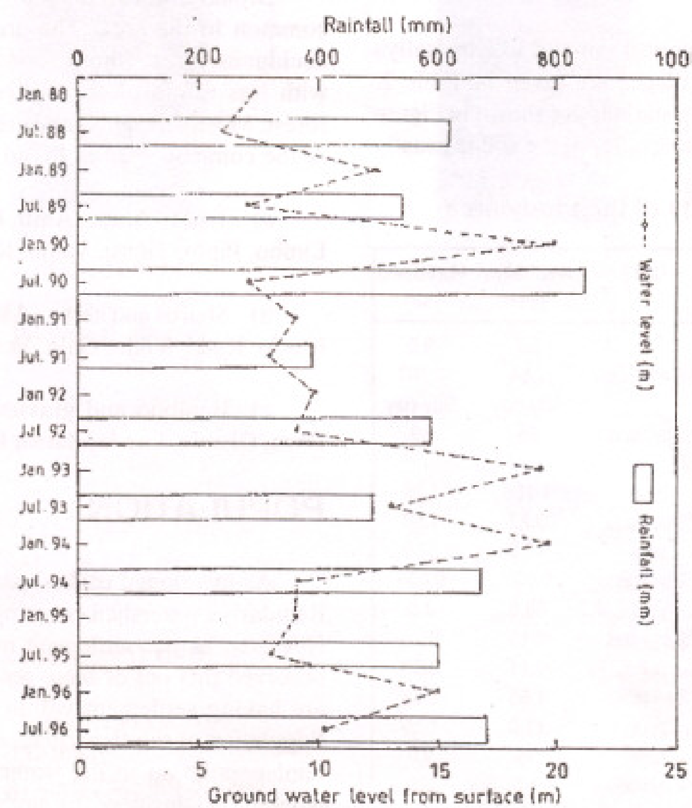

Fig. 7A : Hydrograph of dug well at Padva village

Table 3 : Village-wise population within Ramdasiya watershed

Sl. No.	Village name	Population
1	Alapar	149
2	Bhadbhediya	902
3	Hathab	5365
4	Khadsaliya	3775
5	Morchand	3456
6	Nathugarh	0
7	Kareda	0
8	Padwa	0
9	Sanodar	0
10	Thalsar	0
	Total	13647

GEOLOGY

General geology

The geology of the study area is part of the geology of Saurashtra Peninsula, which is bounded by sea on all sides except on the northeast where alluvial plains and formations ranging from Juro-cretaceous to Recent coastal deposits flank it. About 65% of the Peninsula is covered by basaltic lava flows (Deccan Trap). In the northern part of the Peninsula, the traps overlie the Upper Mesozoic sediments. At the coastal fringe, the traps underlie Tertiary-Quaternary sediments.

The area under consideration predominantly exposes geological sediments that were deposited on the basement provided by Deccan basalt. The geological formations, based on surface geological mapping and sub-surface lithological information of detailed exploration, are given in Table 4.

Table 4 : Stratigraphical sequence of the area

Formation	Lithology	Age
Recent	Alluvium, sand, soil	Recent to Sub-Recent
	---Unconformity---	
Lakhanka	Agate bearing conglomerate, ferrugenous sand stone with intercalation of clays	Pleistocene to Sub-Recent
	---Unconformity---	
Guj	Variegated clays, sandstone, marl, conglomerate, gypseous clay and bentonitic clay	Lower Miocene
	---Unconformity---	
Khadsaliya Clay	Gray to greenish gray clay, plastic clay, fossiliferous clay with carbonaceous shale and lignite with sideritic nodules	Eocene
	---Unconformity---	
Supra Trappean	Laterite Lithomerge	Upper Cretaceous to Lower Eocene
Deccan Trap	Basaltic lava flows with intrusive dykes	

Out of these geological formations, only three types of soil are exposed within the proposed mining block/area. These are alluvial soil, conglomeratic ferrugeneous sandstone and gray bentonitic clays. All other formations are revealed from quarry exposures or from the examination of cores and cuttings from the exploratory boreholes: Lignite seams, as revealed from boreholes, are associated with greenish gray coloured clays and carbonaceous clays probably of Eocene period. The megascopic and microscopic characteristics of various rock types encountered in the region are described below:

i) Deccan Trap:

Basalt Porphyry: The rock is melanocratic in colour, hard compact and fine to medium grained. Under microscope, it shows sub-opthic texture. Plagioclase feldspar and pyroxene arc the main constituents.

