CHAPTER - VI

WATER RESOURCES

PREAMBLE

Water is an important resource for human society. With the rapid pace of all round development, an unprecedented demand on the available water resources all over the world is being witnessed. Utilisation of water in any area cannot be unlimited. Rainfall being the only mode of replenishment to this resource, its erratic pattern and uneven distribution has necessitated an increased emphasis for an optimal utilisation and proper management of the water resources. No strategy, however, can be successfully envisaged and involved in the absence of total evaluation of the hydrogeological regime.

A realistic assessment of freshwater availability must consider climate, location, timing, population, political boundaries, and human intervention. Fig. 34 shows the many factors affecting the availability of water within the study area.

The problem of tapping an adequate water resource in hard rock terrain needs special attention. The paucity of suitable aquifer systems, inconsistency in their occurrence, and distribution makes routine methods less fruitful in augmenting the water demand.

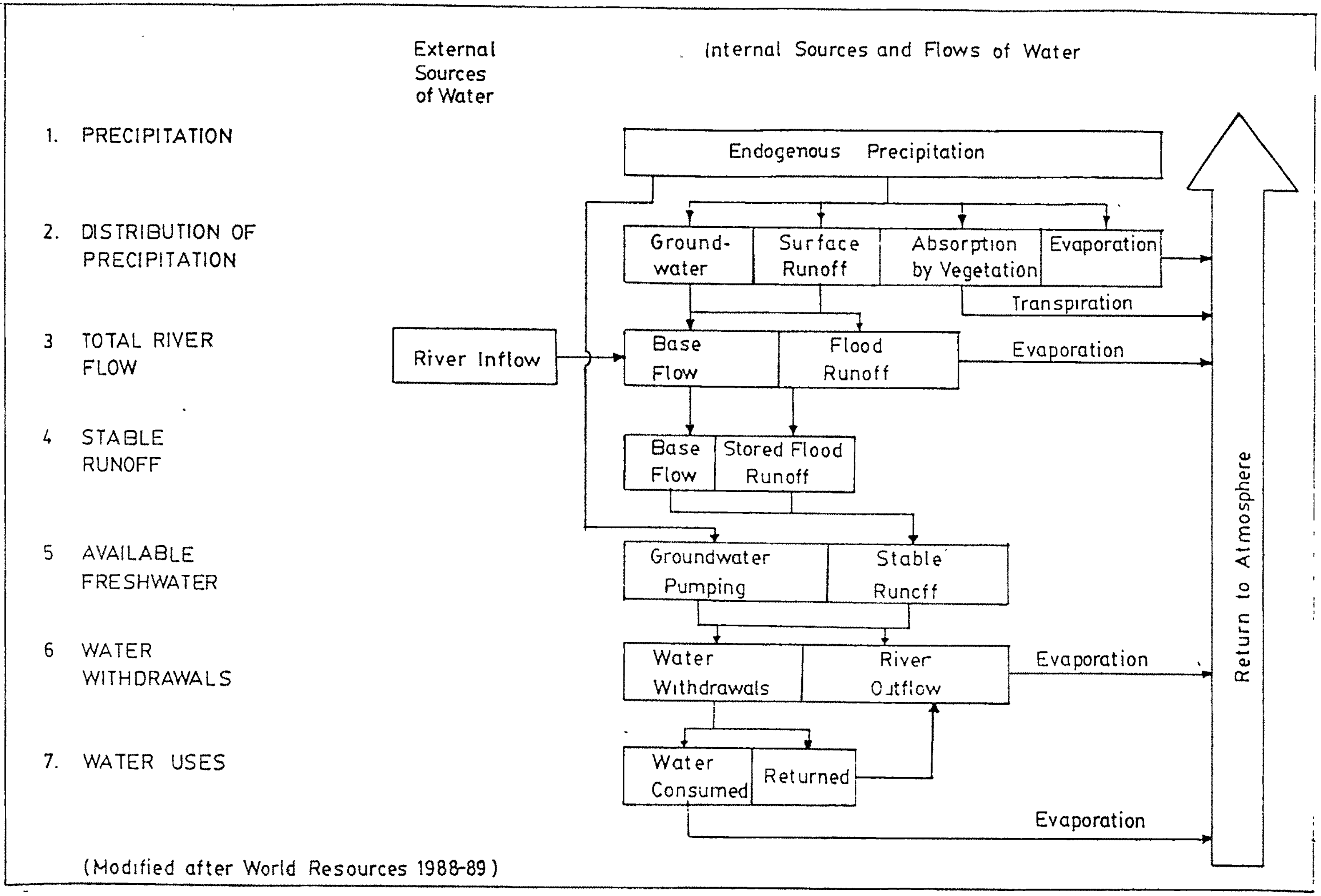

FIG. 34. FRESHWATER AVAILABILITY FOR THE STUDY AREA

Objectives

The study area, which is primarily a preserved forest area, is geologically composed of Deccan Trap basalts and associated rock types. This geological set-up has produced a unique blend of surface and sub-surface water scenario which requires a detailed and systematic study in order to assess the quantity and quality.

Having realised this fact, the author has made an attempt to categorise the study area into relatively favourable and unfavourable classes by critically examining various attributes viz. hydrometeorology, surface and subsurface water resources including mode of occurrence, distribution, potential, quality, etc. For these studies, extensive fieldwork, sampling, geophysical surveys, followed by laboratory analyses was carried out.

A detailed account of the adopted approach and appropriate management strategy for augmenting the water demand is decribed in the chapter on management suggestions.

HYDROMETEOROLOGY

The study of this aspect forms an integral part of water resources development and management. Numerous factors viz. solar insolation, humidity, wind velocity and evapotranspiration are of prime importance governing the precipitation. It is well known that precipitation forms a vital and the only input to the Gir area, contributing towards the occurrence, distribution and the potential of surface and groundwater resources.

As the study area forms a part of tropical region, it is marked with seasonal climatic conditions. The broad trends of various atmospheric parameters governing the occurrence, distribution and the potential of water resources are discussed below.

(i) Temperature

From the beginning of March, the temperature starts rising steadily, and May and June, are the hottest months. The mean daily maximum temperature during the summer season is about 35°C, whereas the mean daily minimum is about 20°C. With the onset of the south-west monsoon by about mid-June (Table : 16), temperatures drop a little, but the relief from the heat is not marked due to the increase in humidity brought on by the monsoon winds.

In the post-monsoon period, the days are hotter than in the summer season, but the nights are cooler. After November, temperatures decrease till January, which is the coldest month. The mean daily maximum temperature in January is about 25°C, whereas the mean daily minimum is about 10°C. In

Table - 16

Mean monthly climatic data observed in the study area

Month	Temperature (^oC) Avg.Max.	Temperature (^oC) Avg.Min.	Relative Humidity (in %)	Wind Speed (km/hr)	Rainfall (in mm)
January	27.59	10.20	33.90	07.70	-
February	29.84	11.99	36.40	09.00	-
March	35.20	12.54	36.75	10.50	-
April	38.43	20.64	50.80	11.90	-
May	34.42	25.51	63.10	13.40	-
June	29.63	24.64	77.90	16.70	150.70
July	27.81	23.48	84.80	20.80	065.00
August	27.90	22.08	87.75	17.70	449.10
September	30.63	20.70	75.90	11.10	046.20
October	32.98	19.87	60.70	07.90	-
November	32.24	12.04	51.38	07.10	-
December	29.64	09.13	45.60	07.10	-

(compiled after Berwick, 1974; Gujarat State Gazetteer, 1975; Sinha, 1987; Govt. of Gujarat, 1988) association with cold waves which sometimes affect the region, in the wake of western disturbances passing across north India during the cold season, the minimum temperature may sometimes go down to about 4^{o}-$5^{o}C$.

(ii) Humidity

Relative humidity observed at Junagadh station reaches as high as 90% during monsoon season. After monsoon through winter and summer, the humidity starts lowering down and attains the minimum value of < 35% (Table : 16).

(iii) Wind

As the study area is in close vicinity of the Arabian sea, the wind speed is usually high to moderate. During the later part of summer and monsoon seasons, the wind is predominantly from the southwest to west. Thunderstorms commonly occur during May and June, and during the monsoon, rain is sometimes accompanied by thunder. During the period from October to March, the wind blows mainly from the northwest to northeast. Occasionally, the area is swept by cyclonic winds, during the post-monsoon period.

The monthly wind velocity observed at Veraval station is given in Table. 16. The average wind velocity in the study area increases from 10-15 km/hr in January, to 20-25 km/hr in

August. The average annual wind velocity is about 15-20 km/hr.

(iv) Precipitation

As it has already been elucidated in the preceeding chapter on Geomorphology, the study area exhibits a large scale orographic variation, which in turn has been responsible in governing the rainfall pattern and distribution. The other aspects related to terrain have influenced the water regime by contributing towards run-off and the recharge to the aquifer systems. Having realised the diverse mode of occurrence of ground water resources and the ephemeral nature of surface water resources, it has become necessary to look into the detailed aspects of rainfall for conceptualization of water resources management strategies.

(v) Rainfall pattern

Rainfall in the study area is erratic and irregularly distributed. The monsoon season normally starts in June and lasts till September (Table : 16). A few showers may occur in the month of October, whereas winter rains are unusual. The initial downpours at the end of May or the beginning of June are considered as pre-monsoon rains, and are usually followed by a short dry spell. About 95% of the rainfall is usually received during the monsoon, with July-August being the period of maximum rainfall. On an average there are about 40 rainy days in a year.

The average annual rainfall over the study area is about 800 mm, decreasing from about 1000 mm at Sasan in the southwest, to 650 mm at Jasadhar in the east. Thus the precipitation steadily decreases as one proceeds from the southwest to northeast. This is obvious in the northeastern part of the study area which falls within the shadow zone of the south western hilly tract, implying an orographic control. The rainfall data from 1977-1988 (Table : 17), indicates that the east has 23-22% less average annual rainfall than the west. The mean annual rainfall observed at Sasan is over 900 mm, the highest for the study area. Whereas in the east, the mean annual rainfall recorded at the Raval reservoir station is 700 mm, the lowest for the study area.

Variation in Annual Rainfall

The study of average annual rainfall (1977-88) extremities within the study area, has revealed that the departure from average annual rainfall is more than minus (-) 50%. Station wise details within the study area are given in Table. 18.

(vi) Weighted area precipitation

A quantitative analysis of rainfall data has been carried out in order to throw more light on the run-off/recharge

Table - 17

Rainfall data of the study area (1977-1988)

YEAR	STATIONS									
	GIR-WEST						GIR-EAST			
	Sasan	Mendarda	Visavadar	Talala	Shingoda	Machhundri	Kodinar	Dhari	Raval	Una
1977	981.80	731.00	620.80	800.10	840.00	594.20	N.A.	N.A.	569.00	873.10
1978	853.20	837.00	708.00	711.00	520.00	244.00	N.A.	N.A.	511.40	777.00
1979	1074.00	1336.00	1289.00	1164.00	1126.00	784.70	N.A.	N.A.	743.50	1189.00
1980	1011.50	1152.00	N.A.	962.75	1288.00	916.90	N.A.	N.A.	846.00	1039.00
1981	630.10	702.00	529.00	948.00	703.00	797.00	N.A.	N.A.	630.00	609.00
1982	703.00	473.00	N.A.	465.60	678.00	460.00	N.A.	N.A.	532.00	387.00
1983	1889.00	1566.00	1071.00	1049.00	678.00	1369.00	1151.32	1304.00	1277.07	1200.21
1984	1004.00	730.50	756.00	866.00	815.00	652.00	815.00	506.00	554.50	1021.00
1985	418.00	368.50	654.00	359.00	310.00	370.00	310.00	514.00	553.50	400.00
1986	755.00	905.00	951.00	827.00	700.00	536.00	700.00	164.00	449.50	487.00
1987	199.00	135.20	224.00	222.00	276.00	239.00	276.00	284.00	203.00	284.00
1988	1444.00	1324.00	1709.00	1125.00	1341.00	1735.00	N.A.	N.A.	1564.50	939.80
Average Annual Rainfall (in mm)	913.55	855.02	788.18	791.62	772.92	724.82	650.50	554.40	702.82	767.20
Decrease in rainfall compared to Sasan (in %)	-	-	-	-	15.4	20.7	-	-	23.07	-

