CHAPTER - IV

HYDROGEOLOGICAL CHARACTERISTICS

" Rivers do not rise with first rainfall;
the thirsty ground absorbs it all "
Seneca(3-65 A.D)

GENERAL

An interplay of geologic and geomorphologic parameters control the movement of water right from precipitation to final debouchment into the ocean. The ground water availability mainly depends on the aquifer conditions which inturn is governed by the geological factors. Distribution of the rain water, it's run-off and underground recharge, on the other hand, are controlled by landforms, drainage pattern and slope. From the point of understanding the hydrogeological characteristics of the Bhadar basin, the details on basic geology, geomorphology, meteorological data have already been discussed in the preceeding chapters. In this chapter, the factors controlling the hydrogeological characters vis-a-vis aquifer conditions and potentiality have been dealt with in detail.

HYDROGEOLOGICAL CONTROL

The interaction between topography, structure and sub-surface geology influences the hydrogeological characters, where in, the topography controls the run-off and recharge, while structure and subsurface geology control the occurrence and potentiality of an aquifer. The factors controlling hydrogeology of the study area has, thus been divided into three, viz. :

1. Lithological control
2. Structural control and
3. Geomorphic control

LITHOLOGICAL CONTROL

The ground water in the Bhadar basin water-shed occurs mainly in the unconfined aquifers which are associated with the basaltic rocks of Cretaceous-Eocene age and the biogenic calcareous sands of Pliestocene age (Fig. 4.1). Following Karanth (1990, p. 388), based on ground water storage, movement and yield, rocks within the basin can be broadly classified as :

1. consolidated formation (Basalts)
2. semi-consolidated formation (Miliolites) and
3. un-consolidated formation (Recent deposits),

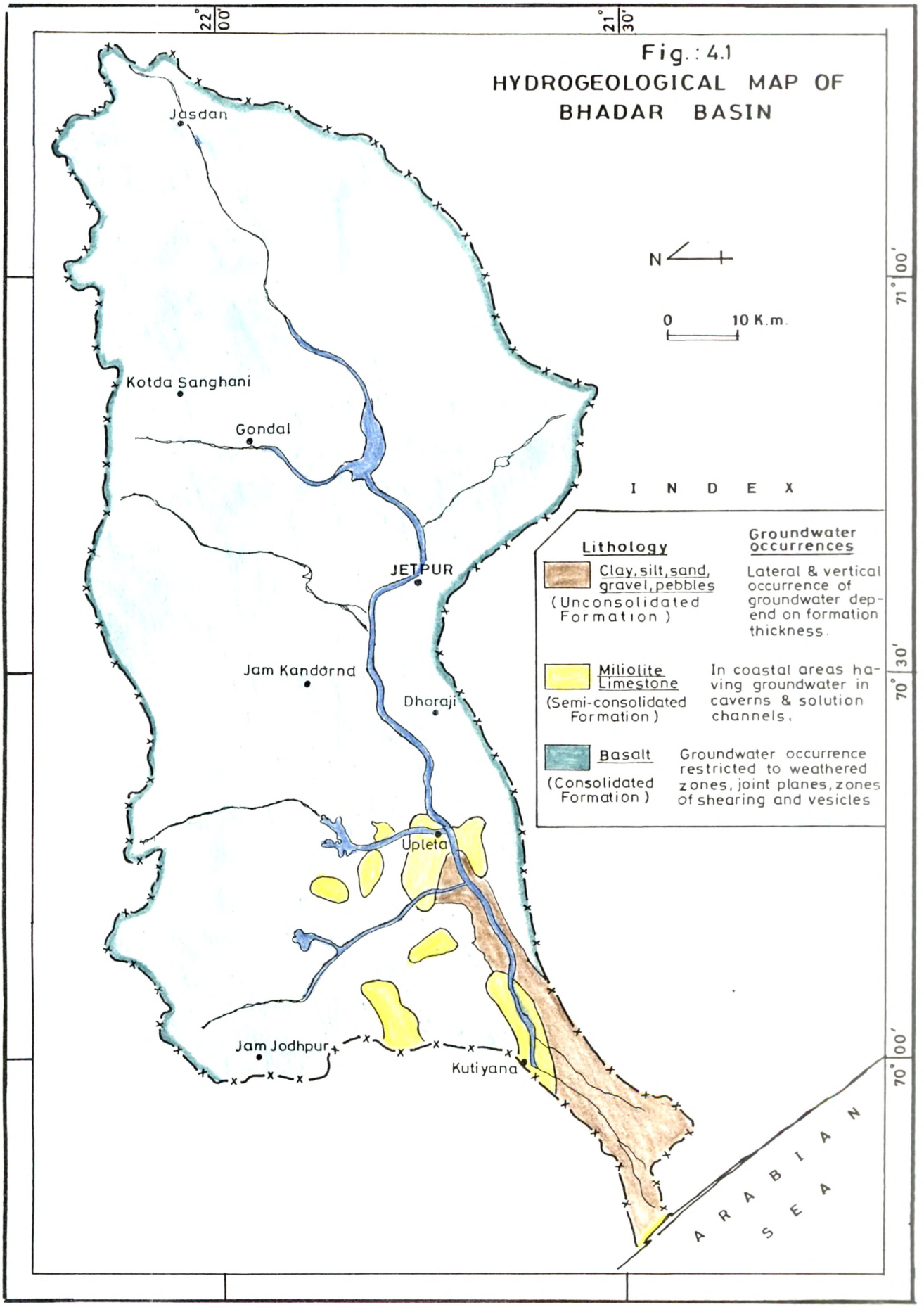


Fig. : 4.1
HYDROGEOLOGICAL MAP OF
BHADAR BASIN
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
Jasdan
Kotda Sanghani
Gondal
JETPUR
Jam Kandorna
Dhoraji
Upleta
Jam Jodhpur
Kutiyana
N
0 10 K.m.
I N D E X
Lithology
Clay, silt, sand, gravel, pebbles
(Unconsolidated Formation)
Miliolite Limestone
(Semi-consolidated Formation)
Basalt
(Consolidated Formation)
Groundwater occurrences
Lateral & vertical occurrence of groundwater depend on formation thickness.
In coastal areas having groundwater in caverns & solution channels.
Groundwater occurrence restricted to weathered zones, joint planes, zones of shearing and vesicles
ARABIAN SEA

Consolidated Formation

Within the area of investigation, the trappean basalts are the consolidated formations. The basalts are usually hard and compact and the porosity present in them, are on account of fractures and joints. In addition to this, primary porosity are present in the form of vesicles in the amygdaloidal and vesicular basalts. Estimation of porosity of fresh basalt showed a range from 0 to 3 percent, whereas weathered basalt has a high porosity, as much as 34 percent (Deolankar,1980).

The movement of ground water in the basaltic rock is decisive and its dependence is on the secondary porosity such as joints, cracks, fractures and weathered zones. Basalts show variablity in their weathering profile depths and thickness of the fracturing zone. The author has constructed a ribbon diagram (Fig. 4.2.), from the lithologs of the wells drilled in this basin to provide the clear picture of these elements (pl. see appendix 1).

The development of these factors are not uniform throughout the trappean highland both laterally and vertically. On account of this, the availability of ground water at depths varies from place to place. Some of the exploratory well dug by G.W.R.D.C. in the villages of Bordi-Samdhala and Khirasara (Jetpur Taluka), Moti-mard, Supedi and Vadodar (Dhoraji Taluka) and Sultanpur, Ambardi and Devla (Gondal Taluka) as failure/dry wells, support the above mentioned view.