Altered Basalt: The rock is gray in colour. It is soft and fine-grained. Under microscope it shows fine-gained texture. It mainly consists of laths of feldspar and pyroxene.

ii) Supra Trappean

Lithomarge: The rock samples show shades of light gray and white. It is semi-compact and fine-grained.

iii) Khadsaliya clay

Gray clay: The rock is greenish gay/ash gray in colour. It is soft and fine-grained. It is sticky by nature. At places, it contains microfossils. Under the microscope, it shows extremely fine-grained texture. On the basis of colour, refractive index and birefrigerence, the sample is found to mainly consist of illite with subordinate amount of kaolinite and montmorilonite.

Carbonaceous shale: It is blackish in colour, soft and fine-grained. It soils the finger. It contains lignite partings at places. It contains minute specks of pyrite. It partially burns when ignited and leaves behind some ash and clayey mass.

iv) Gaj formation

Variegated clay: It shows shades of yellow reddish, gray and white. It is soft and fine-grained. It is sticky by nature. When dipped in water, it readily swells

v) Lakhanka formation

Conglomerate/sandstone: Most of the conglomerate and sandstone occurring in the area are loose and friable in nature. The conglomerate consists of pebbles of chalcedony, agate, quartz and sandstone. The sandstone is ferrugeneous, hard and compact at places.

The sandstone and conglomerate, wherever compact and hard, can be used as building stone.

vi) Lignite of Khadsaliya and Hoidad Basin

The lignite bed in the area extends in length from Lakhanka to Rampur-Navades-Ratanpur and beyond in north-south direction. Width of the lignite is about one to three kilometer east-west in Khadsaliya basin and about two to six kilometre in Hoidad basin. The length of the lignite basin is about 12 km. The average gradient of the lignite seam appear to vary from 5^0 to 10^0 from the edge towards the central part of the basin. The thickness of the seam is more at the contact of the trap while it thins out towards the sea. The observed characteristic feature of the lignite seams is thickening and thinning out both laterally and vertically.

Sub-surface stratigraphy

The formations overlying the lignite seam in the mining area under consideration are soil, conglomeratic ferrugeneous sandstone and clay with 6%, 15% and 79% contributions respectively. The clay just below soil (loose sand) formation is yellowish and mottled in colour and is of lower Miocene. The clays further below are of Eocene age and are predominantly greenish gray to dark gray in colour and plastic in nature. These clays are suitable for use as raw material for roof tiles.

Structure

The strike of the lignite seam is roughly north-south and dipping towards sea i.e. eastwards. Overburden ratio increases towards the sea while the thickness of lignite decreases towards trap. The geological cross-sections and the structural contour plans indicate that the area has not undergone any major structural disturbances.

PUMPING TEST

Determination of aquifer parameters or characteristics is most essential for estimating the groundwater potential of any region, which in turn will give an understanding of the recharge-discharge phenomena and ultimately the water balance. The best tool for determination of the aquifer parameters is pumping tests. With this in view, data collected from two pumping tests, closest to the Khadsaliya mines were analysed and critically studied.

Two pumping tests were conducted - one in the village of Badi and the other in Hoidad village. Both were open wells in Ghogha beds/formations. Tests were conducted maintaining a discharge of 40 m^3/day in the first well and 293 m^3/day in the other well with pumping duration varying from 200 to 280 minutes. The details of the pumping tests and the results obtained adopting the aforementioned procedures are given in Table 5.