Table - 18

Absolute extremes of rainfall (mm/yr)

Station	Avg. Annual	Rainfall		Departure from Avg. annual rainfall (in %)	
		Max.	Min.	above avg.	below avg.
Sasan	913.55	1889.00	199.00	+50.00	-50.00
Shingoda	772.92	1341.00	276.00	+41.67	-58.33
Machhundri	724.82	1735.00	239.00	+41.67	-58.33
Raval	702.82	1564.50	203.00	+33.33	-66.67

Table - 19

Weighted area precipitation

Polygon	Rainfall (in m)	Area (in sq.m)	Weighted Precipitation (in MCM)
Gir-west			
Sasan	0.9135	297.44×10^6	271.71
Mendarda	0.8550	5.12×10^6	4.40
Visavadar	0.7882	142.50×10^6	112.32
Talala	0.7916	24.36×10^6	19.28
Shingoda	0.7729	409.06×10^6	316.16
Gir-east			
Kodinar	0.6505	-	-
Dhari	0.5544	71.75×10^6	39.78
Raval	0.7028	432.88×10^6	304.22
Una	0.7672	29.02×10^6	22.26
		Total	1090.13

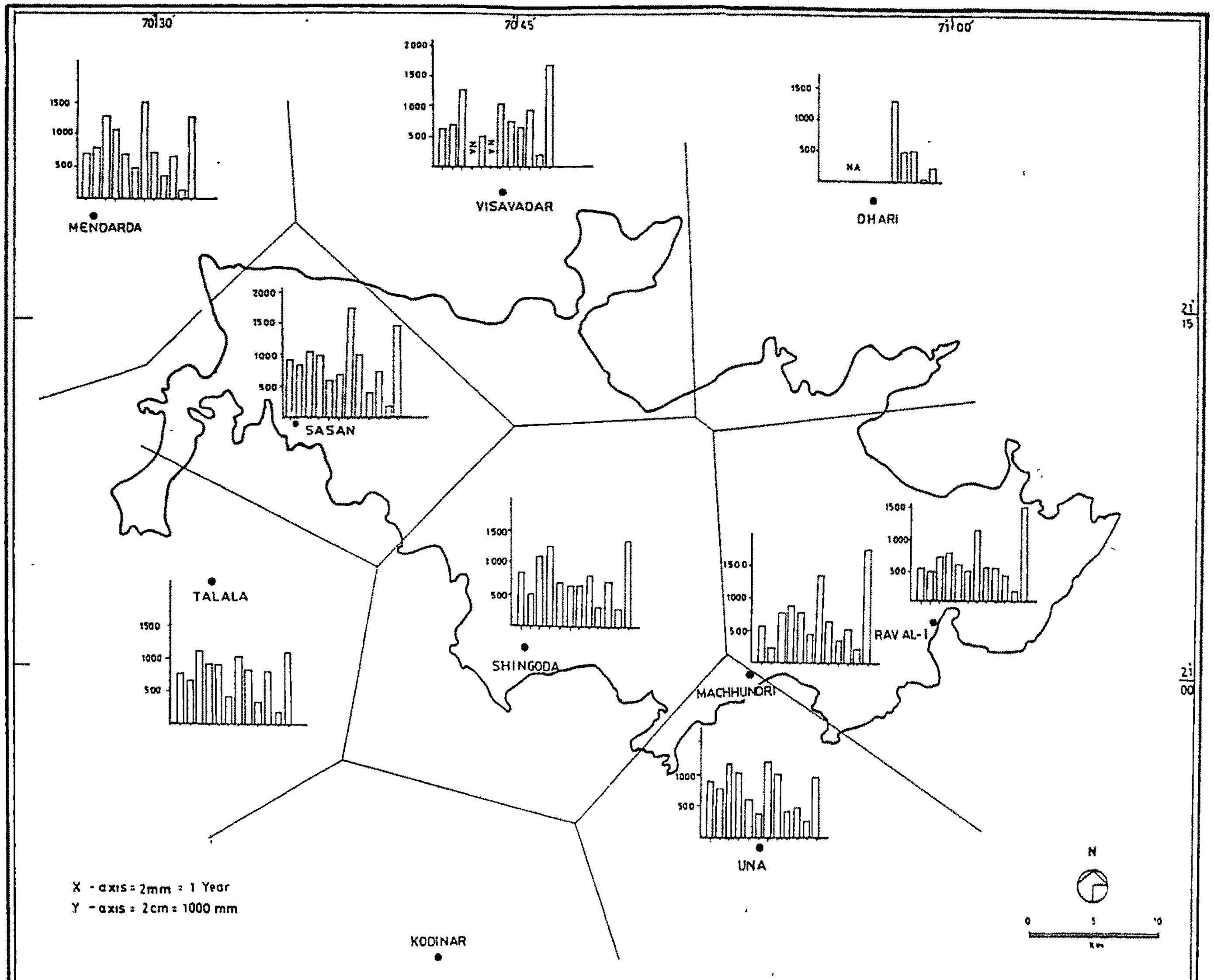

FIG 35 WEIGHTED AREA PRECIPITATION ANALYSIS

relationships, the water budget and the water resources management required. Looking to the terrain conditions and the avalability of the rainfall data, the author has employed Theissen's Polygon Method (Heath & Trainer, 1968).

The raingauge stations located in the study area and its neighbourhood were plotted on a map. Perpendicular bisectors were drawn on the lines connecting adjacent stations. Polygons were constructed by joining these perpendicular bisectrix. The weighted precipitation was computed by calculating the area of polygon and the rain fall there in (Fig. 35).

The weighted precipitation computed at various raingauge stations (Table : 19) shows that the total volume of water received within the area from precipitation is 1090.13 MCM. It can be seen from Table. 19, that western Gir receives about 723.87 MCM water through rain and shares more than 65% of the total volume distributed over the study area.

SURFACE WATER RESOURCES

The surface water, being fed by the monsoonal rains, constitutes a large share of water resources in the study area. The groundwater in the upper reaches also contributes to surface water, as spring flow.

Mode of occurrence and distribution

In the study area, surface water occurs in the form of surficial depressions, streams, rivers and man-made reservoirs. As mentioned earlier, the entire study area is drained by 13 rivers viz. Shetrunji, Hiran, Shingoda, Shingavadi, Machhundri, Raval, Rupen, Saraswati, Dhatardi, Malan, Meghal, Ghodavadi, Popatdi and other tributaries of Ojat. Excepting Popatdi and Shetrunji, all the other rivers flow southwardly (Fig. 11). However, major watersheds within the study area are formed by Popatdi, Hiran, Shingoda, Shingwadi, Machhundri, Raval & Ghodavadi. All these rivers are of ephemeral nature.

In addition to this, there are four man-made reservoirs in the study area. The rivers Hiran, Shinghoda, Machhundri and Raval have been dammed under the medium irrigation soheme (Table : 20). These are mainly storage reservoirs and no canal net work has been laid. Water from these reservoirs is released to be distributed from the downstream pickup weirs situated outside the study area. Therefore, these rivers exhibit a perennial nature, down stream of the reservoirs.

Groundwater outflows, in the form of springs and seepages also contribute to the surface water resources of the study area. These groundwater outflows are essentially fracture/fault controlled (Fig. 36). Most of the springs and

Table - 20

Details of reservoirs of the study area

Details	Name of the Project			
	Hiran - I	Machhundri - II	Shingoda	Raval - II
Area of catchment (in sq.km)	081.00	218.00	281.00	240.00
Area at full reservoir level (in sq.km)	003.35	004.47	005.55	002.46
Gross storage capacity (in MCM)	021.60	031.84	036.40	026.73
Effective storage capacity (in MCM)	020.50	026.37	036.07	024.00
Submergence area (in ha)	335.41	448.00	555.00	246.00
Length of canal (in km)	015.44	17.56(R), 14.80(L)	013.57	006.60
Gross command area (in ha)	8092	9995	8508	8108
Culturable command area (in ha)	3956	8095	8508	4860
No. of villages under command	9	21	17	17

(Source : Water Resources Dept., Govt. of Gujarat, 1989)

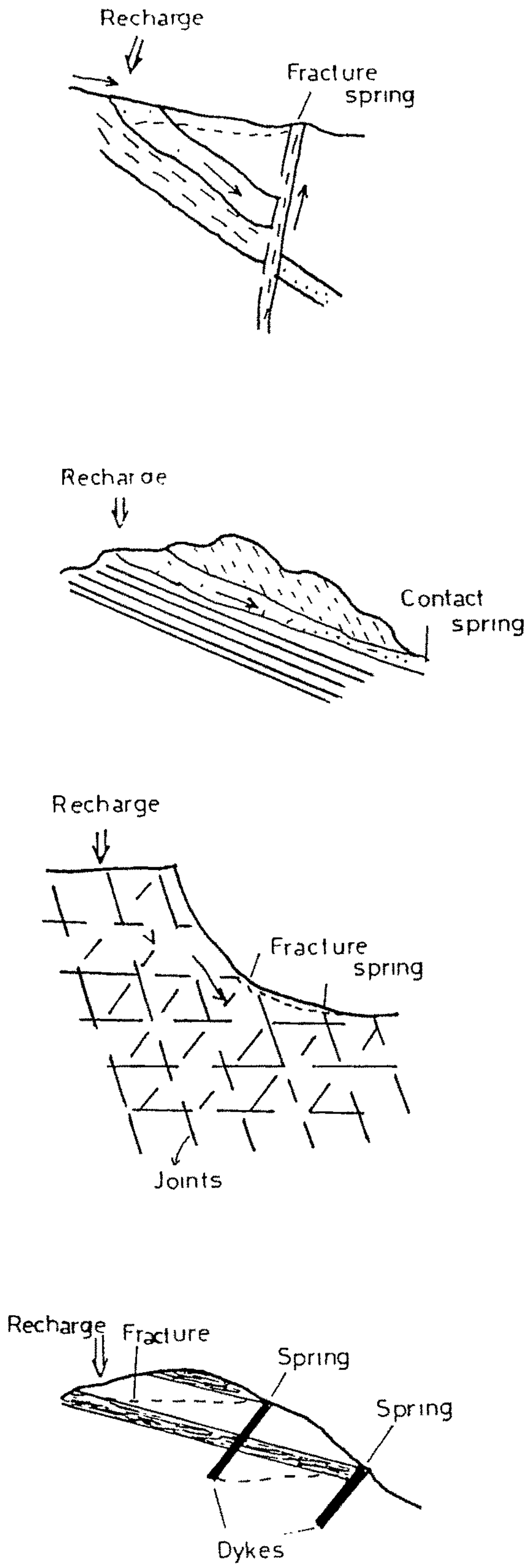

FIG. 36. SPRING CONDITIONS

(after Valdiya, 1987)

seepages are ephemeral in nature and usually dry out during the month of February. The study area comprises seven perennial springs, out of which 04 are falling in western Gir and the remaining 03 in eastern Gir (Fig. 11). The area has got one hot spring located at Tulsishyam. The temperature of the water is as high as 51°C (Gazetteer of Gujarat, 1975).

There is better distribution of water during monsoon, with numerous pools of water found in depressions of various sizes, after rainy spells. But during the summer season, surface water is confined to major surficial depressions and river pools only (Fig. 37 & 38).

Moreover, all the four reservoirs are located along the southern fringe of the study area. So, during the summer, the area experiences acute scarcity of water due to the uneven distribution of surface water. The general southerly slope in this major watershed region, causes acute water shortage in the northern and eastern parts of the study area.