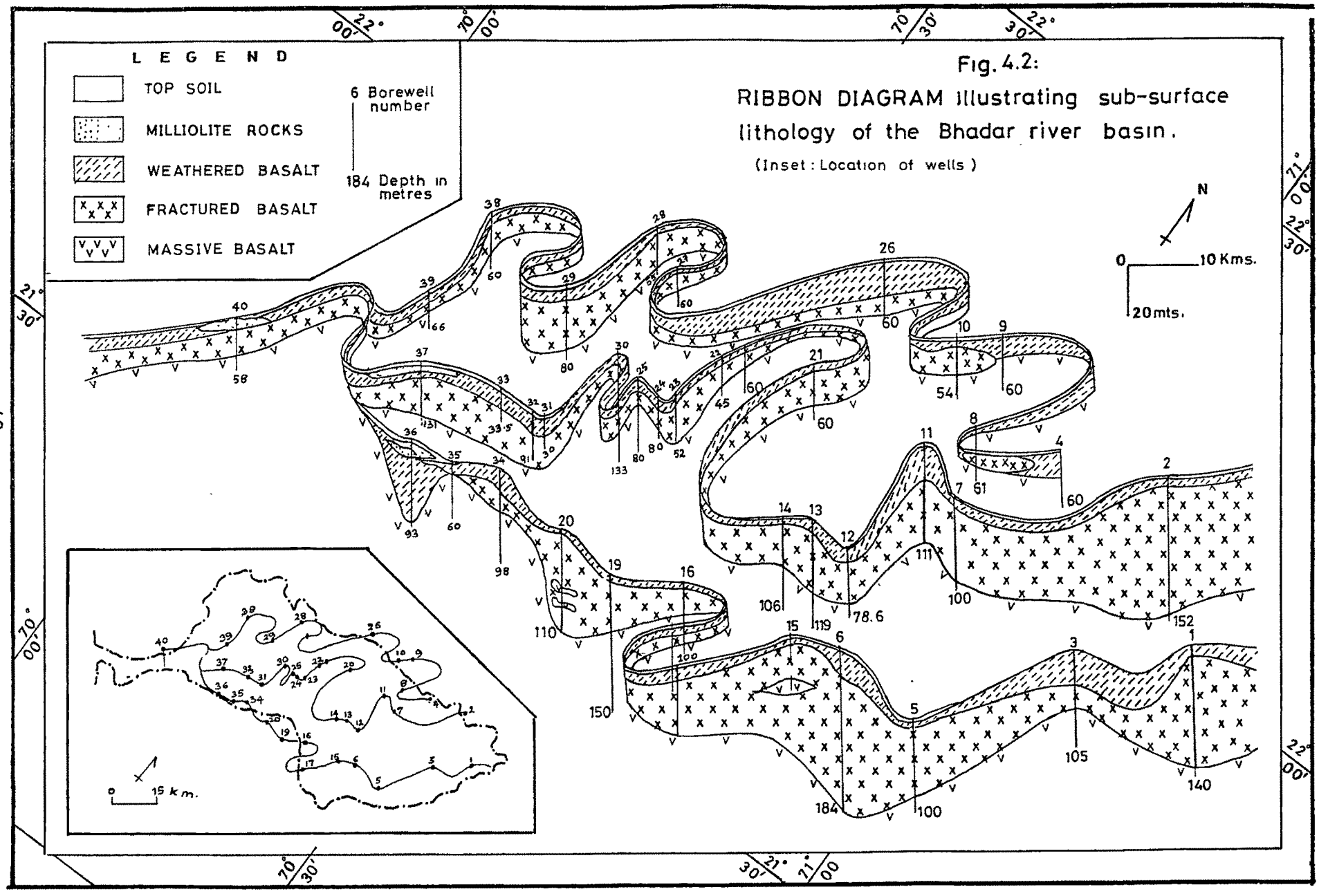
This type of erratic flow may be on account of :

- variable thickness of the weathering zone,
- variable vertical distribution of fractures and joints,
- orientation of joints and fracture pattern not favourable for all directional movements,
- joints and fracture may not be inter-connected,
- mount like bed rock topography below the aquifer (below the weathering and fracture zone) Fig. 4.3 and
- steep slopes.

Further being a semi-arid climatic zone having scattered rainfall and a rolling topography, it is in all probability that local surface water bodies might be helping in the infiltration into the aquifers. It is true, that in recent past the Government of Gujarat had constructed many check dams, more or less in all tributaries which have resulted in formation of many small ponds.

Semi-Consolidated Formations

Rocks belonging to the Miliolite Formation are seen exposed along the river valley upto Upleta, in the form of valley fill deposits. They are also seen occurring as aeolian deposits on the slopes of the Alech and Osham hills. These limestones exhibit well developed cross beddings and horizontal beddings. The thickness of the aeolian deposits on the hill slopes are few tens of metres, whereas on the plains they are few metres to very thin. The aerial extent is restricted to down stream segment of the river Bhadar. Near the coastlines, they occur as coastal paleo-dunes. Owing to its thickness and the bedding planes they act as good repository. Being a calcareous sands, loosely consolidated, having good porosity and permeability, these have been classified into semi-consolidated formation. Calcareous nature of these sands favours secondary porosity due to diagenesis.


LEGEND
TOP SOIL
MILLIOLITE ROCKS
WEATHERED BASALT
FRACTURED BASALT
MASSIVE BASALT
6 Borewell number
184 Depth in metres
Fig. 4.2:
RIBBON DIAGRAM Illustrating sub-surface lithology of the Bhadar river basin.
(Inset : Location of wells)
N
0 10 Kms.
20 mts.
0 15 km.
22° 00'
70° 00'
70° 30'
22° 30'
21° 30'
70° 00'
22° 00'
70° 30'
21° 30'
71° 00'
49

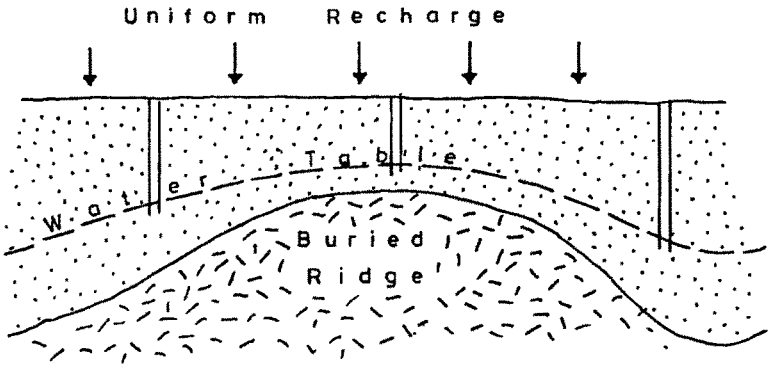


Fig. 4.3: Water table in relation to bedrock configuration

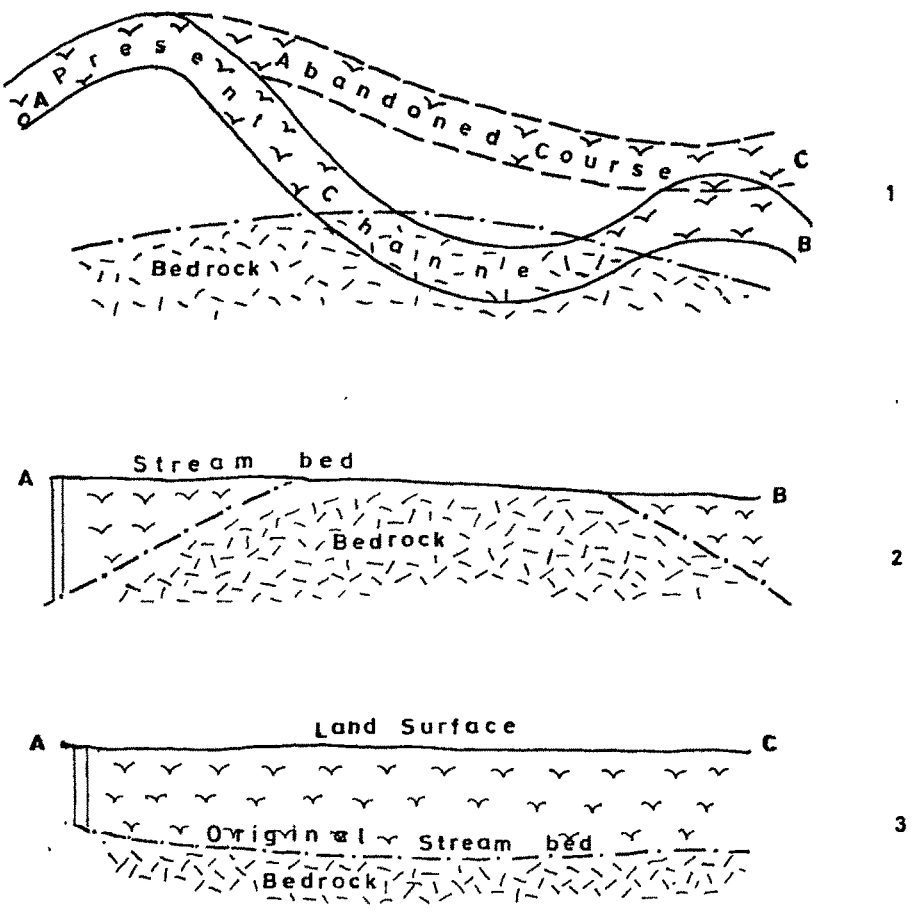


Fig. 4.4: Plan (1) and profiles along present stream bed (2) and original stream bed (3)

Un-Consolidated Formation

Alluvial sediments occurring along the Bhadar river in the down stream segment below Dhoraji have variable thickness, from 3 metres to 30 metres. Generally the thickness increases towards the sea side. At many places, it has been observed that in the river bed the basaltic rocks are exposed, whereas, the alluvial cliffs show more than 20 metre thickness. This could be on account of the shifting of the channels (Fig. 4.4).

Secondly, the paleo-channels seen near the north of Jetpur and south of Upleta exhibit river sediments on the surface showing variable thickness. Similarly south west of Kutiyana, the thickness of sediment increases due to the paleo-lobes. These lobe areas represent the transitional environment of sediment deposition. The sediments in the sub-surface show intertongueing of clays and sands. All these non-indurated sediments, therefore, are grouped into un-consolidated formations, and act as good ground water aquifera.