Table 5 : Pumping test details and computed hydrological parameters of the aquifers in Ghogha bed formations

Sl. No.	Details	Well No. 1	Well No. 2
1	Village	Badi	Hoidad
2	Taluk	Ghogha	Ghogha
3	Geology	Ghogha Bed	Ghogha Bed
4	Total depth	35.45 m	12.70 m
5	Area of well	3.14 m^2	0.785m^2
6	Saturated thickness	3.05m	1.80m
7	Discharge	12.21m^3/hr	1.65m^3/hr
8	Duration of pumping	280 minutes	200 minutes
9	Specific capacity	0.069m^3/min/m	0.026m^3/min/m
10	Transmissivity	28.24m^2/day	65.92m^2/day
11	Permeability	0.38m/hr	1.52m/hr
12	Specific yield	1.6	1.0
13	Computed safe distance between wells	80m	122m

Study of the pumping test data has revealed that the specific capacity varies from 0.026 to 0.069 m^3/min/m which is quite low. Permeability and transmissivity values are also on the lower side. Wells in Badi village was able to sustain a pumping of about 300 m^3/day for nearly 5 hours. With vertical boreholes drilled beyond the bottom of the well, the water potential could be improved and thereby pumping duration could be increased.

HYDROLOGICAL CONDITIONS

Deccan Trap Zone's formation

i) Nature of formations

Deccan formations in the west of the mining blocks are the oldest found in the study area. The traps mostly consist of basaltic lava flows of volcanic igneous origin and belong to Cretaceous to Eocene age.

As these are basically hard formations, they have low porosity and permeability and hence no well-defined aquifer system exists in the area. The storage space is provided by the development of secondary porosity due to weathering, development of fractures, joints and inner flow space. All these features vary in their intensity in lateral and vertical direction, resulting in the development of storage space in the form of small irregular pockets. These pockets may be weakly interconnected or may be separated from each other by the impermeable barriers.

This means that the storage space in these formations is small and irregularly spaced when compared to sedimentary rocks of the same dimension where storage space is large and uniform to a great extent. As the storage space is small, recharge potential also become less.

By gravity and following weak planes, rain water slowly moves down. This feature was often observed in exposed weathered rocks in excavation sites and road cuttings. Groundwater flow continues down below to fractured rocks, controlled by strike and dip of joints and other weak planes. If these openings are connected and there is no obstruction by hard and impermeable formation in between, the flow will be high.

ii) Groundwater conditions

Groundwater in the Deccan Traps occurs in the upper weathered portion as well as in cracks, fissures, joints and fractures. Top 5 to 20 m of ballistic rocks are weathered and fractured at varying degrees and the intensity of groundwater infiltration is dependent on these fractures. Many wells are dug in this weathered zone with depths varying from 5 to 15 m from ground level. Diameter of the wells vary from 2 to 6 m. Depth of water from the ground surface depends on seasonal rainfall, the elevation of ground and also on local stratigraphical conditions. It normally varies from 2 to 5 m west of the mining blocks and 2 to 10 m in the buffer zone.

The gradient of water table follows the surface elevation, which is west to east with moderate slopes ranging from 1 in 300 to 1 in 150. But locally, this gradient varies erratically and at some places is very high. This is due to the irregularities in the occurrences of water in the trap areas. As rainfall is the major source of recharge, the dug wells show maximum fluctuation between pre-monsoon and post-monsoon periods. Fluctuation of 3 to 4 m can be taken as typical for the area.

Yield of the individual wells also vary from place to place depending on the localized geo-hydrological conditions. A properly constructed dug well of about 5 m diameter and 10 to 15 m depth in a fairly well weathered and fractured strata could yield about 300 lpm. Specific yield is also an important parameter for determining as to how much water will be released from the storage of aquifer. Field studies/tests have indicated a value of 3% as specific yield for the formation up to a depth of 2O m from ground level in the Deccan Trap area.

Hydraulic conductivity and transmissivity of the aquifer in the trap area showed area-wise variation, depending upon the local stratigraphical conditions. Similarly, depth-wise variation also occurs due to nature of the aquifer material, thickness, magnitude of weathering etc. Hydraulic conductivity varied from 3 to 8 m/day. Transmissivity values normally varied from 30 to 100 m^3/day in the Deccan Trap area.