Potential

The rainfall pattern influences all the streams and rivers in the area, as after a cloud burst, the runoff is heavy, but decreases with passage of time. Eventually, during the peak summer months, the streams and rivers contain water only in the form of stagnant pools, as all the rivers are seasonal, and contain water i.e. base-flow, till the month of

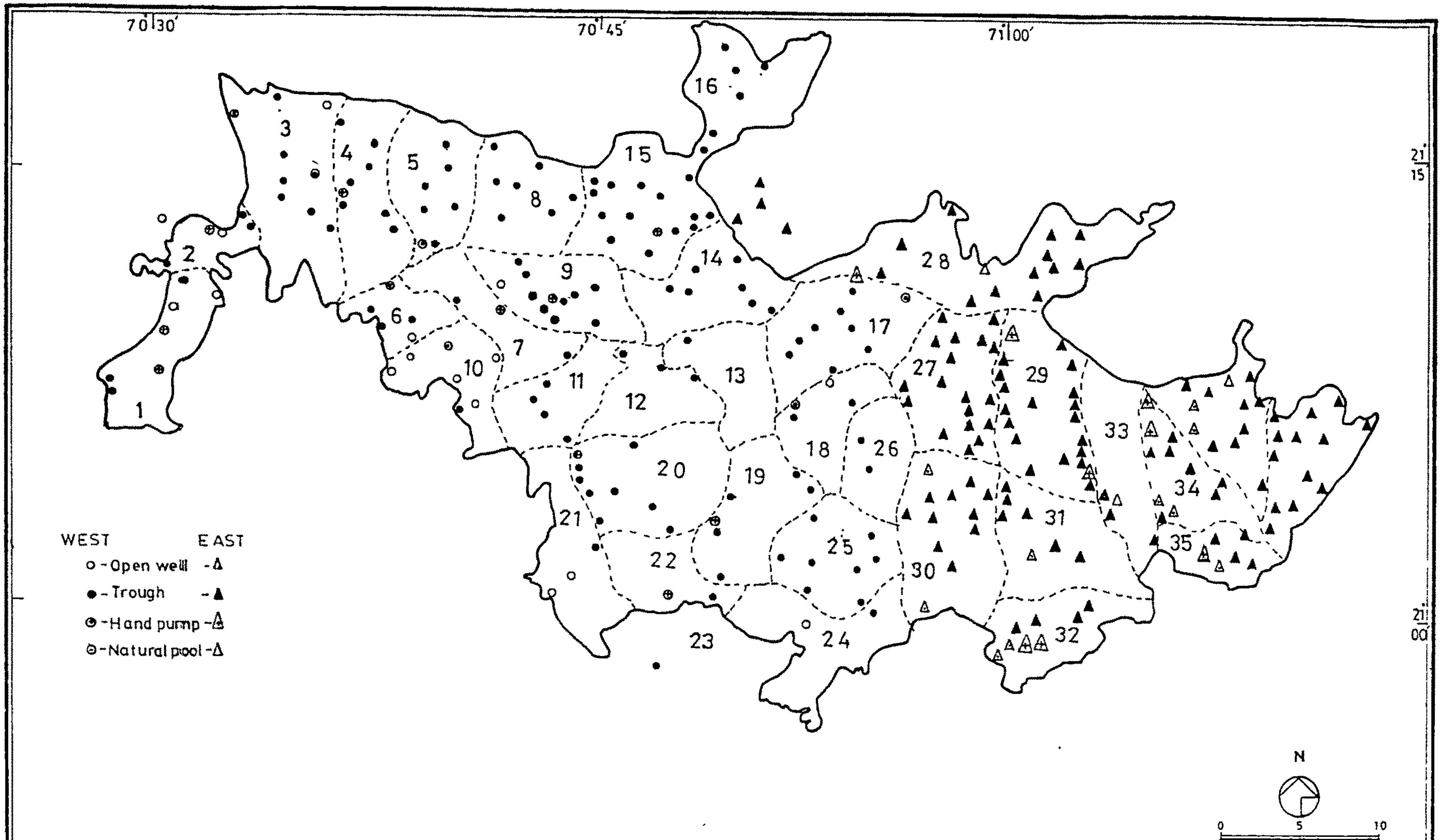

FIG.37. WATER STRUCTURES IN THE GIR AREA (1988)

(Source- Forest Dept 1988)

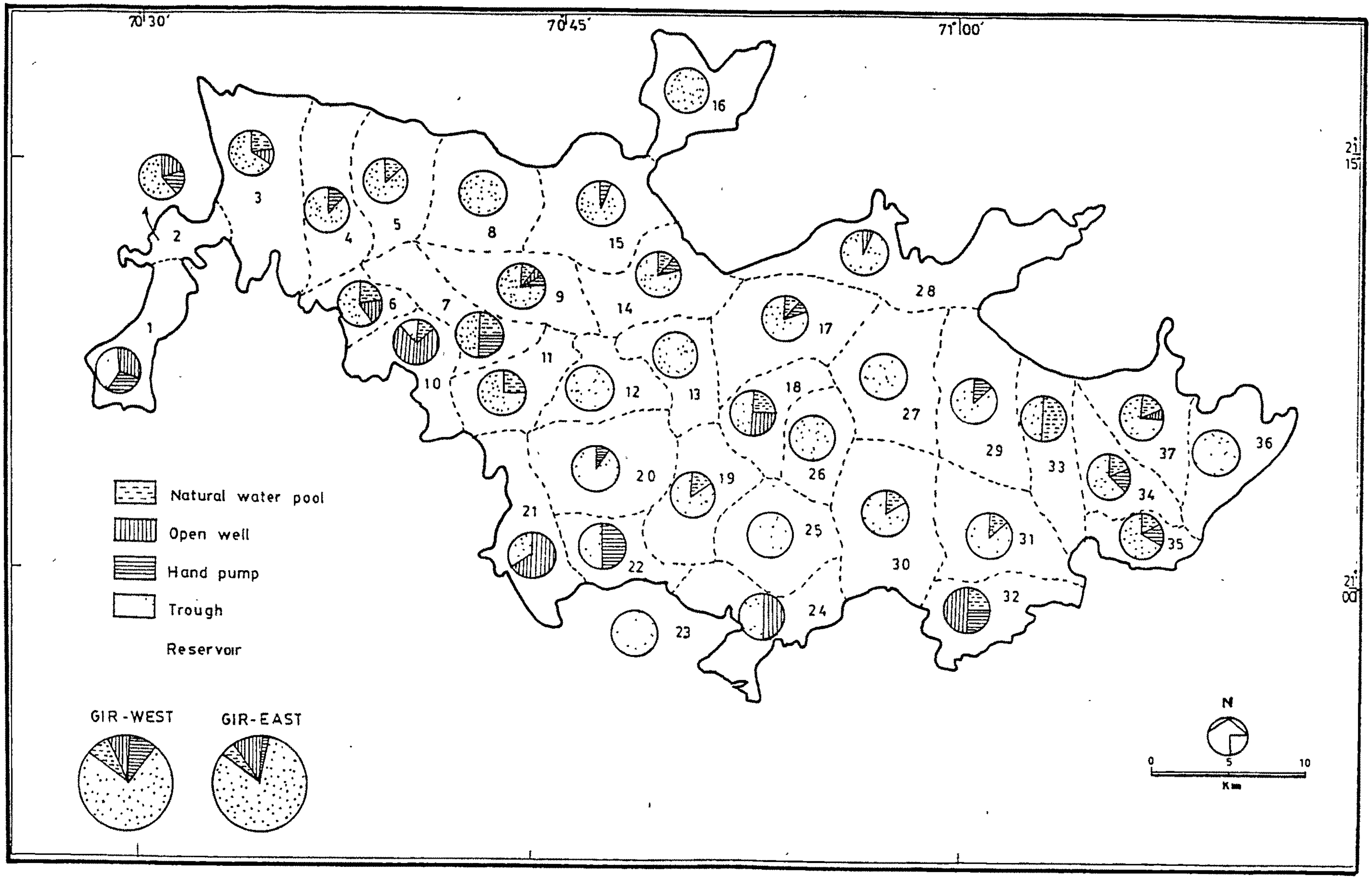

FIG. 38. NATURAL AND ARTIFICIAL WATER SOURCES

February. The study area is influenced by a rough 4 year drought cycle, and this, coupled with the erratic rainfall, poses a big problem vis a vis water availability during drought years, during which, the few perennial surface water sources also dry up.

All the four reservoirs have been constructed with the sole purpose of providing irrigation facilities to the agricultural fields outside the study area. The gross storage of these reservoirs depends solely on the amount of rainfall. Even if there is enough rainfall, most of the water is drained off during the peak summer months for irrigation. Because of these reservoirs, the baseflow period in the downstream has been stretched, due to controlled, continuous release of stored water.

From Table. 19, it can be seen that the annual precipitation is 1090.30 MCM out of which a large amount is lost due to runoff (not calculated in the absence of any discharge data), which is again regulated by the rugged terrain in the study area. With the precipitation restricted only during the monsoon months, the availability of surface water is sporadic during the drier months.

GROUNDWATER RESOURCES

Mode of occurrence and distribution

The study area is a typical hard rock terrain, hence, the groundwater availability and its potential is governed by the factors related to lithological variation and structural configuration. As has been discussed in the preceeding chapter on geology, the area comprises predominantly of basaltic rocks and their derivatives, with valley portions occupied by patchy alluvium lenses.

It is well known that the occurrence of groundwater in a hard rock terrain is dominantly confined to the phreatic aquifer system; occasionally underlain by the deeper aquifers, developed within the fractured rocks. A detailed study of the litho-tectonic and terrain characteristics of the study area, supported by remote sensing data, followed up field checks, has thrown up significant information on the groundwater regime. The area exhibits diverse modes of occurrence of the groundwater resources viz. phreatic / unconfined aquifers, semi-confined aquifers, confined aquifers and springs.

Karanth (1989) has identified number of factors controlling the occurrence and movement of groundwater in volcanic rocks and are given below :

(1) vertical and horizontal porosity and permeability, owing to fractures and interconnected vesicular interstices which permit storage and movement of groundwater,

(2) occurrence of impervious layers and presence of dykes and sills which retard movement of groundwater, and

(3) volcanic rocks like basalts have well defined water-bearing horizons. An alternating sequence of permeable and compact horizons in volcanic rocks gives rise to a multi-aquifer system.

(i) Phreatic/unconfined aquifers

The phreatic or unconfined aquifers are usually found along the foot hills, in the pediment and pediplain areas. Under hot and humid conditions, basalts develop a thick veneer of soils. It has been observed that the weathering of basaltic rocks in the study area is in the range of 5-15 m. It is this weathered zone which possesses a desirable level of hydraulic characteristics, to store and transmit the water. Having hard rock "the aquifuge" as a base, these phreatic aquifers are of limited potential. Thereby, chances of getting perennial supply of groundwater from these aquifers is of a highly localised nature. A large number of dug-wells in the study area are limited to these phreatic aquifer zones with a yield ranging from 150-300 lpm.

(ii) Semi-confined aquifers

The semi-confined aquifer system in the study area are essentially of linear nature, dominantly confined to major fracture/shear zones. It is difficult to distinguish a semiconfined aquifer from a confined one. However, careful scrutiny of available data on bore-wells, hand pump bores etc. has helped the author to separate this intermediate category from the others. It has been observed from the data, that the first encountered water level at the time of boring work, showed a significant rise i.e. to the order of 3-5 m, the next day. This could only be possible when the aquifer was capped by an aquitard layer. It is very difficult to make a marked assessment of these semi-confined aquifers of the study area. However, wherever these have been developed they have turned out to be a good source of supply, with a yield range of 350-700 lpm.

(iii) Confined aquifers

The development of confined aquifers in this predominantly basaltic terrain is attributed to the genetic nature of lithology. As has already been discussed, the study area exhibits a number of lava flows, marked with numerous interflow surfaces, which are the locales of the confined regime. Sometimes, the presence of deeper fractures and fault zones have also contributed in the development of a deeper confined aquifer system. These aquifers are the source of copious supplies of groundwater, with an average yield of more than 700 lpm.

Being a protected area, the information available on hydrogeological aspects is very fragmentary. Hence, the author's own efforts and observations on the hydrological regime of the study area and its neighbourhood, has provided an insight of the problem.

The above details and the preceeding aspects are the net outcome of the author's maiden attempt on this vital environmental, life-sustaining parameter.