STRUCTURAL CONTROL

Structures play an important role in the formation of ground water regime, particularly in hard rock terrains. The study area, comprising of trappean basalt, is criss-crossed by number of joints and fractures. The structural analysis on their pattern has pointed that their trend coincide with the Narmada-Geo fracture viz. ENE-WSW (Fig. 2.3).

On the whole, the Saurashtra Peninsula does not show any spectacular upliftment and subsidence during the Quaternary, however, its various blocks did undergo differential movement (Merh, 1980). Other fractures are in N-S, NW-SE , NNW-SSE directions. Though the fault cannot be easily traced on the surface but their signatures are reflected on the courses of the rivers. Courses of Bhadar and its tributaries follow these weak zones. Since these weak zones are primary in nature, they augment the infiltration of the water to the subsurface strata. Generally, the joints and fractures are interconnected but it disappears downward.

Another important feature is the dykes, which represent weak zones, filled by the magmatic intrusions. From the hydrogeological point of view, the dykes at many places in the area under investigation have been identified as water barrier dykes. These barriers are disposed across the course of the streams and provide a stagnancy in the surface run- off. This inturn augments the recharge of the aquifers. Further, they prevent movement of the ground water (Kulkarni, P. N.; 1990). Such dyke barrier are seen in or near Bhayavadar, Roghel, Jam-Kandorna and north-east of Vavdi.

GEOMORPHIC CONTROL

The geomorphic factors that control the hydrogeological parameters are viz. :

* the distribution and amount of rainfall,
* the rate of run-off and
* the amount of ground water recharge.

The ground water recharge is primarily controlled by the lithologic factors, but the geomorphic parameters play an equally important role. The important factors which are affecting the hydrogeology of an area are as follows :

a) land forms

b) slope

c) the nature of bed rock

d) effect of bed rock topography.

In this chapter, the salient features which are controlling the hydrogeological characters are described.

The stream pattern of the tributaries and the Bhadar have reflected the structural control, which are confirmed by the morphometric analysis.

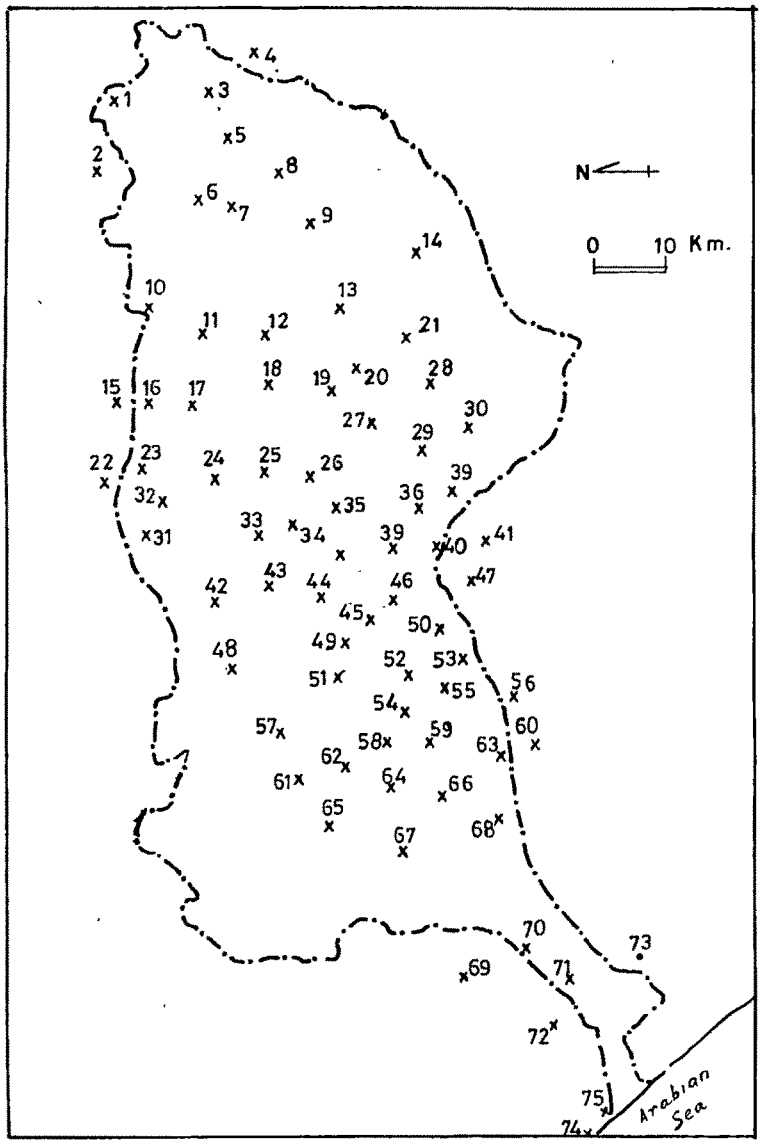
Gravity flow depends on the slope of the ground, for example, *denudational hills* within the basin show steep slopes greater than 18°. Therefore, no significant soil horizon exist which resulted into faster run-off and very negligible percolation. In the case of *pediment*, the slopes become moderate (5° - 10°), the run-off slightly reduces with little chance of infiltration. Percontra, the *burried pediment* reflects very gentle slope angles (2°-5°), which, inturn increases the thickness of the sediments and soil cover and this favours moderate percolation due to less run-off. The extreme case is the *flood plains* where the surface is more or less horizontal. Therefore, very less run-off and good infiltration. Yet another landforms, the *paleo-channels*, are the ideal place for ground water recharge because of their low lying topographic expression with favourable thick sediments. On the other hand, in the coastal tract, the *intra-dunal areas* are favourable for recharge during the rainy season. Owing to the calcareous nature of these dunes, the aquifer characteristics are controlled by the lithological features than the morphology.

The bed rock topography below the aquifer at many times control the movement of the subsurface water. It means, in the study area also, the character of weathering and fracturing zones, and their vertical depths control these movements.

GROUND WATER LEVEL FLUCTUATION

Water level fluctuation in the aquifers of the study area is controlled by the amount of recharge and discharge. However, it is primarily governed by the specific yield and specific capacity. The aquifers in the basin being unconfined in nature, and assuming that aquifers behave uniformly throughout the basin, the specific yield is analogous to that of co-efficient of storage (Karanth, 1990; Raghunath, 1996).

Seventy five observatory wells, spread throughout the basin (Fig. 4.5), were studied to evaluate the rise and fall in water levels. While considering, the following data have been used, viz. (a) within the pre-post monsoon and (b) past and present years. Based on the last ten years data, the



Observatory Well No	Stations
1	Kamlapur
2.	Bhadla
3	Jasdan
4	Gokhlana
5.	Atkot
6	Bhaldoi
7	Mota Dadva
8	Jivapar
9	Santhali
10.	Bhadui
11.	Kotda Sangani
12	Gogavader
13	Srinathgadh
14	Derdi
15	Sapar
16.	Ribda
17.	Bhunava
18	Gondal
19	Bandra
20	Shivrajgadh
21	Sultanpur
22	Chibda
23	Sanganva
24.	Kolithad
25.	Daiya
26	Chakaradi
27.	Lilakha
28	Amarnagar
29.	Khirasara
30	Charam Samdhala
31	Jetukaba
32.	Thordi
33	Hadmadiya
34	Umrali
35.	Jepur
36	Jetpur
37	Bordi Samdhala
38	Bhadara
39	Panchpipla
40	Mandilkpur
41.	Pipalva
42	Dadvi
43	Rampor
44	Jam Kandrona
45.	Raydi
46	Vegdi
47	Nani Parabdi
48	Gundasari
49	Roghel
50.	Dhoraji
51	Sodavadar

Observatory Well No.	Stations
52.	Supedi
53	Pipliya
54	Nani Vavdi
55.	Chadavadar
56.	Vadodar
57	Khirasara
58	Khakhi Jaliya
59.	Upleta

Observatory Well No	Stations
60	Kalana
61	Padvala
62.	Bhayavadar
63.	Patanvav
64.	Kolki
65.	Paneli Moti
66	Varjang Jalia
67	Dhank

Observatory Well No	Stations
68	Lath
69.	Ishwariya
70	Kutiyana
71.	Segras
72.	Jambu
73	Kadegi
74	Tukda
75.	Gosa

Fig. 4.5: Locations of observatory wells.

Source : G.W.R.D.C.

author has prepared reduced water level maps for pre and post monsoon seasons (Fig. 4.6 and 4.7). They depict that the water levels in either seasons behave more or less in same pattern. The north and north- eastern sectors show greater depth in water level than the middle and lower reaches of the Bhadar basin.