Alluvial and Tertiary formations

1) Nature of formations

Alluvial and tertiary formations are exposed within the mining block. Alluvial formation comprises of silt, sand dune and beach sand. Geologically, these are of recent origin. Tertiary formations of Lower Miocene consist of conglomerates, sandstones and clays. Stretches of Supra-trappean formations of Lower Eocene age, consisting of laterite and bantonite, are exposed at the western and southern fringe. The storage is directly proportional to the porosity of the formation in this type of soil.

ii) Groundwater conditions

The thickness of alluvial formation together with upper sandstone, clays and conglomerates varies from 10 to 30 m. Dug well constructed in these formations vary in depth from 3.10 to 22.5 m and diameter of the wells varies from 2 to 5 m. Figure 7A shows the hydrograph of a dug well located at Padva village within the study area. The depth of water in the dug wells depends on the elevation of ground surface, rainfall, season of the year and stratigraphical conditions. Normal range is between 2 to 8 m from ground level. The average water level fluctuations between pre-monsoon and monsoon seasons can be taken as 1.50 m for calculation purposes.

Table 6 indicates the water level fluctuation data of wells near Khadsaliya and Hathab villages during pre and post-monsoon seasons for the period of 1990-2000. Gradient of the water table normally follows the surface slope and is from west to east with slope of 1 in 1000 to 1 in 500. Yield of the dug wells and dug-cum-tube wells vary from place to place, within the mining block and other areas of occurrence of sedimentary formations. Normal range can be taken as 100 to 600 lpm. Specific capacity of the wells in these formations though high but shows wide variations from 50 to 300 lpm/d of draw down.

Hydraulic conductivity of the top 30 m of the formation in Khadsaliya mining block showed appreciable vertical variation depending on the type of strata (alluvium or sandstone or conglomerate or clay). The normal range is 5 to 15 m/day.

The transmissivity values also correspondingly show variations depending on the hydraulic conductivity of the formations and the thickness. The normal range is 100 m^3/day for the formations encountered within the depth of about 30 m in the mining block & other sedimentary zones.

Table 6 : Grounwater fluctuation data for wells in the Khadsaliya and Hathab villages

Village & Well No.	Season	Groundwater depth from surface (m)										
		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Khadsaliya Village												
219	Pre-monsoon	NA	10.30	12.20	28.10	18.00	13.30	20.60	24.00	18.30	19.80	22.50
	Post-monsoon	12.50	11.50	9.20	16.00	14.50	14.20	19.50	20.50	22.10	NA	NA
220	Pre-monsoon	NA	4.80	10.50	11.40	7.80	4.00	14.10	14.50	12.50	12.30	12.40
	post-.monsoon	5.40	6.30	10.70	6.10	5.70	12.10	12.10	8.50	9.00	NA	NA
221	Pre-monsoon	NA	13.30	18.50	17.70	17.50	13.50	20.40	19.80	19.90	18.00	20.00
	Post-monsoon	12.60	14.50	14,40	15.00	12.70	10.20	18.20	18.40	20.20	NA	NA
222	Pre-monsoon	NA	10.00	19.50	10.80	12.60	8.80	14.10	15.10	12.90	11.60	13.00
	Post-monsson	9.40	9.60	15.10	9.20	9.00	10.00	13.50	12.50	13.50	NA	NA
223	Pre-monsoon	NA	12.10	11.90	9.60	9.60	9.50	10.10	10.80	10.70	10.20	10.60
	Post-monsoon	10.50	11.50	12.60	8.80	9.20	6.70	10.50	10.00	9.80	NA	NA
224	Pre-monsoon	NA	9.50	13.00	7.40	12.80	3.10	EM	EM	EM	EM	EM
	Post-monsoon	8.00	9.30	10.40	4.40	3.40	3.80	EM	EM	EM	NA	NA
Hathab Village												
225	Pre-monsoon	NA	7.00	15.30	8.00	9.00	7.50	9.20	10.50	EM	EM	EM
	Post-monsoon	6.70	8.00	7.80	7.60	7.30	7.60	8.50	10.00	EM	NA	NA

GROUNDWATER AVAILABILITY

Source of recharge

Recharge to the groundwater basin or an aquifer system mainly depends on infiltration capacity of the soil, hydrological characteristics of the sub-strata and the groundwater flow dynamics apart from the topography of the region and the rainfall. Groundwater potential is directly linked with the recharge to the aquifer.