HYDROGEOLOGICAL EVALUATION

The occurrence and distribution of water resources in any area is a function of three vital parameters viz. (i) lithology, (ii) structural framework, and (iii) geomorphology. The varied rock types and their distribution in time and space exhibit differential response to the various physio-chemical processes. This has resulted into an overall heterogeneity in the weathering; influencing an overall development of the aquifer system. The structural framework of the area provides conduits/channels, through which the entire surface as well as subsurface flow of water is being regulated. The geomorphology, a genetic atitribute of litho-structural parameters, helps in regulating the various surficial processes, thereby playing a pivotal role in the shaping of an overall groundwater regime by the processes of recharge and runoff.

The relative favourability of these above mentioned parameters, from the point of view of groundwater availability-potential has provided the basis to evaluate the study area's water resources. In the context of above discussed basis the author has divided these hydrogeologic attributes into three broad categories viz. hydro-lithology, hydro-structures, and hydro-geomorphology.

(I) Hydro-lithological characteristics

Lithology plays an important role as it determines the basic parameters like porosity, permeability, etc. required for the development of an aquifer.

Based on the author's own observations and the work of Dhokalikar (1991), the important rock types of the study area and their hydrogeological significances are given below :

Lithology	Hydrolithological significance
(i) Alluvium	Tallus along the pediments, flood plain deposits along the river valley are the potential zones of groundwater.
(ii) Miliolite limestone	Fragile sedimentary rocks highly porous, and permeable, provide excellent conditions for the aquifer development. Since, limestones are capping the Deccan

Traps along the hill fringes and in the valley, their thickness is a limiting factor.

Type Area - Sasan, Sirwan and Janwadla

(iii) Weathered basalt	Deeply weathered rock material associated with highly fractured bed rock are good repositories of groundwater. Type Area - Dudhala, Jambuthala and Hadala
(iv) Vesicular basalt	The jointed and vesicular-cavernous lavas and associated beds of volcanic ash and buried soils/weathered rock material developes between eruptions have been found to be of excellent hydraulic characteristics. Type Area - Karamdadi, Chhodaudi and Wanka Jambu Nes.
(v) Amygdaloidal basalt	Amygdaloidal basalts have moderate porosity and permeability. Therefore, they are moderately favourable formations for subsurface water development. If they are characterised

		by high degree of interconnecting vesicles and pipes, they can be of high yield. Type area - Banej, Suvardi Nes and Bajriya Nes.
(vi)	Massive basalt	These rocks have low porosity and permeability. Therefore, these are unfavourable for groundwater development. But, when these formations are highly fractured and jointed, secondary porosity becomes very favourable for groundwater exploitation. Type Area - Ravta Nes, Lilapani and Asodriali Nes.
(vii)	Intrusives/ associated dykes	Dykes, usually congeal rapidly and develop joints within the intrusive body as well as in the host rocks, so they must be considered as good water producers when occuring amidst more impervious rocks and as barriers or confining layers if they occur amidst comparatively more permeable rocks. Dyke junctions are also excellent sites for groundwater development. Certain barrier

dykes have given rise to a number of springs. Groundwater development along rhyolite dyke has to be dealt carefully as it usually creates water quality problems. In many parts of the study area, dykes are forming linear ridges, these are not favourable for groundwater development.

Type Area - Suvardi Nes, Jamwali Nes and Tulsishyam.

(II) Hydrostructural characteristics

The influence of structural parameters in shaping the groundwater regime is well known. The intensity and type of structure are the major governing factors, imparting secondary geohydrological characteristics to the rock. An overall channelization and storage of groundwater in the hard rock terrain, like present one is attributed to the structural framework of the area. As evident from various physiographic features such as drainage, landforms, etc., structural control is very dominant in the study area.

All the major rivers flow along various fault zones and streams follow joints and fracture zone. Various landforms like depressions and ridges are also tectonically controlled. Numerous structure influencing the groundwater regime and its potential can be put under two categories viz. (i) major structures, (ii) minor structures. The role of major structures is to regulate entire flow of the watershed; while the minor one acts as recharge streaks. A critical account of different structures their hydrogeological significance is given below.

Structures	Hydro-structural significance
<u>Major</u>	
Fault zone Shear zone Master joints	Zone of influence devoid of any infilling material or with calcareous in-fillings are favourable from the view -point of groundwater occurrence and movement as well as for high potential aquifer or spring condition.
Dykes/Sills	Dykes running across the groundwater flow may create subsurface water pool, the otherside may remain dry. Sills act as an aquifuge thereby, preventing groundwater losses to deeper zones. Type Area : Rajasthali, north of Ravta Nes and Devaliya
Shear zone Fracture	Possibility of localized development of aquifers and or spring conditions

Joints	otherwise of insignificant value. Contributing towards the recharge to the aquifer system. Type Area : Kansiya Nes, Patla Mahadev and Dabhala Nes.

(III) Hydrogeomorphological characteristics

Geomorphology plays a vital role in the development of groundwater regime. Almost all the terrain characteristics viz. physiography, landforms, slopes etc. are the manifestations of the lithostructural setup and various surficial processes; which are responsible in imparting the geohydrological characteristics. The basic inputs of water budgeting (run off-recharge) are dominantly by governed by the geomorphological parameters of the study area. Geomorphology vis-a-vis water resource distribution potential are given below.

Geomorphic unit	Hydrogeomorphological significance
(i) Drainage pattern	The study area by and large exhibits dendritic drainage pattern, contributing towards more run-off. Trellis and sub-dendritic are the main patterns favourable for the development of potential

aquifer system. Locations showing these drainage pattern are favourable sites for groundwater exploitation.

Type Area : Patla Mahadev, Somanisar Nes and Kothariya.

(ii) Slope

(a) Gentle

Favourable for groundwater development as runoff is less and infiltration is more.

Type area : Rebadi, Rajasthali, Roshali Nes and Devaliya.

(b) Moderate

Favourable for both surface and groundwater development; ideal condition for the occurrence of springs.

Type Area : Jamri Nes, Janwadla, Khajuri.

(c) Steep

Unfavourable for both surface and groundwater development as it contributes towards high runoff.

Type Area : Wanasali, North of Vakumba Nes, NE of Banej.

(iii)	Flood plain & river terraces	Although, occurring sporadically in the study area, they can be very good sites for groundwater exploitation depending upon the thickness of the unconsolidated material. Type Area : All along major rivers.
(iv)	Valley fills	Comprises colluvial / fluvial deposits of various grain size. Moderate to good site for groundwater accumulation, depending upon the thickness of filled material. Type Area : Chhodaudi, Kardapan and Sikhalkuba.
(v)	Denudational hills	Generally rocky and steep-sided, major sites of recharge and therefore, unfavourable for groundwater development. Type Area : Vansadhol, Raidi and Nandivella.
(vi)	Buried pediment	Favourable sites for the development of phreatic aquifer

	system of moderate to good yield. Thickness of aquifer varies with underlying lithology. Type area : Devaliya, Rajasthali and Patla Mahadev
(vii) Buried pediplain	Narrow strips of local extent essentially covered with relatively thick deposits of weathered material. Moderate to good potential. Type area : Kapuriya Nes, Bateshwar Nes and Kardapan
(viii)Dissected plateau	Favourable for phreatic types of aquifers; good along lineaments and their intersections. Type area : Ravta Nes, Viragala and Leriya

GROUNDWATER EXTRACTION STRUCTURES

Groundwater is the major source to meet the demand of wildlife as well as the human settlements located in the study area. As its availability and distribution is strongly influenced by the geologic environment, this replenishable resource is extracted by various modes and means. Within the study area, groundwater is harnessed by constructing various groundwater structures. A blockwise data of various structures used for groundwater extraction and other sources of water supply are given in Table. 21. These can be broadly classified as :-

(I) Temporary structure

(i) Troughs

During the peak summer months, when the river bed dries up the maldharis dig the river bed to exploit the subsurface water flow. With the gradual fall in the water level, the troughs are deepened further. But, this is solely on a temporary basis as the troughs get silted up during the monsoon season.

These troughs are shared by the maldharis and their livestock, as well as by wildlife. Thus, the maintenance of waterholes by maldharis during scarcity period partly benefits the wildlife.

(II) Permanent structures

(i) Dug-wells

In all there are about 18 open dug-wells in the study area. These are mainly circular in shape and are about 2-3 m in diameter. Dug-wells are constructed to tap the

Table - 21

Present status of water structures in the study area (1988)

Forest Block	Natural water pool	Trough	open dug well	Handpump	Reservoir
<----------		GIR-WEST			---------->
1. Devaliya	-	3	2	2	-
2. Surajgadh	-	3	2	1	-
3. Raidi	2	6	1	-	-
4. Dudhala	-	7	-	1	-
5. Alawani	1	6	-	-	Hiran - I
6. Sasan	1	3	1	-	-
7. Amla	1	2	-	1	-
8. Barwania	-	7	-	-	Hiran - I
9. Chasagola	1	10	1	1	Hiran - I
10. Khokhara	1	1	5	-	-
11. Kansoriya	1	3	-	-	-
12. Vankidas	-	3	-	-	-
13. Kankai	-	1	-	1	-
14. Rampari	1	7	-	1	-
15. Kachhighad	-	14	-	1	-
16. Malpara	-	6	-	-	-
17. Sap Nes	1	8	-	1	-
18. Chhodaudi	1	2	1	-	-
19. Khodiyar	-	5	-	1	-
20. Janwadla	-	8	-	1	-
21. Rasulgadh	-	1	2	-	-
22. Jamwala	-	1	-	1	Shingoda
23. Ghantwad	-	1	-	-	-
24. Babaria	-	1	1	-	Machhundri
25. Banej	-	8	-	-	-
26. Sismal	-	2	-	-	-
Total	11	109	16	13	3

contd.

Table 21-contd.

Forest Block	Natural water pool	Trough	open dug well	Handpump	Reservoir
<------------------------- GIR-EAST ------------------------->					
27. Vanka Jambu	-	18	-	-	-
28. Shemardi	-	12	1	-	-
29. Hadala	-	18	-	2	-
30. Kardapan	2	10	-	-	Machhundri
31. Tulsishyam	1	6	-	-	-
32. Jasadhar	2	4	-	2	-
33. Vejal Kotha	3	3	-	-	Raval - II
34. Timberva	2	7	-	2	Raval - II
35. Kotharia	1	4	-	1	Raval - II
36. Pipalva	-	13	-	-	-
37. Bhania	2	9	1	-	-
38. Dhari	-	4	-	-	-
Total	13	89	2	7	2

Source : Forest Department, 1988.

unconfined aquifers, with a maximum depth range of 15-20 m from the ground level.

These wells are solely utilized for drinking and other domestic purposes by the maldharis and forest-staff.

(ii) Hand pumps

A number of hand pumps, for drinking water facility, are provided near human habitations. These hand pumps are generally of 50-80 m depth tapping deeper aquifers of semi-confined nature. Since hand pumps are manually operated device, the equilibrium of recharge-discharge is maintained. Hence, these are the perennial source of water supply.

(iii) Bore-well

The study area has two bore-wells. The first one, located at Sasan has been installed to cater to the demands of local population. The second one, located at the safari park in Devaliya block has been recently drilled to provide water to the wild animals within the safari park. Also, during water scarcity period, water from this bore-well is supplied through the tankers to the artificial waterholes located in the sanctuary area.

WATER RESOURCES EVALUATION

To mitigate the demand of water in the study area i.e. an exclusive wildlife sanctuary, it is essential to have an insight of the problems faced by the study area.

SURFACE WATER RESOURCES

In any area, the optimum utilisation of surface water resources relieves pressure on the groundwater regime. The development and harnessing of this resource also helps in solving the problems related to annual replenishment to the groundwater regime, its availability and demand at the utility end.

The study area, which is falling under moderate-low groundwater potential categories, owes its characteristics mainly to the terrain i.e. steeper slopes, barren outcrops, etc. Undulating terrain and high order of ruggedness are significant factors, providing ample opportunities for favourable locales, to create artificial reservoirs.

Looking to the present status of available surface-water resources and the prevailing geo-climatic conditions in the study area, the following facts emerge :-

(i) rainfall is the only source of water, which again is seasonal and erratic,

(ii) the study area has got tremendous surface water resource potential,

(iii) the average annual input of surface water through rainfall is to the tune of 1090 MCM,

(iv) the study area's surface water is presently harnessed by four reservoirs viz. Hiran, Machhundri, Shingoda and Raval (constructed for irrigating farmlands outside the study area), with an aggregate capacity of merely 110 MCM,

(v) these four reservoirs accounted for 820 sq.km catchment area, while the resources of the remaining 600 sq.km catchment (42.49 % of total area) remains untapped,

(vi) geo-environmental parameters of the study area are influencing the overall water regime and offer a most conducive environment for creating additional storage facilities by means of developing the catchment areas at micro-levels.