To assess the conditions of water level fluctuation in the past and present, the values of 1984 and 1993 were considered and plotted (Fig. 4.8 and 4.9). Almost all the areas show a decline in the water level from 2 mts to 10 mts, whereas places such as Bhadui, Bhunava, Gondal, Gogavatar, Gundasari, Jetpur, Kamlapur, Kolithad, Kotda Sanghani, Lilakha, Patanav, Rampar, Sangava, Shivrajgadh, Sodavadar, Srinathgadh localities have shown a rise of 0.10 - 6.70 meters. This could be on account of the presence of reservoirs near to these places. The above results point out that over the years, the consumption rate of water has considerably increased as compared to the rate of recharge of the basin. The malady is dangerous and requires immediate attention and rectification.

The amount of water that is replenished or released from the sub-surface aquifers, resulting in the elevation or depletion of water table levels were calculated as, $\Delta v = \Delta s \times \Delta h$ (Karanth, 1990; P. 62), where Δv= volume of water, Δs = specific yield and Δh= difference in water level. The results reveal that the maximum recharges are in Srinathagadh, Jetpur, Sodavadar, Gundasari, and Patanvav places having 0.118, 0.103, 0.090, 0.088, and 0.072 % volume per unit surface area respectively. Like wise the maximum discharges are from Jetakuba, Bordi Samdhala, Raydi, Srinathgadh, Bhaldoi, Ribda, and are 0.286, 0.245, 0.216, 0.212, 0.156, 0.147 % volume per unit surface area respectively.

GROUND WATER FLOW DIRECTION

The movement of water is always in the direction along decreasing water heads. In the Bhadar basin, the major trends of sub-surface water movement are depicted in figure 4.10, where their movements have been shown by arrows, the general movement being from east to west. The variation in the ground water flow directions are controlled by the criss-crossed fracture pattern which varies both in lateral as well as in vertical extent. The hydraulic gradients have been calculated following Karanth (1990) for the different micro-water sheds (Table 4.1).

TABLE 4.1 : Hydraulic gradient in various sub-basins

Micro - water sheds	Hydraulic gradients
Jasdan	1:185 ,1:333
Gondli	1:416 , 1.392
Vasavari	1.471, 1:357, 1:410
Champarvadi	1.295 , 1:428
Phophal	1·309 , 1.273
Moj	1·300 , 1·314
Vinu	1·392 , 1·285
Survo	1 357
Karmali	1·114.

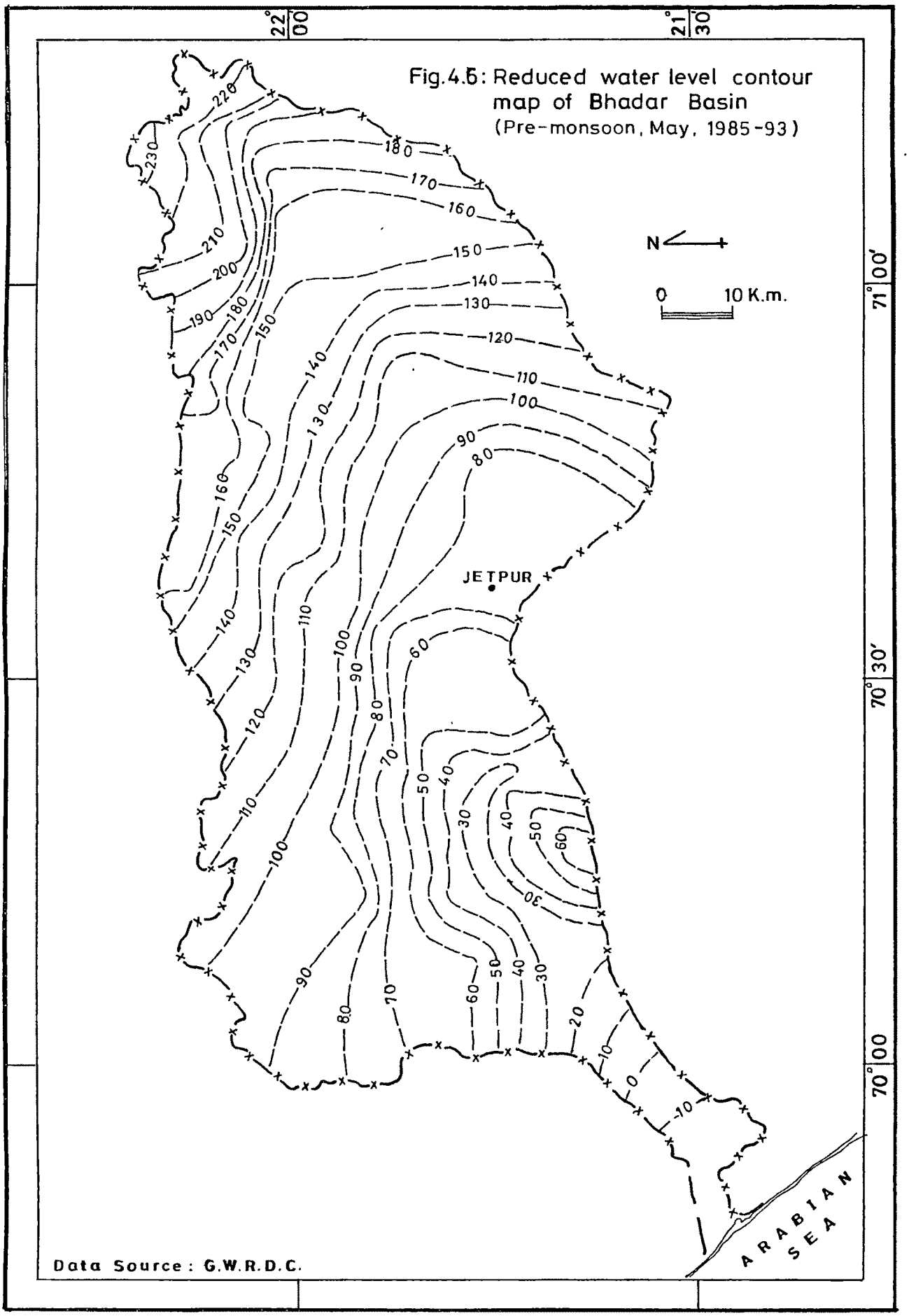


Fig.4.5: Reduced water level contour map of Bhadar Basin (Pre-monsoon, May, 1985-93)

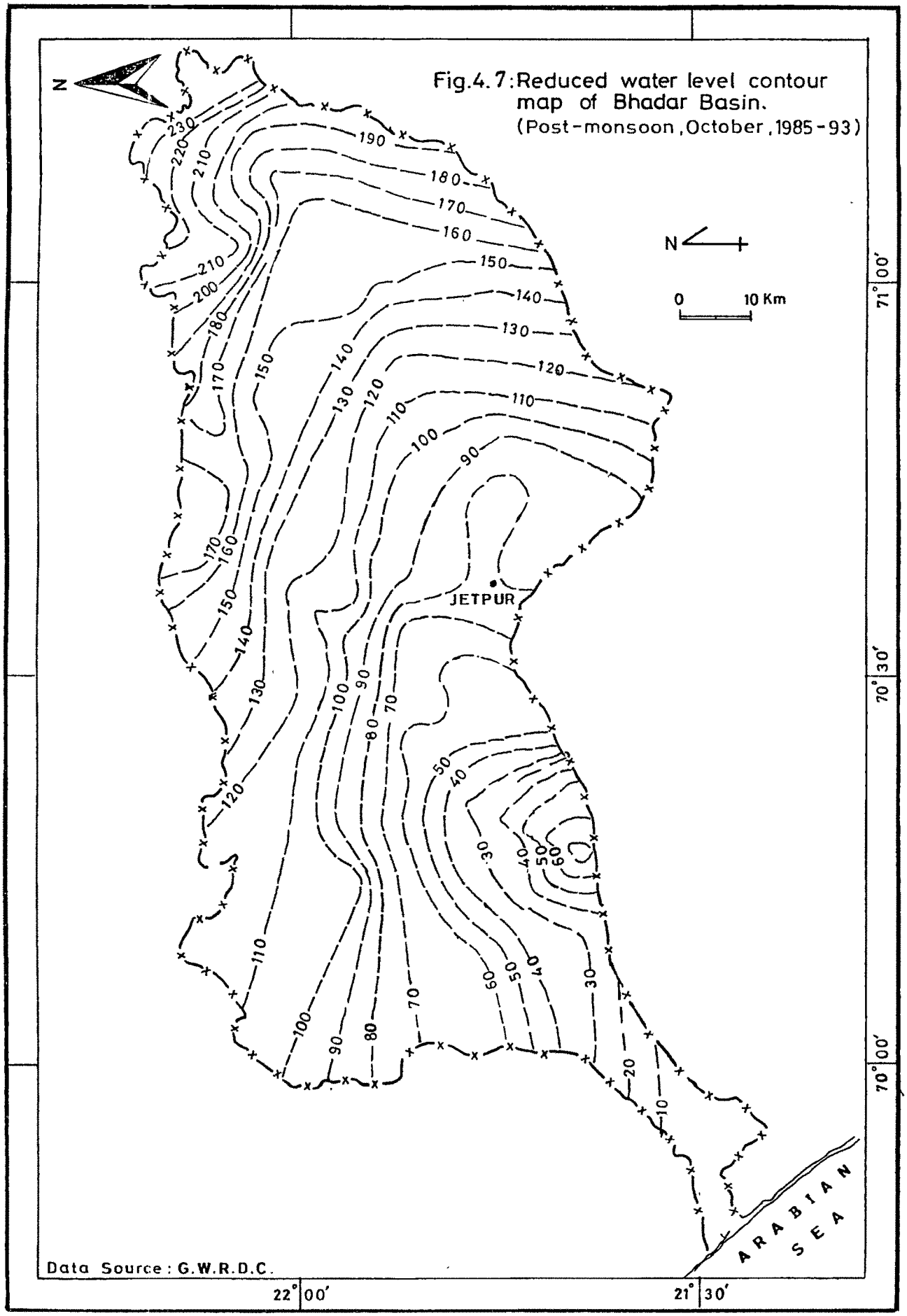


Fig.4.7:Reduced water level contour map of Bhadar Basin.
(Post-monsoon, October, 1985-93)
N
0 10 Km
JETPUR
ARABIAN SEA
Data Source: G.W.R.D.C.
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'