Infiltration capacity of the soil is the major influencing factor in the determination of quantum of the recharge of a basin. Infiltration capacity in turn depends on the type and textures of the soil exposed at the surface or near the surface. In the area studied it has been observed that rain water infiltration is the primary and predominant source of recharge to the groundwater system. Percolation/seepage from the surface water bodies and the drainage canals, spread over the area, also contribute to the recharge.

Quantum of recharge

i) Rainfall infiltration method

Average annual rainfall of the area is 567 mm, out of which 40 per cent is lost as surface runoff, 24 per cent of the balance amount is partly lost through evaporation and transpiration, and the remaining enter into the subsoil. About 50 per cent of gravitational water, entering into the soil is lost through slow downward movement of groundwater towards the sea. Therefore, only remaining 50 per cent of gravitational water becomes utilizable as groundwater resources.

Water resource availability for the Ramdasiya watershed has been calculated on the basis of above data, collected from Irrigation Department. The dynamic groundwater resource available for the watershed is 3.25 million cubic metre (MCM), detail breakup is given in Table 7.

ii) Specific yield method

Recharge has also been calculated based on specific yield method and assuming a typical specific yield value of 7% for the type of formation exposed at the surface.

a) Catchment area - 31.92 sq. km
b) Specific yield - 7%
c) Water level fluctuation between pre-monsoon & post-monsoon period - 1.5 m
d) Annual recharge - $31.92 \times 10^6 \times 1.5 \times 7/100\ m^3$ = 3.35 MCM

Average recharge based on these two methods is = (3.25 + 3.35)/2 = 3.30 MCM. It may also be noted that the water demand for the Khadsaliya lignite mine will be 0.044 MCM, which is only 1.33 per cent of total groundwater available in the watershed. Therefore, it may be stated that the proposed lignite mine will not significantly affect the groundwater resource of the region.

Table 7 : Water resource status within the ramdasiya watershed

Watershed area (m^2)	Av. annual rainfall (m)	Total precipitation within watershed (MCM)	Surface runoff (MCM)	Evapotrans-piration (MCM)	Sub-surface loss (MCM)	Utilisable groundwater (MCM)
1920000	0.567	18.10	7.25	4.35	3.25	3.25

WATER DEMAND

Water demand for the region comprises of industrial demand, domestic demand and agricultural demand. Detailed calculation for each category is described below:

Industrial Demand

There is no existing industry within the Ramdasiya watershed. Therefore at present industrial water demand is nil. The only industry proposed within the watershed is Khadsaliya lignite mine. The total water requirement for the proposed lignite mine will be 120.49 m^3/day = 120.49 x 365 m^3/year = 43978.85 m^3/year = 0.044 MCM.

Domestic Demand

As mentioned earlier, total population within the Ramdasiya watershed is 13, 647. Considering 45 liter per day (LPD) per head water consumption (as per Indian Standard, IS), the total annual domestic water demand for the watershed becomes

$$(13647 \times 45 \times 365) / 1000 \text{ m}^3 = 224251.98 \text{ m}^3 = 0.224 \text{ MCM}$$

Agricultural Demand

Total irrigated double crop agricultural land within the basin is around 1306 ha as described earlier. For agricultural purpose, a thin film of 5 mm water over the cultivated area should be maintained for good yield as per the standard norm. However, for Gujarat state where rainfall is less; a layer of 1 mm water over cultivated land is practicable considering the groundwater availability. It may be noted that in this region sprinkling irrigation is widely practiced. The irrigation is required at least for seven months in this region. Therefore, total agricultural water demand becomes:

$$1306 \times 10^4 \times 0.001 \times 210 \text{ m}^3 = 2.743 \text{ MCM}.$$

Total Demand

Therefore, the current total water demand status for the watershed is as follows:

(i)	0.000 MCM	for industry	
+ (ii)	0.224 MCM	for domestic	
+ (iii)	2.743 MCM	for agriculture	
	Total water demand	2.967 MCM	

WATER BALANCE

The status of groundwater development for the Ramdasiya watershed is given in Table 8. From this table, it can be seen that the stage of groundwater development for the watershed has already been around 90%, and falls under "Dark" category, which means that the development of groundwater is more than 85% of available groundwater resource. Therefore, problem of water scarcity exists in the region. Long-term groundwater level of the region indicates that water level is progressively going down due to decrease in rainfall during last few years. Another point to be noted here is that only a small part of heavy surface runoff is stored in the form of streams and remaining significant quantity of rain water is being lost. Therefore, this heavy quantity of surface runoff water should be stored effectively for utilization by implementation of effective groundwater recharge techniques. Programmes may also be launched for the construction of percolation tanks, check dams and contour bunding, which will conserve rain

Table 8 : Status of groundwater development in the Ramdasiya watershed

Item	Quantity
Groundwater recharge (MCM)	3.300
Net groundwater draft (MCM)	2.967
Balance groundwater available for development (MCM)	0.333
Stage of groundwater development (%)	90

Table 9 : Location of water sampling stations

Location No.	Location/ village	Remarks
W1	Morchand (Bore well)	Drinking water
W2	Khadsaliya (Open bore well)	Drinking water
W3	Khadsaliya (Well water in core zone)	Drinking water
W4	Thalsar (Well water)	Drinking water
W5	Hathab (Bore well)	Drinking water
W6	Padwa (Open bore well)	Drinking water
W7	Sea water	Surface water

Table 10 : Summary of water test result

Characteristics	Water Test Result						
	W1	W2	W3	W4	W5	W6	W7
Suspended solid (mg/l)	16-26	18-23	24-26	18-29	14-44	19-32	22-40
Dissolved solid (mg/l)	480-738	1408-1519	1160-1354	431-638	1485-12185	408-517	22815-30014
Chloride as Cl (mg/l)	47-224	383-544	104-612	48-64	514-5478	48-98	12436-19674
Fluoride as F (mg/l)	0.13-0.24	0.05-0.13	0.10-0.21	0.12-0.23	0.02-0.14	0.03-0.12	Nil-0.09
Dissolved Phosphate as PO_4 (mg/l)	0.004-0.007	0.003-0.007	Nil-0.012	Nil-0.012	Nil-0.008	0.007-0.013	0.005-0.019
Total hardness as $CaCO_3$ (mg/l)	203-432	636-800	470-680	272-363	436-5600	168-228	736-5400
BOD (mg/l)	1.2-2.2	1.2-2.2	1.4-2.0	1.0-3.0	0.8-2.2	0.6-2.2	1.2-2.4
COD (mg/l)	8-16	10-14	18-22	6-12	10-18	6-14	12-19
Calcium hardness (mg/l)	44-112	131-257	89-211	75-91	104-768	28-57	228-672
Magnesium as Mg (mg/l)	26-36	37-73	34-40	19-28	32-883	20-26	38-892

water and facilitate additional recharge to the groundwater reservoir and help to overcome the scarcity of groundwater during dry season.

WATER QUALITY

Water samples were collected from seven locations and analysed to determine the water quality characteristics. The locations of the water sampling stations are illustrated in Figure 7 and described in Table 9.

The results of analysis are summarised in Table 10. It is thus observed that the concentrations of most constituents are well within limits. The coliform was observed only in the sea water. The concentration of dissolved solids was higher in case of sea water and lower in case of Morchand bore well and Thalsar well water. The total hardness ranges from 168 to 5600 mg/l while the calcium hardness varies from 28 to 768 mg/l, higher values being recorded at Hathab bore well.

Total dissolved solids (TDS) in the groundwater along the coast of the study area are being regularly measured by Salinity Control Division, Bhavnagar. Figure 8 depicts the 2000 mg/l TDS contour map along the coast during the May month of 1988, 1998 and 1999 including location of observation wells. TDS contour map for the region during May 1999 is also illustrated in Figure 9.