GROUNDWATER RESOURCES

Study of detailed hydrogeological set up, its numerous parameters and its subsequent categorisation from the view point of groundwater potential has served as an important basis for evolving a water resource development and management strategy.

The groundwater potential map of the study area (Fig. 39) highlights the following facts :

(i) the category denoting high potential of groundwater is dominantly confined to the low lying areas, comprising of intermontane valleys and pediplains. Almost 39.83% (562.50 sq.km) of the total area falls under this category,

(ii) the category representing intermediate or moderate groundwater potential constitutes about 30.52% (430.88 sq.km) of the study area, and is shared partly by recharge and discharge areas. It comprises various landform features of intermediate category, viz. buried pediment, moderately dissected plateau, etc., contributing towards run-off as well as subsurface infiltration,

(iii) the category characterised by the lowest groundwater potential comprising of various landforms contributing towards run-off are steeply sloping hills, barren rocky areas, poorly dissected rocky outcrops, denudational hills, etc. This zone covers almost 29.65% (418.75 sq.km) of the total study area.

It is interesting to note that the category comprising high potential shares the maximum percentile area. Inspite of this, the study area witnesses severe scarcity of water

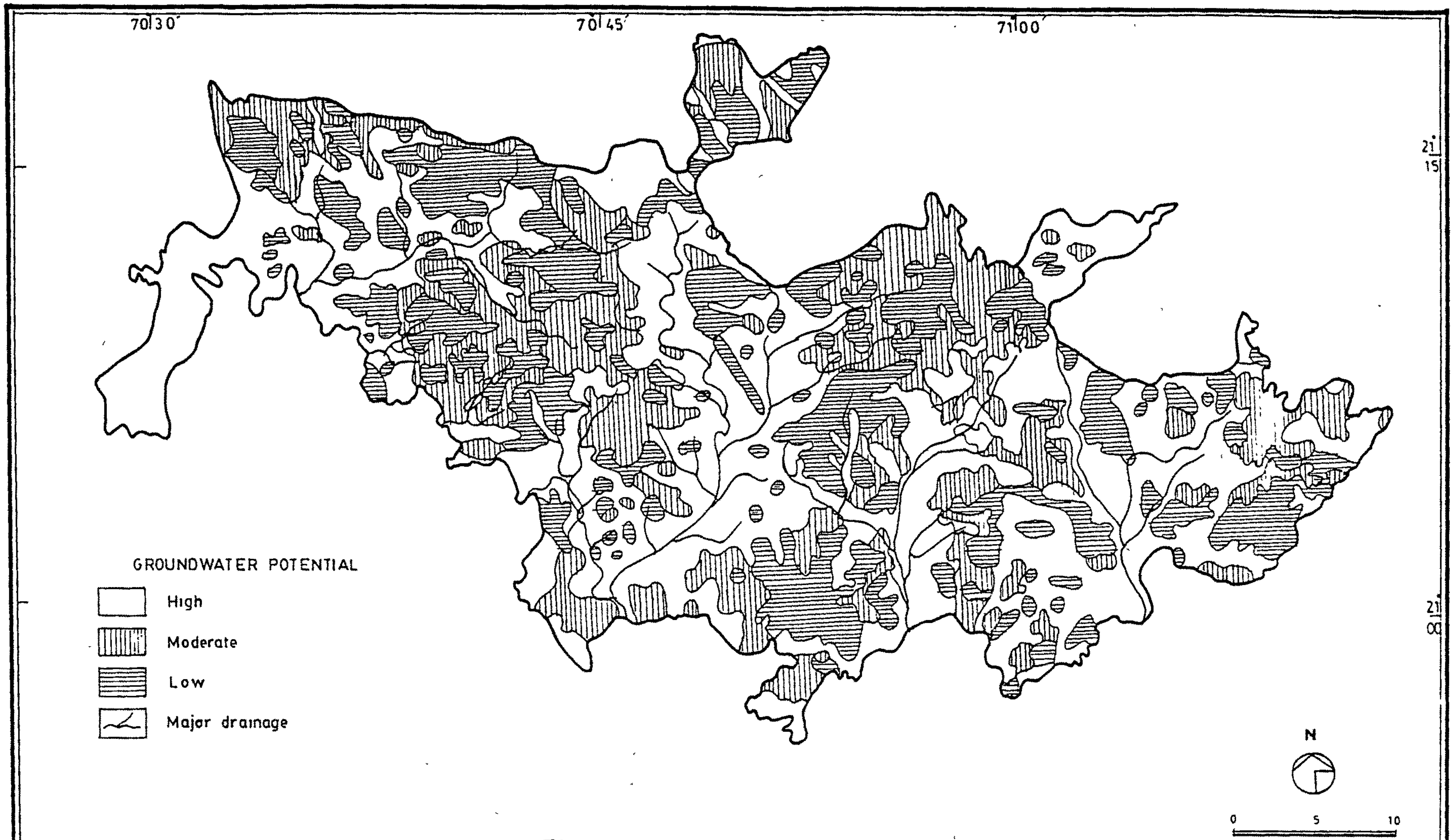

FIG. 39. GROUNDWATER POTENTIAL MAP

resources, particularly in the period stretching between February to June. This condition further worsens, especially in the years of lean monsoon. A critical study of various aspects responsible for these meagre resources have thrown up the following points :-

(a) the study area, being a notified one has remained under-developed, from the point of view of groundwater resource,

(b) it has got tremendous potential for groundwater development,

(c) as there is less lithological heterogeniety, and more of structural and geomorphological control, the availability of potential aquifers is highly localised,

(d) availability of maximum sustainable yield of groundwater is a big problem, as a large proportion is simply drained away as subsurface run-off,

(e) the erratic rainfall is the main source of recharge, and the paucity of it, further deteriorates the present condition,

(f) the existing mode of groundwater extraction is through the shallow wells, tapping the phreatic aquifer systems. However, in a basaltic terrain, the possibility of encountering deeper aquifers is highly favourable, but remains unexplored,

(g) except the four reservoirs, the study area lacks surface water structures, resulting in a high run-off from the upper reaches. The augmentation of such structures will certainly enhance the recharge to the groundwater regime, thereby shortening the scarcity period.

QUALITY ANALYSIS METHODOLOGY

The chemical parameters viz. pH, Total dissolved solids [T.D.S.], Total hardness, calcium, magnesium, chlorides, sulphates, nitrates, and fluorides were selected for analysis, to assess the suitability of surface and groundwater for drinking purposes. The determination was carried out at the Public Health Engineering Laboratory (PHEL), Baroda.

Standard methods for the examination of water recommended by American Public Health Association (1971 and 1975) and Indian Standard Specification for drinking water (IS:10500-1983) are used.

(i) pH

pH is the logarithm of the reciprocal of the hydrogen ion concentration, more precisely of the hydrogen ion activity, in moles per litre. pH enters into the calculation of carbonate, bi-carbonate, and carbondioxide. The pH of most natural water falls within the range 5 to 9. A majority of water are slightly basic due to the presence of carbonate and bi-carbonate. A departure from the normal for a given water could be caused by the entry of strongly acidic or basic industrial wastes.

The pH value is measured electronically on a direct pH-meter, using a glass electrode with a saturated potassium chloride-calomel reference electrode.

(ii) Total Dissolved Solids

Water yielding considerable residue are generally inferior with respect to palatibility, or they may include an unfavourable physiological reaction in the transient condition. Highly mineralized water is also unsuitable for many industrial applications. For these reasons, a limit of 500-1500 mg/l residue is desirable for drinking water.

Principle and Procedure

A well mixed sample is evaporated in a weighed dish and dried to constant weight in an oven at 103^{o}C to 105^{o}C. The increase in weight over that of the empty dish represents the total residue.

A platinum dish is weighed, and is filled with water sample of known volume, it is kept in a drying oven at a temperature of 103°C to 105°C for evaporation or dryness. If necessary, sometimes successive sample portion is added to the same dish. After evaporation of water, the same dish is weighed, and the total dissolved solid is calculated.

(iii) Hardness

Originally the hardness of water was understood to be a measure of the capacity of water for precipitating soap. Soap is precipitated chiefly by the calcium and magnesium ions commanly present in water. When the hardness is numerically greater than the sum of the carbonate alkalinity and the bicarbonate alkalinity, that amount of hardness which is equivalent to the total alkalinity is called carbonate hardness. The amount of hardness in excess of this is called non-carbonate hardness. In excessive amount it contributes taste change, gastro-intestinal trouble and scale formation on instruments. A limit of 600 mg/l hardness limit has accordingly been imposed on drinking water as a means of averting this condition.

(iv) Carbonate and Bicarbonate

When the pH value of a sample of water is above 8.4, carbonate ion is present, normally as sodium carbonate. If the sample is treated with a standard mineral acid to a PH of 8.4 the carbonate ion is converted to bicarbonate and the amount of acid used is a measure of the carbonate present.

Procedure

25 ml of water sample is taken in a flask and 3 to 4 drops of phenopthalein indicator is added which gives pink colour. The carbonate present is titrated with 0.05N H_2SO_4 until the pink colour disappears. Burette reading is noted and volumetric calculation is done to get concentration of carbonate in water.

Bicarbonate

Bicarbonate ion reacts with mineral acid and releases carbondioxide into the solution. The pH value at complete neutralization being about 3.8. Thus, bicarbonate is measured by titration with mineral acid to a pH of 3.8, using an indicator uneffected by carbondioxide. Methyl orange is used as an indicator.

Procedure

The same solution resulting from carbonate titration is taken (or the original solution if no pink colour is resulted). Two to three drops of methyl orange indicator is added and the titration is continued till the first change in the methyl orange colour. Total burette reading is noted. Volumetric analysis is done and the concentration of bicarbonate is calculated by substracting the amount of carbonate, if present.

(v) Calcium and Magnesium

The presence of calcium in water results from seepage through or over deposits of calcium rich strata and by industrial sewage. Small concentration of calcium combat corrosion of metallic pipes by laying down a protective coating salts, on the other hand, break down on heating to form harmful scale in boilers, pipes and cooking utensil. A desirable limit recommended for calcium concentration in potable supplies is 75 mg/l and for magnesium is 30 mg/l.

Principle and Procedure

At an optimum pH value of 10.0 EDTA (Ethylene diamine tetra acetate) forms soluble complexes with calcium and magnesium ions, thus removing them from solution without precipitation.

A buffer solution is adopted to a solution containing calcium and magnesium ions (water). So that a pH of about 10.0 is produced. Ericrom black-T is added to the solution, a red colour is formed. EDTA is then slowly added, thus calcium and magnesium ions are gradually transferred from the dye complexes to the more stable EDTA complex, and the red colour of dye complexes give way to the blue colour of the dye itself. Volumetric calculations are done to get the amount of calcium and magnesium in the water.

Calcium

If a solution containing calcium and magnesium ions is made strongly alkaline (pH about 12), magnesium is selectively precipitated as magnesium hydroxide. Although when the amount of magnesium is small, no evidence of a precipitation is seen. At the same pH the dye endochrome black-T forms a red compound with calcium ions, but it is not affected by magnesium present as magnesium hydroxide.

Procedure

Water sample is made strongly alkaline by adding NaOH and is treated with murexide (Ammonium purpurate indicator). Red colour is developed by reaction of the dye with calcium ions. EDTA solution is slowly added, thus calcium ions are gradually transferred from the dye complex to the more stable EDTA complex, and a liquid acquires a purple blue colour. Volumetric calculation are done to get the amount of calcium in water. The concentration of magnesium is obtained from the value of calcium plus magnesium obtained above.

(vi) Chloride

Chloride is one of the major anions of water. The salty taste produced by chloride concentration is variable and dependent on the chemical composition of water. A high chloride content also exerts a deleterious effect on metallic pipes and structures as well as on agricultural crops. A limit of 250 mg/l is desirable for drinking water.