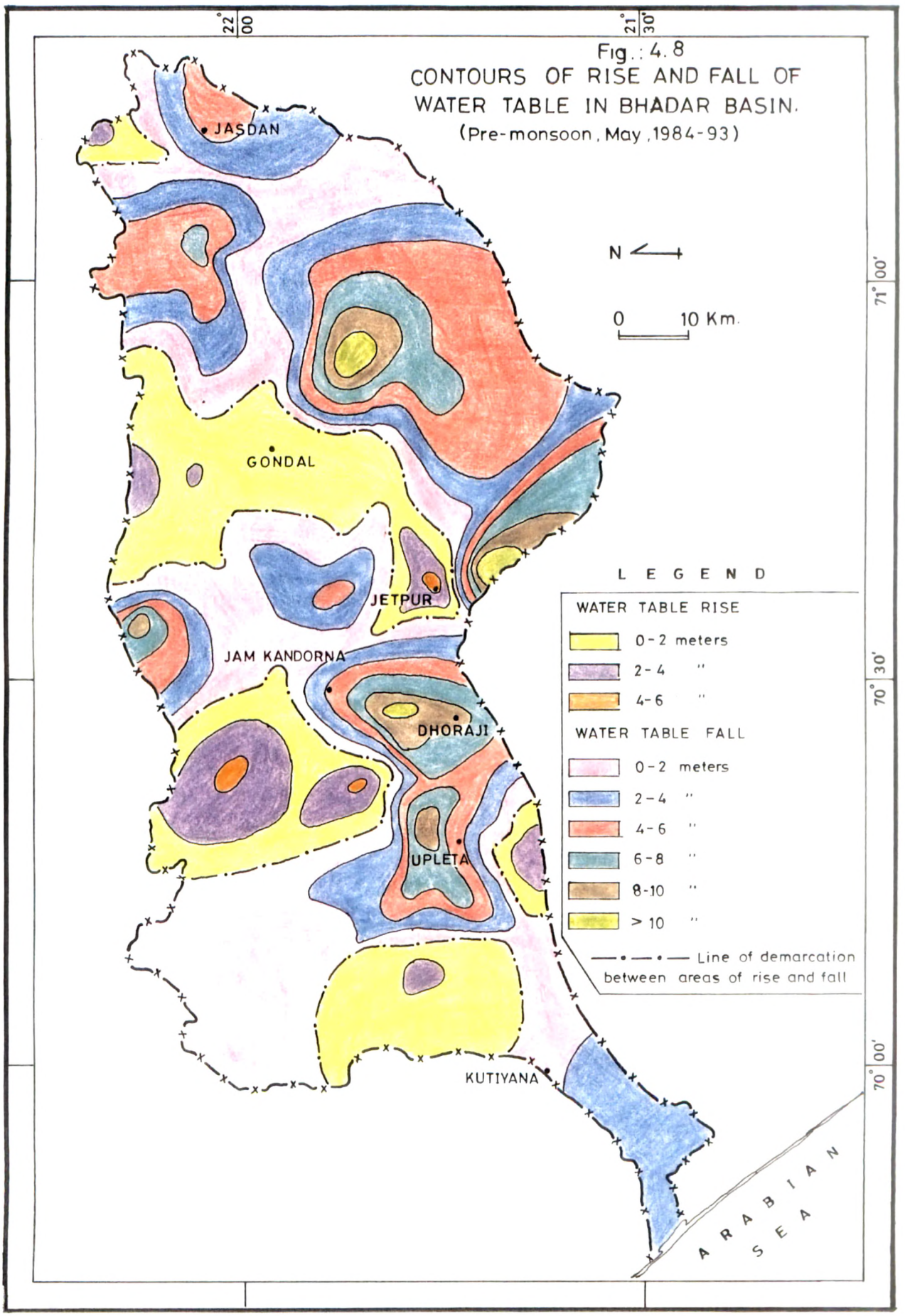


Fig.: 4.8
CONTOURS OF RISE AND FALL OF WATER TABLE IN BHADAR BASIN.
(Pre-monsoon, May, 1984-93)
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
N
0 10 Km.
JASDAN
GONDAL
JETPUR
JAM KANDORNA
DHORAJI
UPLETA
KUTIYANA
ARABIAN SEA
LEGEND
WATER TABLE RISE
0-2 meters
2-4 "
4-6 "
WATER TABLE FALL
0-2 meters
2-4 "
4-6 "
6-8 "
8-10 "
> 10 "
Line of demarcation between areas of rise and fall

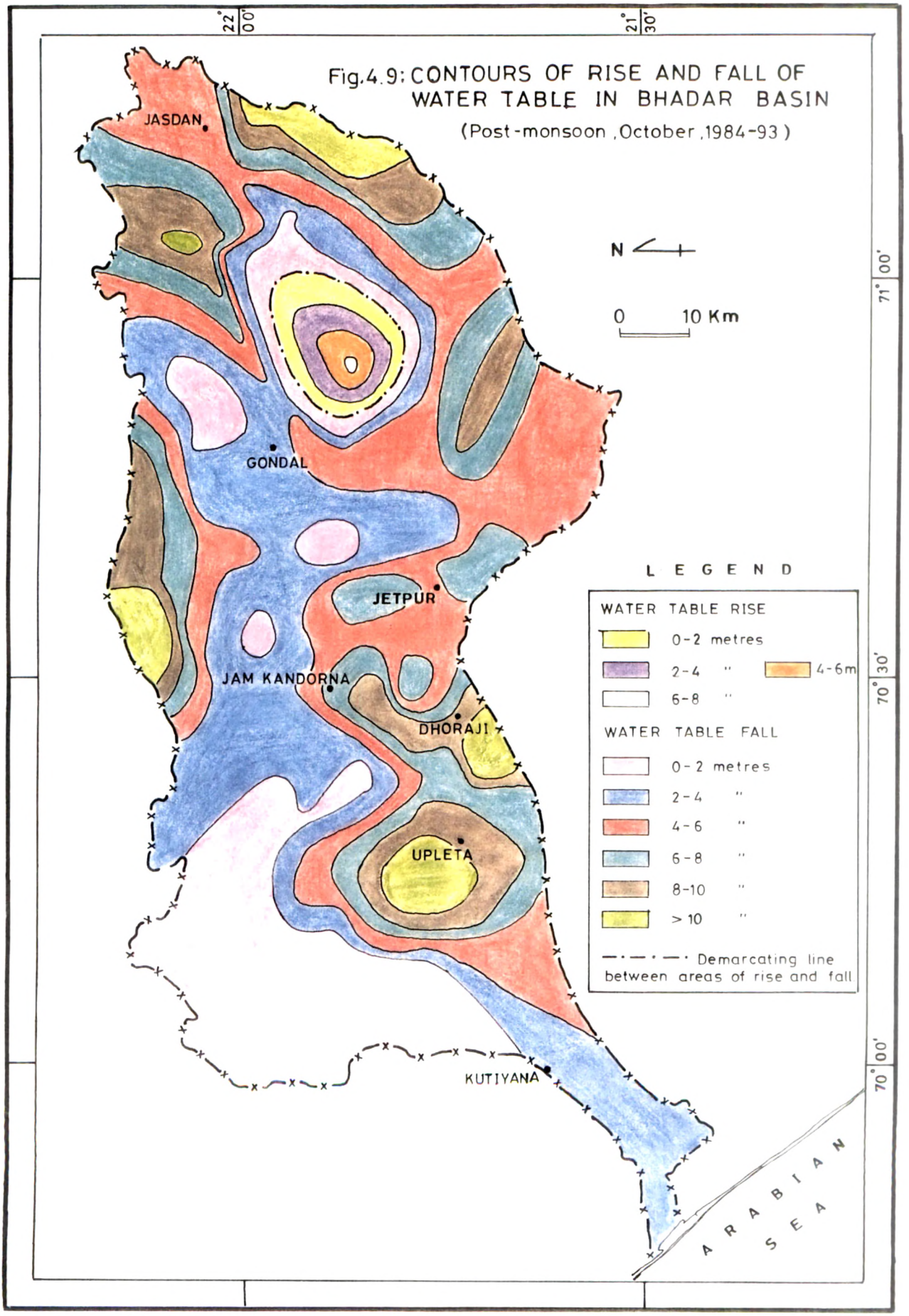


Fig.4.9: CONTOURS OF RISE AND FALL OF WATER TABLE IN BHADAR BASIN
(Post-monsoon, October, 1984-93)
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
N
0 10 Km
JASDAN
GONDAL
JETPUR
JAM KANDORNA
DHORAJI
UPLETA
KUTIYANA
ARABIAN SEA
LEGEND
WATER TABLE RISE
0-2 metres
2-4 "
4-6m
6-8 "
WATER TABLE FALL
0-2 metres
2-4 "
4-6 "
6-8 "
8-10 "
> 10 "
Demarcating line between areas of rise and fall