WATER RESOURCE MANAGEMENT

Groundwater Recharge

i) Artificial recharge possibilities

In view of the favourable hydro-geological conditions, the natural recharge to groundwater from rainfall is 15-20%, which is moderate for the area. There is no surface water source available within the area except seasonal streams to augment the ground resource by artificial recharge. Water has to be brought from outside area to artificially recharge the aquifers for augmenting the groundwater potential of the area so as to meet the future demands. An irrigation canal called Shetrunji canal has been developed in the area by the state government. Few more canals have to be developed in the region to enhance the water resource.

ii) Methodology for artificial recharge

Various methods are available and are being practiced world-wide for artificial recharge of aquifers (Linsley et al., 1975; Freezy & Cherry, 1979; Kashef, 1987; Fetter, 1994; Todd, 1995; Soliman et al., 1997). They include water spreading, contour bunding, contour trenching and construction of check dams, percolation ponds, recharge

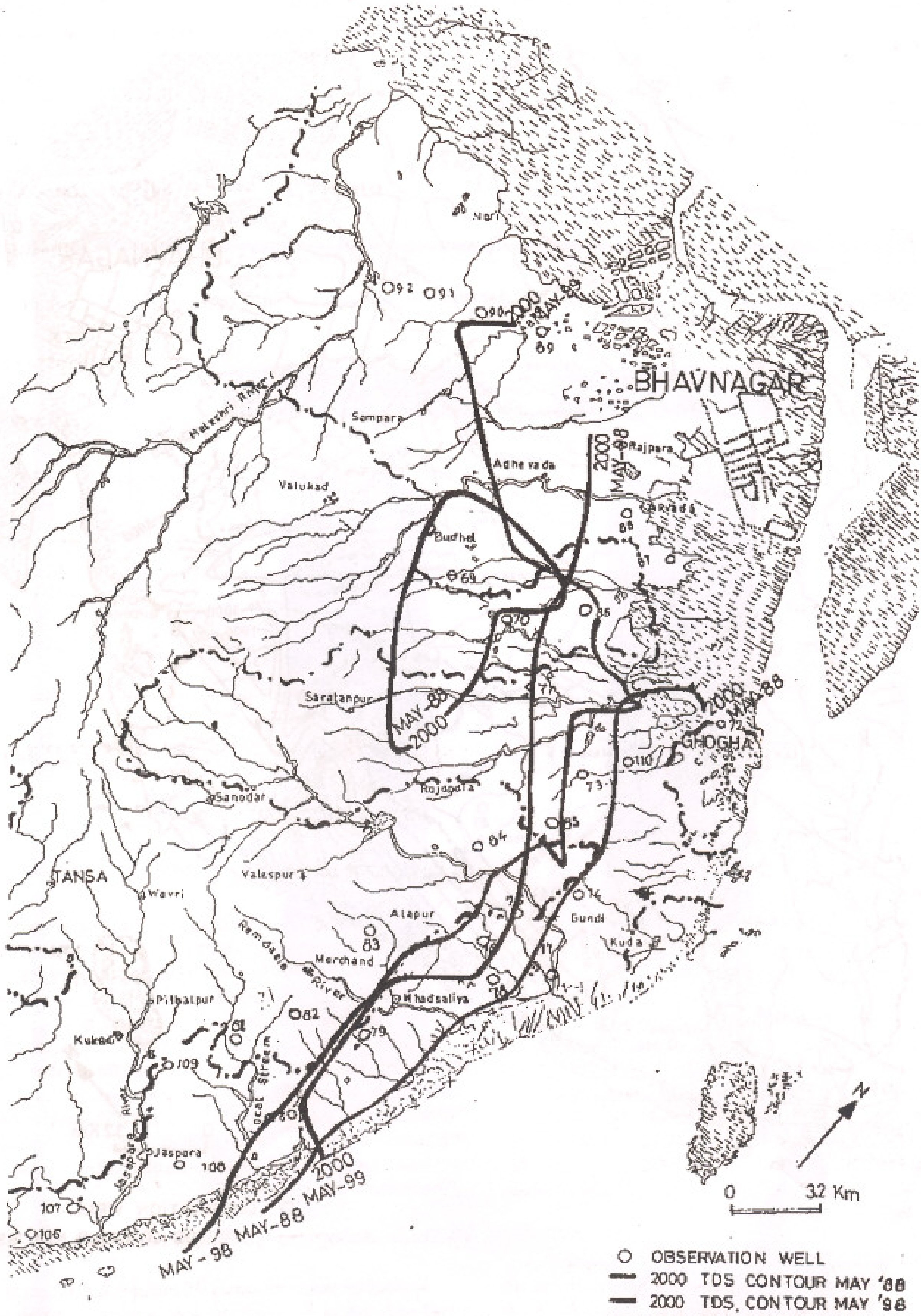

Fig. 8 : Map showing the 2000TDS contour

Fig 9 : TDS contour map during May 1999.

wells, etc. (Soliman et al., 1997). The suitable method for a particular situation is dependent on the hydrological and topographic conditions of the area and the purpose for which the artificial recharge of aquifers is resorted to (El Ouali et al., 1999; Farah et al., 2000). For example, if the natural recharge to the aquifer from the rainfall is low and the run-off is high due to terrain conditions, retention of surface water for longer time within the area by checking the run-off will be the most cost-effective method of artificial recharge.

On the other hand, if the entire rainfall occurring in an area is used fully for natural recharge to groundwater, evaporation and evapo-transpiration and no appreciable run-off takes place, water has to be brought from elsewhere by suitable conveyance system and stored within the area in suitable structures to cause deep percolation to recharge the aquifers.

Construction of Retaining Structures

The following are the general recommendations for the Ramdasiya watershed to enhance groundwater recharge and also to abate salinity ingress along the coastal area:

a) The watershed area has to be categorized into four recharge zones, namely highly favourable, moderately favourable, less and poor. In general, high and moderate zones are the areas suitable for artificial recharge. In these zones soil conditions, slope characteristics, lithology, geomorphology, etc., are favourable for the purpose of recharge. However, in other zones (less and poor) need-based appropriate low cost small recharge structures may be contemplated.