Principle and Procedure

As silver nitrate solution is titrated into a chloride solution in the presence of chromium oxide, only momentary formation of red oxides of silver and chromium occurs so long as some chloride persists in the solution. When the chloride in solution is exhausted through precipitated silver chloride. The red precipitate of oxides of silver and chromium sharply signals the end point.

25 ml of water sample is taken and 1 ml of potassium chromate indicator is added. Titration is done against standard 0.05N silver nitrate solution untill the appearence of the reddish brown or pale chocolate pits. Burette reading is noted and volumetric analysis is done to know the concentration of chloride in the water sample.

(vii) Sulphate

Sulphate is widely distributed in nature and may be present in natural water. Because sodium and magnesium sulphate exert a cathartic action, the recommended sulphate concentration in potable supplies is limited to 150 mg/l.

Principle and Procedure

Sulphate is determined indirectly by precipitating as barium sulphate with an excess of standard barium chloride solution and titrating excess barium-ion with standard EDTA solution.

Dilute hydrochloric acid is added to destroy carbonates, along with 5 ml of barium chloride solution, 10 ml of buffer solution (Ammonium chloride) of pH 10 and 5 drops of Ericrome black-T indicator. Finally the solution is titrated with the standard EDTA solution. Volumetric calculation is done to get the concentration of sulphate in the water sample.

(viii)Nitrate

Nitrate represents the most highly oxidized phase in the nitrogen cycle and normally reaches important concentration in the final stages of biologic oxidation. It generally occurs in trace quantities in surface water but attains high levels in some groundwater. In excessive amounts it contributes to the illness known as infant methemoglobinemia. A limit of 45 mg/l nitrate has accordingly been imposed on drinking water as a means of averting this condition.

Principle and Procedure

The yellow colour produced by the reaction between nitrate and phenoldisulfuric acid obeys Beer's law up to at least 12 mg/l N at a wavelength of 480 mu when a light path of 1 cm is used. At a wavelength of 410 mu, the point of maximum absorption, determination may be made up to 2 mg/l with the same cell path.

Water sample is decolorized (if coloured) by adding 3 ml of aluminium hydroxide. 1 ml of H_2SSO_4 and few drops of H_2O_2 solution is added to convert nitrite to nitrate. Solution is neutralized and the entire residue is dried. Residue is diluted by 20 ml of distilled water. 6 to 7 drops of ammonium hydroxide is added to get maximum colour. Drop wise EDTA reagent is added until the turbidity is redissolved.

Photometric measurement is done by passing 1 cm or longer light path a wavelength of 410 mu. and 5 cm light path for measurements in nitrite interval from 5 to 50 ug.

(ix) Fluoride

A fluoride concentration of approximately 1.0 mg/l in drinking water effectively reduces dental caries without harmful effects on health. Some fluorosis may occur when the fluoride level exceeds the recommended limits of 1.5 mg/l.

Analysis of water sample for fluoride concentration determination was done at PHEL Laboratory, Baroda, by standard SPADNS method recommended by American Public Health Association (1975).

HYDRO-CHEMICAL CHARACTERISTICS

The study of the hydro-chemical characteristics of water resources in any area is of utmost importance. It is a well known fact that when the water is channelized through surface and subsurface channels, it dissolves numerous constituents and becomes chemically rich. These adopted chemical characteristics in turn, affect the quality of water, which is to be used for various purposes. Therefore, the quality of water, is of nearly equal importance to that of quantity available. As greater development and use of water is envisaged in the study area, water quality becomes a most important parameter to be looked into.

To have an overall picture of water quality in the various blocks of the study area, the author has collected 40 samples of surface water and groundwater (Fig. 40). All major parameters which are vital for evaluating the quality of water have been determined by subsequent laboratory work. An attempt has also been made to correlate the ultimate source of various constituents and to compare the quality of

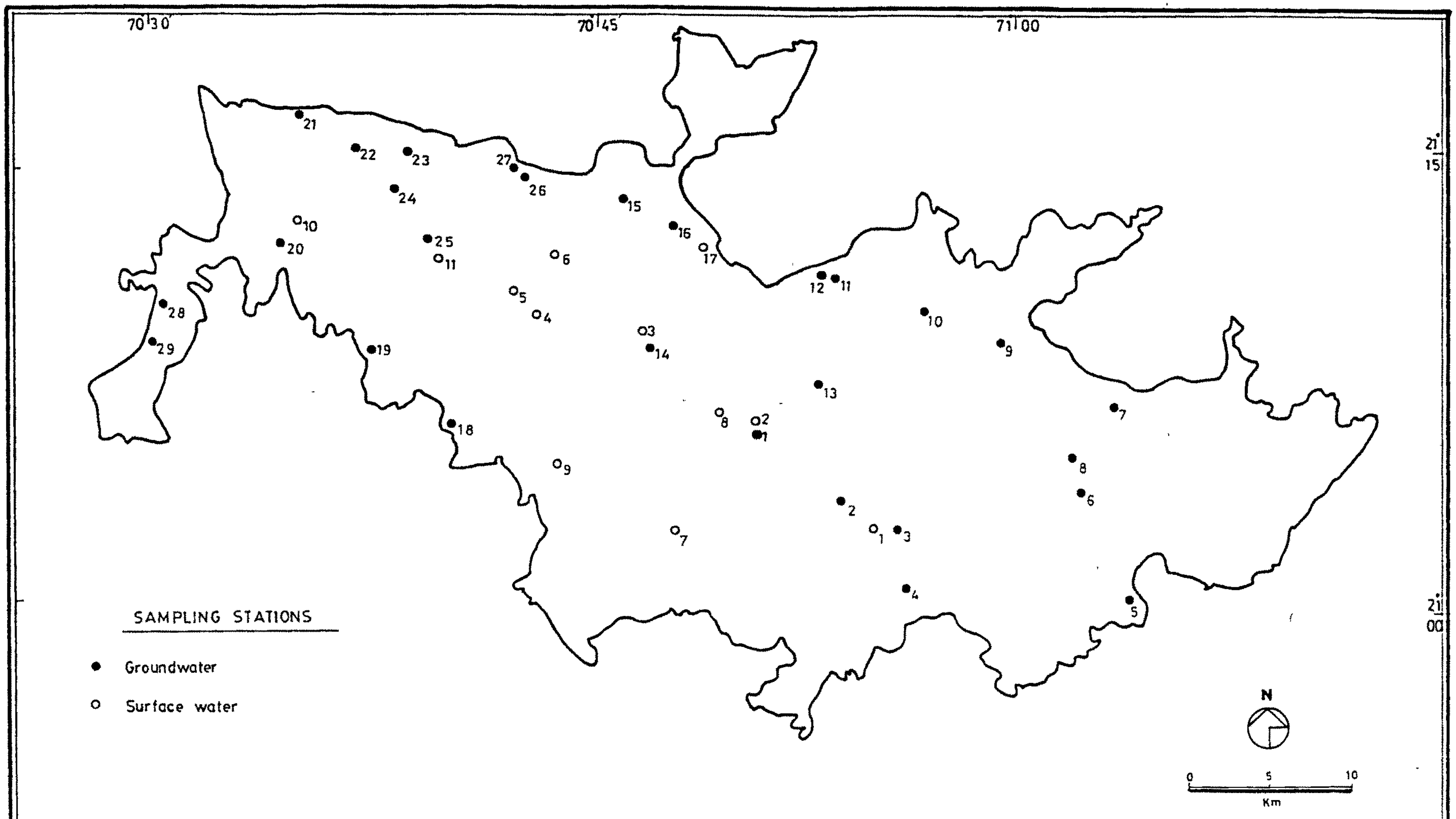

FIG. 40 WATER SAMPLING STATIONS

water in the study area with the quality norms prescribed by the Indian Standards Institute (ISI) in 1983 (Table : 22).

Important parameters viz. hydrogen ion concentration (pH), Total Dissolved Solids (TDS), various cations (calcium & magnesium), anions (nitrate, sulphate, chloride & fluoride), total hardness, alkalinity and other bacteriological parameters have been studied (Table : 23 & 24). The distribution patterns of these constituents in the study area are discussed below.

Total Dissolved Solids (TDS)

Total dissolved solids in a water sample includes all solid material in solution, whether ionized or not (Davis & DeWeist, 1970). Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes, and higher costs because of corrosion or the necessity for additional treatment (Train, 1979).

All the stations showed TDS levels in the surface water within the permissible limits. The highesst level, 608 mg/l, was observed at Karamdadi, whereas the lowest value of 398 mg/l was observed at Kamleshwar Reservoir (Hiran River). The average TDS level in the surface water of the study area is about 515.1 mg/l.

Table - 22

Indian standard specification for drinking water

Constituent	Permissible value as per IS : 10500/1983	
	Desirable limit (fit)	Relaxable in absence of better source(ABS)
TDS (mg/l)	500-1500	3000
pH	6.5-8.5	9.2
Total hardness(mg/l)	300	600
Calcium (mg/l)	075	200
Magnesium (mg/l)	030	100
Chloride (mg/l)	250	1000
Sulphate (mg/l)	150	400
Nitrate (mg/l)	045	-
Fluoride (mg/l)	0.6-1.2	1.5
COD in flowing river	100	-
BOD in flowing river	030	-

COD & BOD are absent in both surface & subsurface water in the study area.

Table - 23

Surface water quality of the study area

Location code	Sampling station	Source of Sample	T.D.S	pH	Calcium (as Ca)	Magnesium (as Mg)	Chloride (as Cl)	Sulphate (as SO_4)	Nitrate (as NO_3)	Fluoride (as F)	Total Hardness	Alkalinity (as $CaCO_3$)	Turbidity NTU	Overall Quality
1	Banej	R	598	8.30	52	43	80	5	-	0.08	308	448	-	F
2	Chhodaudi	S	516	8.05	58	50	56	5	-	0.02	352	396	5	F
3	Kankai	R	498	8.05	56	47	56	5	-	0.02	336	388	-	F
4	Karamdadi	S	528	8.00	62	50	64	5	-	0.08	364	420	8	F
5	Karamdadi	S	608	7.95	68	57	64	15	4.43	0.18	408	480	-	F
6	Jamri Nadi	R	532	8.10	60	47	72	8	-	0.02	344	408	-	F
7	Dabhala	S	476	7.65	84	34	48	5	-	0.02	352	384	-	F
8	Kankai	R	468	8.05	52	49	88	2	-	0.08	336	324	-	F
9	Janwadla	S	582	7.50	102	27	80	5	62.0	0.18	368	280	-	ABS
10	Raidi-Kadeli Nes	S	462	7.70	82	33	48	8	-	-	354	368	-	F
11	Kamleshwar	D	398	7.65	64	38	40	5	-	0.18	320	296	-	F

All chemical parameters, except pH & Turbidity, are expressed in mg/l.
R = River, S = Stream, D = Dam
F = fit, ABS = alternate best source, UF = unfit