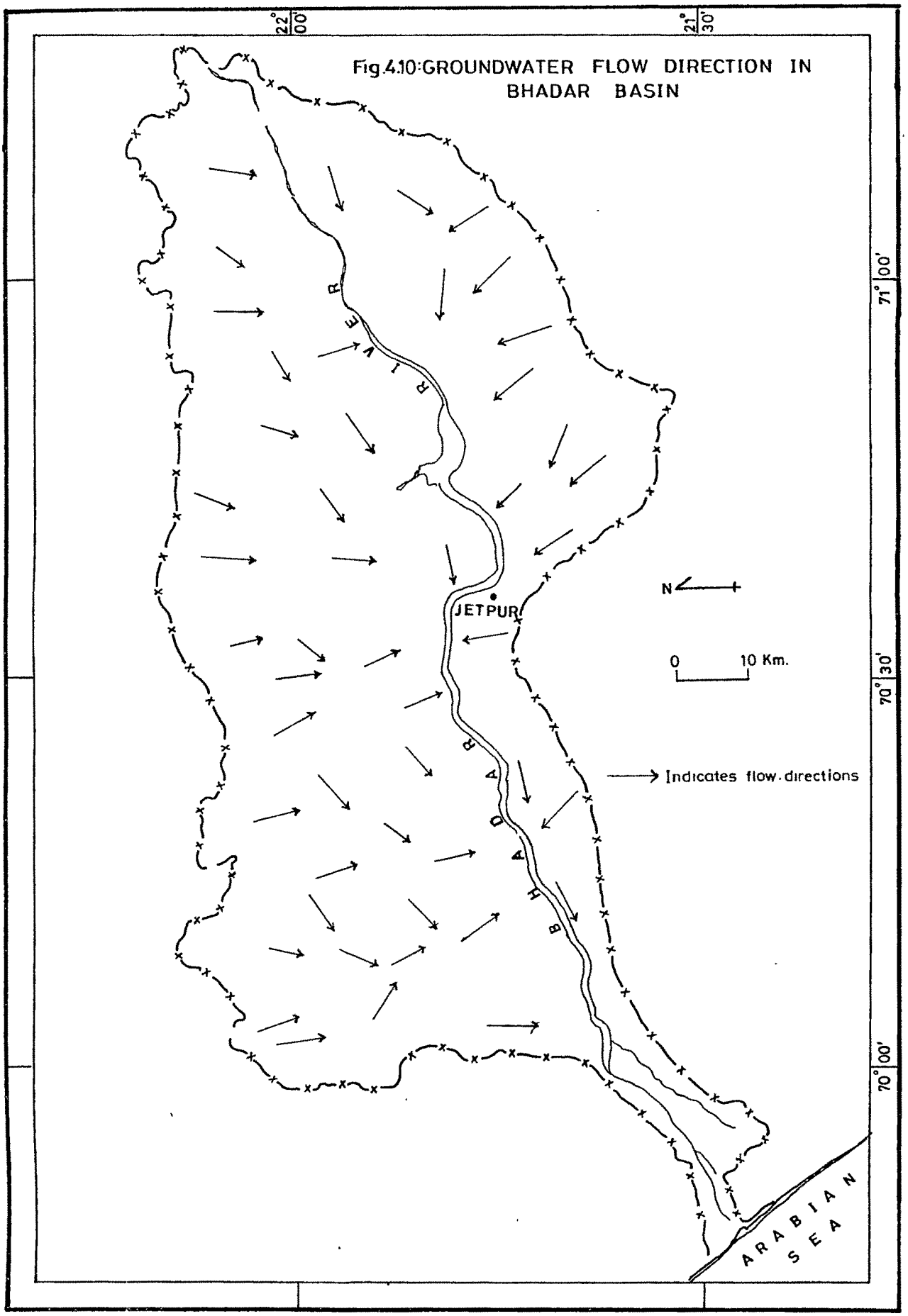


Fig.4.10:GROUNDWATER FLOW DIRECTION IN BHADAR BASIN
22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
RIVER
BHADAR
JETPUR
N
0
10 Km.
Indicates flow directions
ARABIAN SEA

AQUIFER

CONSOLIDATED FORMATION

The area under investigation comprises basaltic lava flows. Structurally flows have horizontal disposition, and features, such as joints, cracks, fractures, dyke emplacement, are common. The trends of these structures indicate wide scale ramification of the major regional trends. Hydrogeological surveys over the years have shown that the traps generally represent an unconfined aquifer system (Karanth, 1990). However, it can be classified into 3 minor aquifer system like

1. Shallow aquifer in weathered profile
2. Multi-tier aquifer in different flows and
3. Linear aquifer of fractured zone.

Shallow Aquifer

The shallow aquifer in weathered profiles in basalts have the thickness, ranging from 2 metres to 14 metres, the maximum being met at Jivapar, Bilyala and Pipardi villages (litholog number 3, 11 and 26 respectively) while only at Patanvav (litholog number 36) it is as thick as 26 metres, (Fig. 4.2). In general, these are underlain by fractured zones. The water levels in them range from 7.50 to 30.00 metres.

The specific capacity of the shallow aquifers varies from 0.039 lpm/min to 0.271 lpm/min (G.W.R.D.C.) Specific capacity, besides being an index of well productivity, serve also as a parameter of yielding and transmissive capacity of the aquifer. The yielding capacity, denoted by specific capacity index (yield factor) of the shallow aquifer of the basin, ranges from 0.01 Imp/min to 0.02 lpm/min.