b) Cheek dams are recommended across the streams, wherever suitable.

c) Percolation ponds are recommended in the favourable recharge zones by integrating various parameters, mostly for impounding water for recharge.

d) Desilting of tanks are recommended for the storage sources located in the vicinity of the water bodies. Desilting can be combined with a few recharge pits. Recharge pits are recommended inside the tanks to facilitate recharge.

CONCLUSIONS

Ramdasiya watershed area is running short of groundwater and 90 per cent of groundwater has already been developed. Due to decrease in rainfall during last few years, groundwater level is going down progressively in the area. Therefore, an effective water resource management plan has to be prepared and properly implemented in the field. For this an Integrated Zonation Map (IZM) has to be prepared for the region. By integrating various thematic layers such as geomorphology, geology, soil, land use, slope and making use of derived maps such as lineament density, drainage density and run-off, the watershed area may be classified into various recharge zones like High (highly favourable), Moderate (moderately favourable), Less (less favourable) and Poor (not favourable). Based on the IZM, specific recharge structures should be identified and constructed within the watershed. Detailed geophysical surveys using ground penetrating radar (CPR), electromagnetic surveys and electrical resistivity surveys may also be conducted for locating water bearing zones and lineament zones, and thereby selecting the suitable sites for groundwater recharge.

Implementation of recommended water resource management strategy for the region requires a combined effort by the Central and State Government agencies like Central Groundwater Board, Public Works Department (groundwater), Irrigation Department, Salinity Ingression Department, River Measurement Department, etc. including various non-government organizations (NGOs). The Government of India in various states is implementing the 'Watershed Management Programmes'. In the area where such measures have been taken, beneficial effects on water resources have been observed. Therefore, the Central government, State government and NGOs should effectively implement similar programmes in the area for proper management of water resource in the region.

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