Table - 24

Groundwater quality of the study area

Location code	Sampling station	Source of Sample	T.D.S	pH	Calcium (as Ca)	Magnesium (as Mg)	Chloride (as Cl)	Sulphate (as SO_4)	Nitrate (as NO_3)	Fluoride (as F)	Total Hardness	Alkalinity (as $CaCO_3$)	Turbidity NTU	Overall Quality
1	Chhodaudi	OW	620	7.85	88	39	48	10	77.5	0.02	384	440	-	ABS
2	Banej	HP	560	7.50	80	50	56	12	2.22	-	408	452	-	F
3	Kardapan	HP	812	7.75	108	59	176	18	-	0.02	516	372	-	F
4	Kardapan	OW	718	7.85	88	57	88	8	70.9	0.08	456	472	-	ABS
5	Jasadhar	HP	1362	7.75	136	118	304	52	-	-	832	364	-	UF
6	Dodhi	HP	482	7.70	70	46	40	5	-	-	368	412	-	F
7	Timberva	HP	498	7.65	70	41	40	5	-	0.13	344	412	-	F
8	Asodriali	HP	602	8.95	52	08	224	-	70.9	0.08	164	068	-	ABS
9	Hadala	HP	672	7.80	102	69	80	15	-	0.08	554	496	-	F
10	Jamwali Nes	HP	618	7.85	74	64	72	12	75.4	0.02	452	484	-	ABS
11	Sap Nes	HP	496	7.65	72	41	48	5	-	0.08	352	388	-	F
12	Sap Nes	OW	604	7.60	70	60	72	10	-	0.13	424	472	-	F
13	Biliyat Nes	OW	526	7.65	74	53	64	10	-	0.08	404	420	-	F
14	Kankai	HP	478	7.55	68	45	56	5	-	0.02	356	376	-	F
15	Bajriya	HP	496	7.50	74	39	72	5	-	0.13	348	368	-	F
16	Suvardi Nes	HP	1078	7.60	136	72	172	28	108.5	0.08	640	464	-	UF
17	Lilapani	HP	472	7.95	74	32	48	2	-	0.02	320	356	-	F
18	Sirwan	OW	410	7.55	93	19	48	2	-	0.02	312	324	-	F
19	Khokhra	HP	458	7.85	90	30	56	8	-	0.02	352	340	4	F
20	Bhambha Phod	HP	402	7.80	72	19	40	2	8.86	-	260	328	-	F
21	Dedakadi	HP	542	7.60	96	46	64	10	-	-	432	440	-	F
22	Jambuthala	HP	502	7.60	45	32	48	12	-	-	420	412	-	F
23	Kansia	HP	478	7.60	75	42	48	8	-	0.02	364	384	5	F
24	Alawani	OW	626	7.50	95	49	80	15	-	-	440	476	-	F
25	Kathitad	HP	418	7.35	61	46	48	5	4.43	-	344	280	-	F
26	Kutiya	HP	368	7.85	74	26	40	5	8.86	-	292	272	6	F
27	Kutiya	OW	628	7.50	138	16	64	14	73.2	-	412	576	-	ABS
28	Devaliya	TW	448	7.40	134	10	40	8	8.86	-	376	356	-	F
29	Beriya	HP	516	7.40	146	10	56	14	-	-	404	404	-	F

All chemical parameters, except pH & Turbidity, are expressed in mg/l.
OW = open well, HP = hand pump, TW = tube well
F = fit, ABS = alternate best source, UF = unfit

In the case of groundwater, TDS values for almost all the stations range within the permissible limits. The maximum TDS levels, 1362 mg/l and 1078 mg/l have been observed at Jasadhar and Suvardi Nes respectively. These high TDS values suggests that at both these locations, the groundwater is slightly brackish (Table : 25). The minimum level of 368 mg/l was recorded at Kutiya.

Table - 25

Types of water based on the total concentration of dissolved solids.

(after Gorrell, 1958)

Category	TDS (in mg/l)
Fresh water	0 - 1000
Brackish water	1000 - 10,000
Salty water	10,000 - 100,000
Brines	> 100,000

To study the overall distribution pattern of Total Dissolved Solids in the study area, an Iso - TDS contour map was plotted (Fig. 41). It is evident from the map that there are two maximas (1000 and 1200 mg/l), located in the northern and eastern parts of the study area. Although the TDS values are within the limits, it is interesting to note that the eastern maxima is confined to the Raval river and the northern maxima is also along a river valley. Hence, it can be concluded that in the upper reaches, the rocky aquifers have less TDS values, while in the river valley comprising alluvium, the TDS values show an increasing trend.

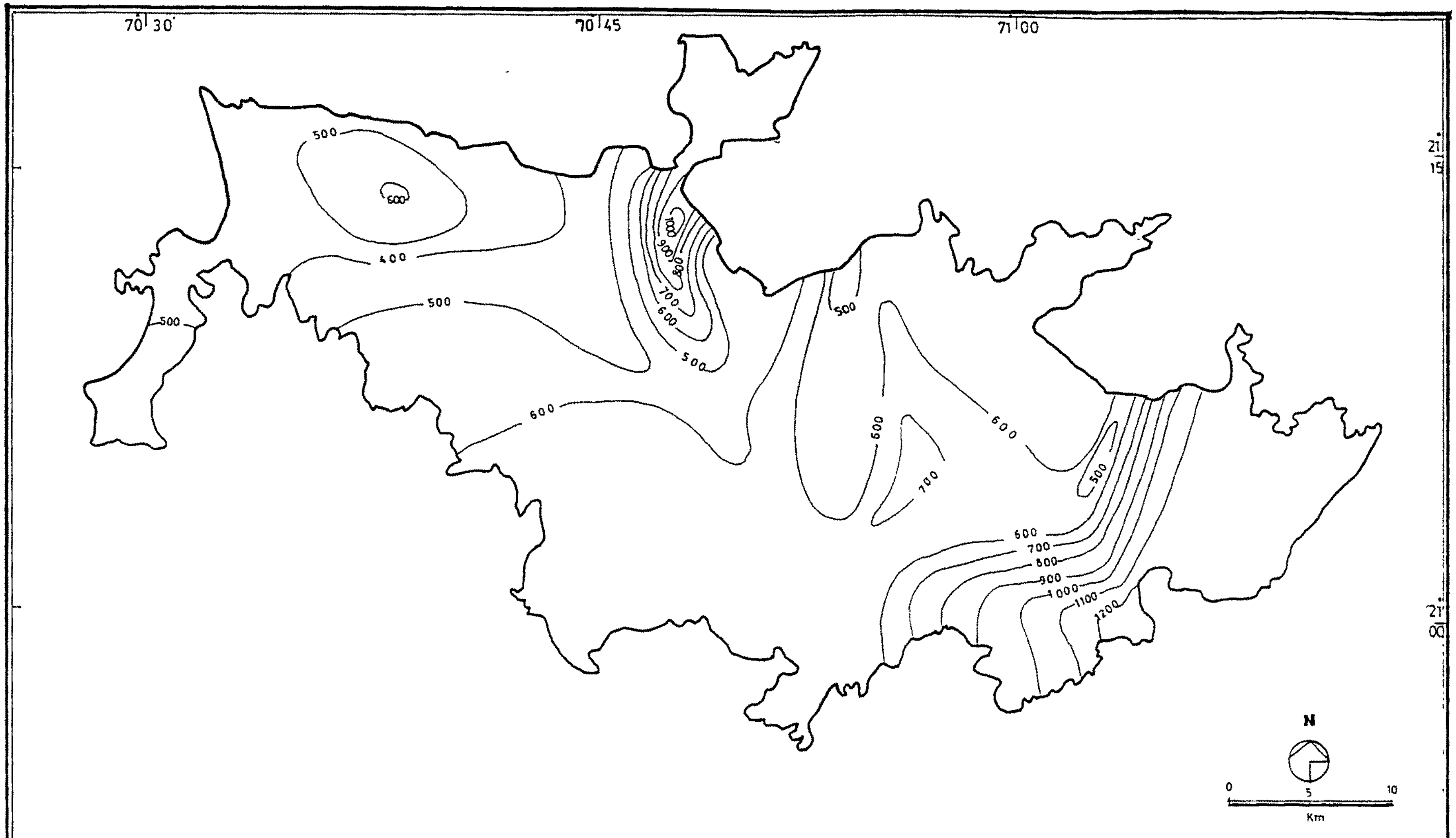

FIG. 41. ISO-T.D.S. (mg/l) MAP

Hydrogen ion concentration (pH)

"pH" is a measure of hydrogen activity in water and is regulated by the carbonate system. It provides a mean of classifying the water into acidic, neutral and alkaline categories.

pH	Category (after Valdiya,1987)
< 7.0	acidic
7.0 - 7.8	neutral
> 7.8	alkaline

pH values in surface water at all stations were recorded within the permissible limits. Maximum pH value (8.30) was recorded in Machhundri river at Banej. Kamleshwar reservoir and a stream at Dabhala recorded 7.65, the minimum pH value.

Asodriali recorded the maximum pH value (8.98) for groundwater, while all other stations exhibited normal limits. The lowest (7.35) pH was recorded at Kutiya. The high pH value at Asodriali is indicative of alkaline water, though within the permissible limits.

Calcium

The presence of calcium in water results from seepage through or over deposits of calcium rich strata. In igneous rocks, weathering of feldspars, amphiboles and pyroxenes releases calcium (Davis & DeWeist, 1970). Calcium is extremely mobile in the hydrosphere, and is one of the most common ions in subsurface water.

Three stations recorded >70 mg/l of calcium in surface water, rendering it unfit for drinking. However, these values are permissible in the absence of a better source (IS : 10500, 1983). The highest value (103 mg/l) was recorded at Janwadla. This can be attributed to the leaching of calcium from the surface exposures of miliolite limestone. The lowest value (52 mg/l) was recorded at Kankai and Banej.

Since the study area comprises essentially of Deccan Trap basalts, the groundwater shows high concentration of calcium, ranging between 45-146 mg/l. Concentration of calcium in normal potable groundwater generally ranges between 10 and 100 ppm. Calcium in these concentrations has no known effect on the health of humans or animals. Indeed, as much as 100 ppm of calcium may be harmless (Davis & DeWeist, 1970). Out of 29 stations, 15 stations have recorded calcium values ranging from >70 - 100 mg/l, seven stations recorded >100 mg/l calcium, and seven stations recorded 0 - 70 mg/l calcium. However, all the stations showed calcium values within the permissible limits.

Magnesium

One of the common sources of magnesium in the hydrosphere are the igneous rocks rich in minerals like olivine, hornblende, and augite. In addition, abundant amounts of magnesium is yielded by calcite veins and limestone (Davis & Deweist, 1970), from magnesium rich rocks like olivine basalt (dominant rock type in the study area) which may also contain two to three times more magnesium than calcium.

At all the stations, magnesium content in surface water was recorded within the permissible limits. The highest value (57 mg/l) of magnesium was recorded at Karamdadi, whereas the lowest value (27 mg/l) was recorded at Janwadla.

In the case of groundwater, the lowest value (8 mg/l) of magnesium was recorded at Asodriali. Jasadhar recorded the highest value (118 mg/l). Based on the drinking water specifications (IS : 10500, 1983), the groundwater at Jasadhar is unfit for drinking purpose.

Chloride

Chloride is a minor constituent of the earth's crust, but a major dissolved constituent of most natural waters. Most of the chloride in groundwater comes from : (i) concentration by evaporation of chloride contributed by rain, (ii) solution of dry fall-out from the atmosphere. A locally important source may be from volcanic water in hot spring systems (Davis & DeWeist, 1970).

Chloride content in surface water at all the stations was recorded below the desirable limits. Banej and Janwadla stations showed the highest chloride values (80 mg/l). The lowest chloride content (40 mg/l) was recorded at Kamleshwar reservoir.

Jasadhar station showed the highest (304 mg/l) chloride in groundwater, which is more than the desirable limit. However, it can be considered usable in the absence of a better source. The lowest value (40 mg/l) was recorded at five different stations viz. Dodhi, Timberva, Bhambha, Phod, Kutiya and Devaliya.

To study the distribution pattern of chloride in groundwater, an Iso-chloride contour map was prepared (Fig. 42). It reflects more or less the same picture as the total dissolved solids. There are two maximas ranging from 60-160 mg/l and 60-280 mg/l in the northern and eastern parts, coincideing with those of T.D.S.

Sulphate

In the hydrosphere, sulphates are attributed to the oxidation of sulphides from igneous rocks and volcanic sources. (Junge, 1963; Davis & DeWeist, 1970). Sulphate is one of the major dissolved constituents of rain and commonly occurs in absolute concentrations of less than 2 ppm.