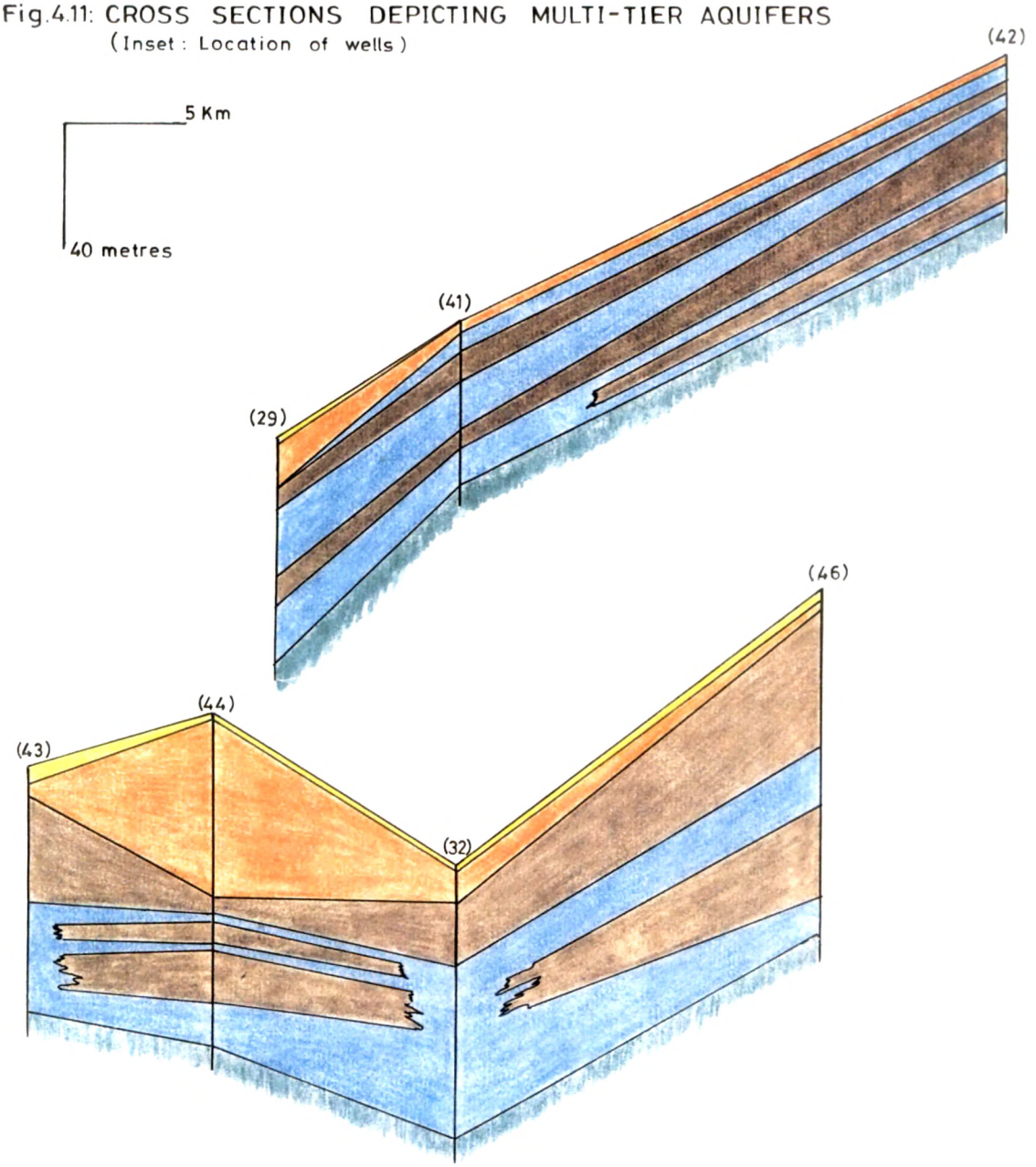
Multi-tier Aquifer

The vesicles and amygdules in the basaltic rocks are of primary porosity and act as an aquifer. Since the area represents different flows, it is not uncommon that some of these flows occur at depth below the weathered zone with intermittent massive or compact basalt. Therefore, this aquifer have been termed as multi-tier aquifer. Generally, they are connected by the fractures and joints in the vertical direction. Since, the thickness of the confined horizons are thin, these aquifers could not be clearly shown in the ribbon diagram (Fig.4.2) and therefore has been mapped in the fractured zone. One such multi-tier aquifer system is well represented in the cross-section (Fig. 4.11) from station Arni-Anida Vachhara and Kharachiya-Jam Kandorna.

The water level varies from 10.5 m to 114 0 m with respect to the surface The total aquifer thickness is between 2.0 m. and 52.0 m.. The yield factor of the wells tapping multi-tier aquifer ranges from 0.003 lpm/min to 0 05 lpm/min.

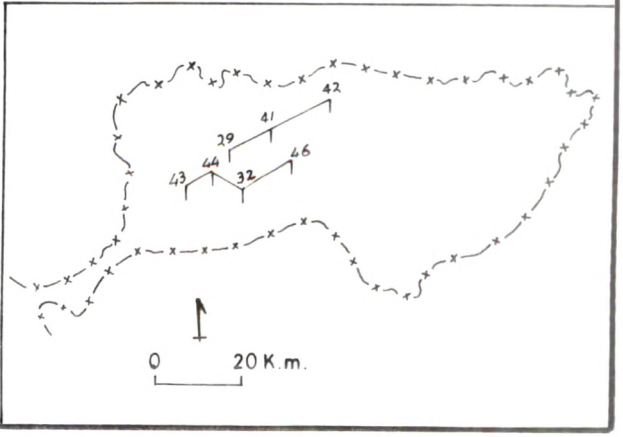
Fig.4.11: CROSS SECTIONS DEPICTING MULTI-TIER AQUIFERS

(Inset : Location of wells)



L E G E N D

- Top soil
- Weathered Basalt
- Fractured Basalt
- Amygdaloidal Basalt
- Massive Basalt
- (29) Borewell number



Linear Aquifer

Conspicously, fractures are common in the trappean basalts, their intensity may reduce as the depth increases. Since, these are linear structures and represent secondary (either on account of cooling or block movement) porosity, they act as a good aquifer. But their morphology is elongated in linear fashion, therefore these are called linear aquifers. The depth of the fracture zone varies in thickness from place to place (Fig.4.2) ranging from 4.0 meters to 52.0 meters. These fractures are often cut, vertically, resulting in the water infiltration into these systems. The water level ranges from 15.0 meter to 64.0 meters. These aquifers show yield factor from 0.02 lpm/min to 0.003 lpm/min.

SEMI-CONSOLIDATED FORMATION

The Miliolite limestones are semi-consolidated aquifers, in which the water occurs in phreatic conditions. Having primary and secondary porosities, these limestones act as a good repositories. Low topographic expressions, nearness to the sea, have caused the water table to occur at low depth (Fig. 4.6 and Fig. 4.7).

UN-CONSOLIDATED FORMATION

Valley deposits are porous and permeable, having phreatic aquifer condition, whereas near the mouth of Bhadar, where alluvial sediments are intertongued by marshy clays, the aquifer changes to aquiclude.

DISTRIBUTION AND OCCURRENCES

SURFACE WATER

Being a semi-arid climatic zone in which Bhadar valley lies, the surface water occurrences depend on the amount of precipitation. Based on last 12 year's (1984-1995) precipitation data from more than 10 stations, spreading over the basin, isohyet map has been prepared (Fig. 3.4). Further, the average depth of precipitation was calculated for the basin by following Thiessen polygonal (Fig. 3.5) method and isohyetal method (Raghunath, 1996; P.28) and it was found to be 494.32 mm and 489.97 mm respectively.

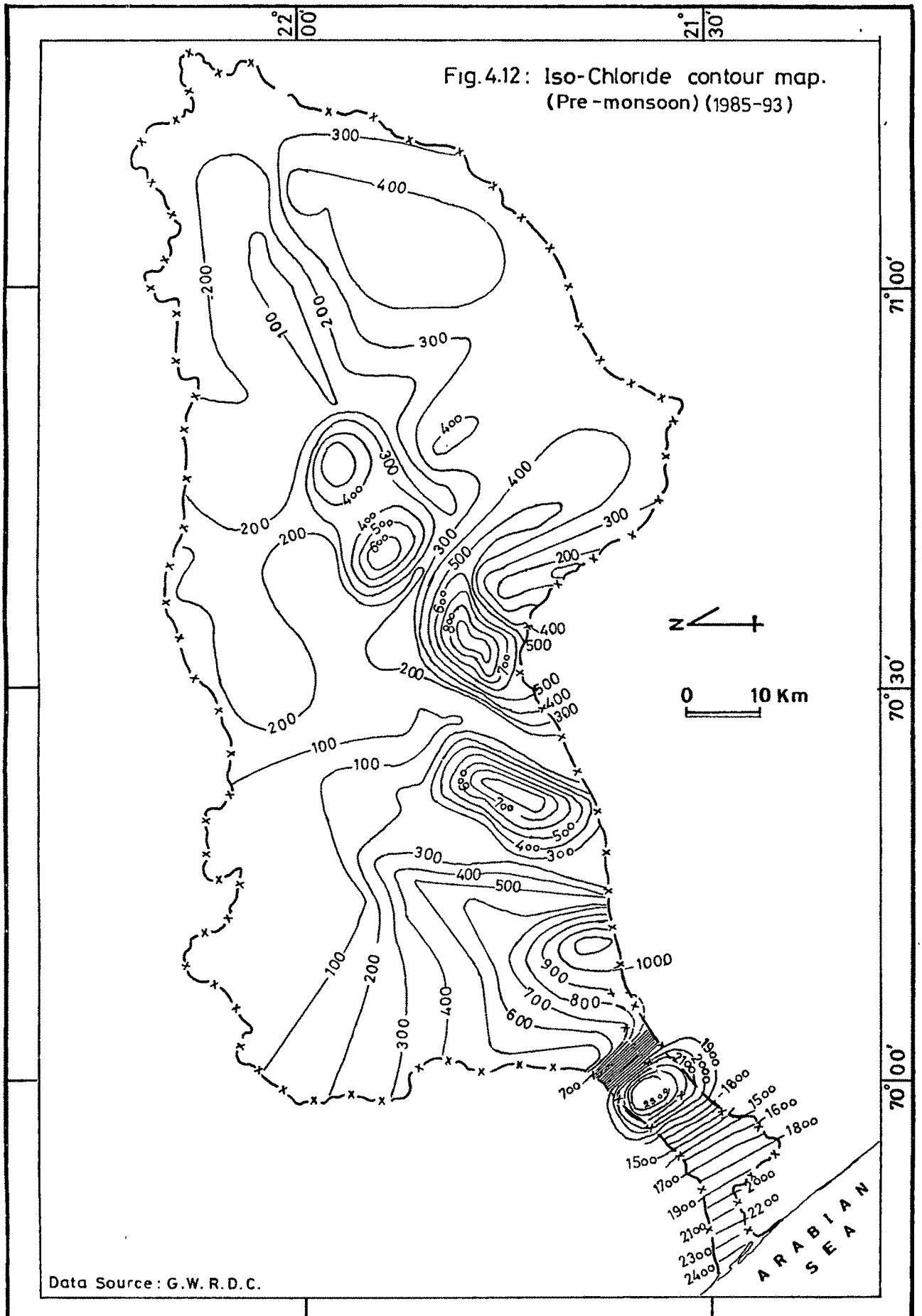
The basaltic rocks exhibit typically rolling topography, with dissected drainage pattern mainly controlled by the structure and slopes. The catchment area reflects denudational high lands and pediment, showing high to moderate sloping ground, which enhance the more speedy run- off to the major trunk of the Bhadar. However, numerous man made structures on Bhadar (Bhadar dam) and its tributaries such as Champarvadi, Phophal, Moj, Vinu and Survo have resulted in major areas of the surface water occurrence. In addition to these, there are ample number of ponds viz; Veri talav, Paneli talav, Supedi, Goghovodar, Amarnagar, Roghel, Bhayavadar, Dhank, Garej, etc. which are situated in low lying intra highland regions.