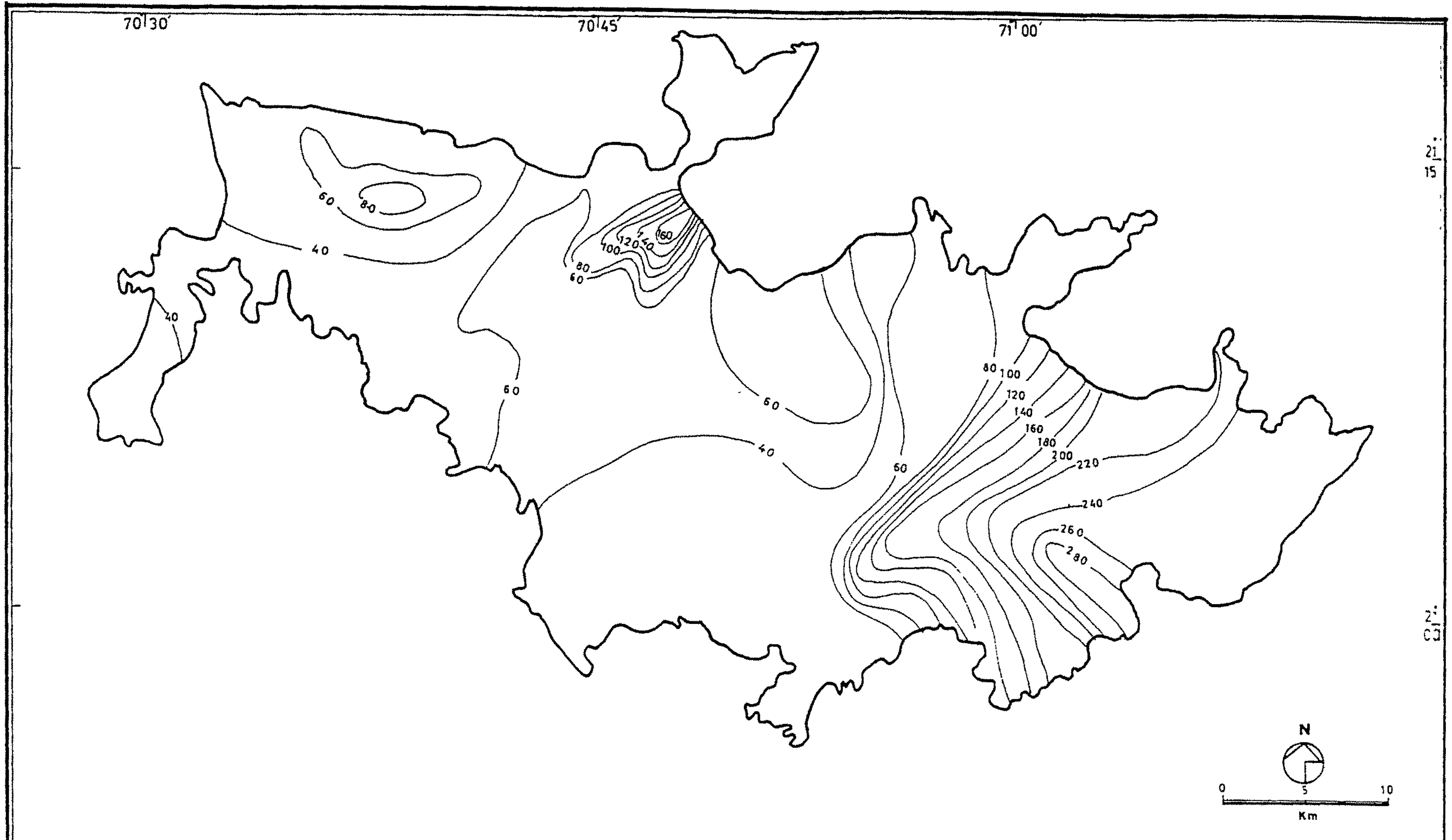

FIG. 42. ISO-CHLORIDE (mg/l) MAP

Concentrations of sulphate from less than 0.2 ppm to more than 10,000 ppm are found in nature. Groundwater from igneous rocks, generally contain less than 100 ppm and many contain less than 1 ppm if sulphate-reducing bacteria are active in the soil through which recharge water has percolated.

Sulphate content in surface water was found to be highest (15 mg/l) at Karamdadi station, whereas Kankai recorded the lowest value (2 mg/l) of sulphate. All the sampling stations were found to be having normal sulphate content.

Sulphate content in groundwater was found to be within permissible limits at all stations. The maximum value (52 mg/l) of sulphate was recorded at Jasadhar, whereas sulphate was totally absent at Asodriali. Moreover, Bhambha Phod, Sirwan and Lilapani recorded only 2 mg/l sulphate content. There is every possibility that sulphate reducing bacteria are very active at stations showing low sulphate contents.

Nitrate

Although igneous rocks contain small amounts of soluble nitrate or ammonia, most nitrate in natural water comes from organic sources or from industrial and agricultural chemicals (Waring, 1949). Nitrate concentrations in rain water range from 0.1 to 0.3 ppm. Normal groundwater contains only from 0.1 to 10.0 ppm nitrate (Davis & DeWeist, 1970). High nitrate concentrations are frequently found in shallow farm and rural community wells, often as the result of inadequate protection from barnyard drainage or from septic tanks (USPHS, 1961; Stewart, et al. 1967 : in Train, 1979).

Only two stations viz. Janwadla and Karamdadi, recorded nitrate content in surface water. At Karamdadi, nitrate concentration was found to be 4.43 mg/l. But, the nitrate content showed an extreme of 62 mg/l (higher than the permissible limits) at Janwadla. Since the area is free from any industrial or agricultural activity, the high nitrate can be attributed to leaching of surplus nitrates produced by nitrogen fixing bacteria living on root nodules of certain plants, or leaching of nitrates from organic wastes in the upstream.

Out of 29 groundwater sampling stations, only 11 stations showed nitrate content. Five stations recorded nitrate contents ranging from 2.2 mg/l (at Banej) to 8.86 mg/l. The other six stations recorded nitrate contents exceeding the permissible limits. Nitrate level having more than twice (108.5 mg/l) the permissible limit (45 mg/l) was recorded at Suvardi Nes.

The aquifers of an igneous terrain, with a thin veneer of soil are highly vulnerable to biological contaminations. The hydrofractures may be of less than 1 mm wide openings, pollutants will move more efficiently than through the interstices in normal alluvial aquifers.

Discussions with the forest-staff members at Kutiya and maldharis at Jamwali Nes revealed health problems caused by the consumption of the groundwater. At both these stations, an excess of nitrate has contaminated the groundwater. At Jamwali Nes (Plate. 36), a small stream has been blocked by a causeway. This has caused the leaching from the domestic animal wastes to accumulate in the stream. The blocked contaminated water has seeped through the wall curbing, into the open well (Plate. 37). Just adjacent to it is a handpump, from which the water sample was collected. It was found that the groundwater sample had 75.4 mg/l nitrate. Thus, a blocked drain and nearby animal waste have rendered the groundwater unfit for drinking purposes.

In quantities normally found in food or feed, nitrates become toxic only under conditions in which they are, or may be, reduced to nitrites. Otherwise at "reasonable" concentrations, nitrates are rapidly excreted in the urine. High intake of nitrates constitutes a hazard primarily to warmblooded animals under conditions that are favourable to their reduction to nitrite. Under certain circumstances, nitrate can be reduced to nitrite in the gastrointestinal tract and its direct reaction with heamoglobin causes a disease known as methemoglobinemia (Train, 1979). Serious and

Plate 36 - Blockage of stream by causeway.

Plate 37 - The well which is contaminated by seepage of water from the blocked stream.

occasionally fatal poisoning in infants have occurred following ingestion of untreated well waters shown to contain nitrate at concentrations greater than 10 mg/l nitrate (NAS, 1974). Methemoglobinemia symptoms and other toxic effects were observed when high nitrate well waters containing pathogenic bacteria were fed to laboratory mammals (Wolff & Wasserman, 1972; Trainer, 1979).

Since the study area is a wildlife sanctuary, high levels of nitrate concentration in surface and subsurface water is a matter of concern.

Fluoride

Natural concentrations of fluoride commonly range from about 0.01 to 10.0 ppm. The natural concentration of fluoride is generally dependent on the solubility of fluorite (CaF_2), which is about 9 ppm fluoride in pure water (Hem, 1959; Davis & DeWeist, 1970). It has been observed, however, that waters high in calcium do not contain more than about 1 ppm of fluoride.

Fluoride-bearing groundwater formations are common in volcanic areas, due to volcanic activities and the dissipation of fluoride in hot gases. The higher the deposited thickness of volcanic rock, the higher the content of fluoride in groundwater (Liu & Zhu, 1991).

Semi-arid climate causes high evaporation of groundwater, which is an important factor in concentrating salts (including fluoride) in groundwater.

Fluoride content in surface water at all stations was found to be within the permissible limits. Maximum fluoride (0.18 mg/l) was observed at Karamdadi, Janwadla and Kamleshwar reservoir, whereas the minimum values (0.02 mg/l) were recorded at Kankai, Jamri Nadi, Dabhala and Chhodaudi.

However, fluoride content in groundwater was found to be ranging from 0.02 mg/l to 0.13 mg/l. Out of 29 stations 11, stations showed absence of fluoride in groundwater.

Total Hardness

Water hardness is caused by polyvalent metallic ions dissolved in water. In fresh waters these are principally calcium and magnesium (Train, 1979). Hardness, commonly is reported as an equivalent concentration of calcium carbonate ($CaCO_3$). Natural sources of hardness principally are limestones which are dissolved by percolating rainwater made acidic by dissolved carbon dioxide.

Based on the total concentration of $CaCO_3$, Sawyer (1960) has classified water into four classes as given below :

$CaCO_3$ (mg/l)	Class
(i) 0 - 75	Soft

(ii) 75 - 150	moderately hard
(iii) 150 - 300	hard
(iv) > 300	very hard

Surface water at all stations was found to be very hard, but within the permissible limits. Karamdadi recorded the maximum (408 mg/l), whereas Banej exhibited the minimum (308 mg/l) hardness.

Total hardness in groundwater was found to be exceeding the permissible limit at Jasadhar (832 mg/l) and Suvardi Nes (640 mg/l). Except Asodriali (164 mg/l), Bhambha Phod (260 mg/l) and Kutiya (292 mg/l); the groundwater at all other stations is very hard, but falls within the permissible limits.

Alkalinity

Alkalinity is the sum total of components in the water that tend to elevate the pH of the water above a value of 4.5. Therefore, it is a measure of the buffering capacity of the water, and since pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality (Train, 1979). Alkalinity is produced almost exclusively by bicarbonate and carbonate ions.

Generally, carbonate and bicarbonate ions in groundwater are derived from the carbondioxide in the atmosphere and soil, and solution of carbonate rocks. Groundwater generally contains more than 10 ppm but less than 800 ppm bicarbonate. Concentrations between 50 and 400 ppm are most common (Davis & DeWeist, 1970). Naturally occurring maximum levels upto approximately 400 mg/l as calcium carbonate are not considered a problem to human health (NAS, 1974; Train, 1979).

In the case of surface water, the highest value (480 mg/l) of alkalinity was observed at Karamdadi and the lowest (280 mg/l) at Janwadla.

In groundwater alkalinity was observed to be ranging from 516 mg/l (Kutiya) to 68 mg/l (Asodriali).

Turbidity

Turbidity in water results from the presence of suspended particles of silts and clays. Turbidity often occurs following rains when rapidly flowing water carries clay from fissures and caves into the wells, and in some places indirectly from the surface soil into the wells.

A maximum of 8 and a minimum of 5 NTU turbidity in surface water was observed at Chhodaudi, Karamdadi and Kankai. Rest of the stations were free from turbidity. Turbidity levels in surface water can be attributed to the post-monsoon water flows carrying suspended particles.

In groundwater, a maximum of 6 and a minimum of 4 NTU turbidity was observed at Khokhra, Kansia and Kutiya. Since the water samples at these three stations were collected from handpumps, turbidity can be attributed to small particles of ferric oxide coming from rusty casings and pump columns. All other stations were free from turbidity.

Overall Quality Rating

In general, the surface and groundwater in the study area is free from any major quality problem. Overall quality of surface water in the study area is upto drinking water standards, excluding Janwadla wherein high nitrate concentrations were observed.

Considering water quality criteria, nitrate contamination in groundwater is a matter of grave concern. At six stations nitrate value was recorded as having >70 mg/l. Only at two stations total hardness was higher than the permissible limits. Whereas a high pH value (8.95) at Asodriali indicated alkaline water.

Only at two stations (out of 29) viz. Jasadhar and Suvardi Nes, groundwater is totally unfit for drinking purposes. Whereas five stations showing nitrate contamination can be utilized till an alternate source is developed.