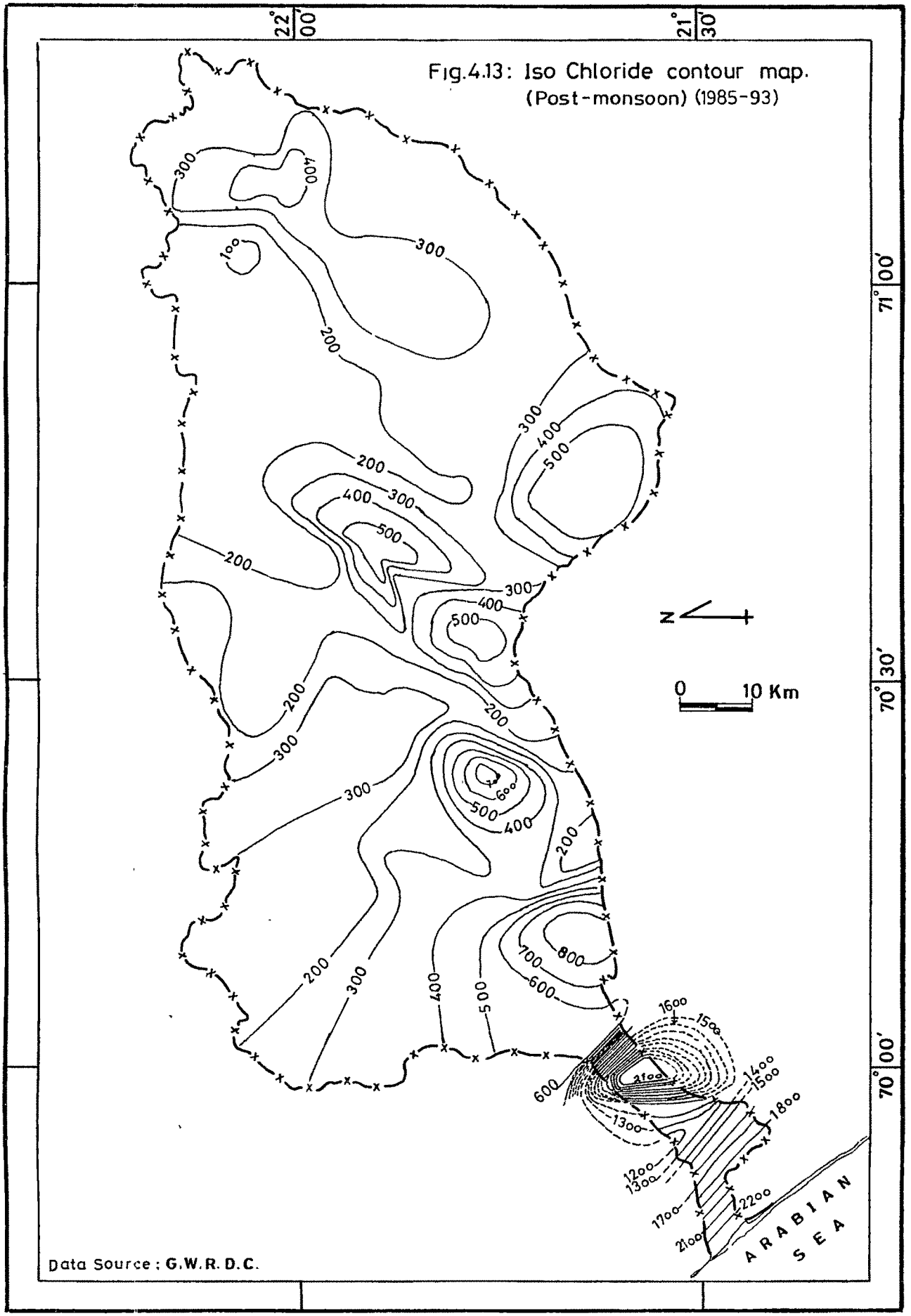
The construction of check dams (for details, refer Appendix II) and dams have face-lifted the life style of the people of this region and also increased, to a certain extent, the ground water recharge potential of the valley. But on the other hand, it has made the river ephimeral in the down stream regions.

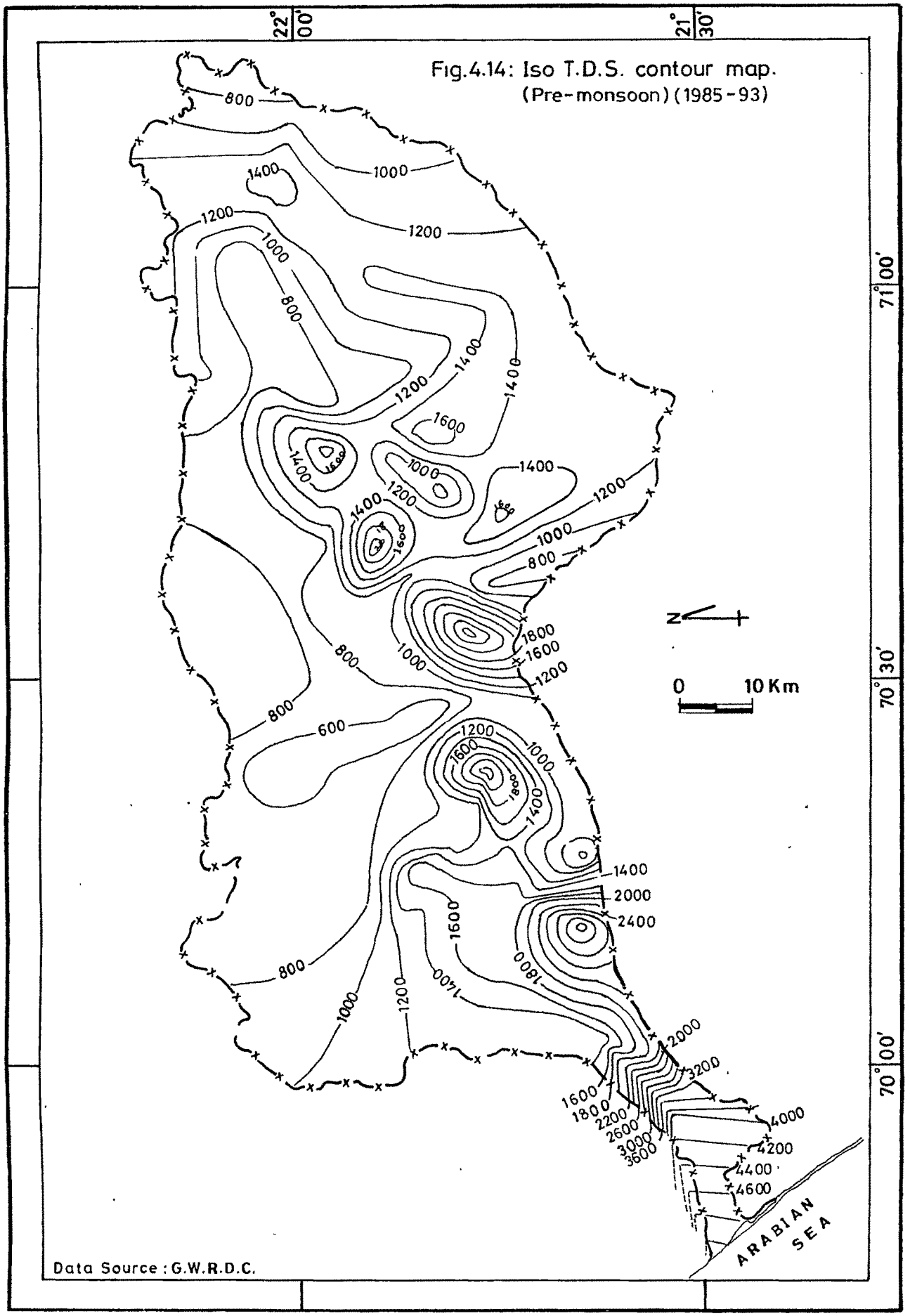
SUBSURFACE

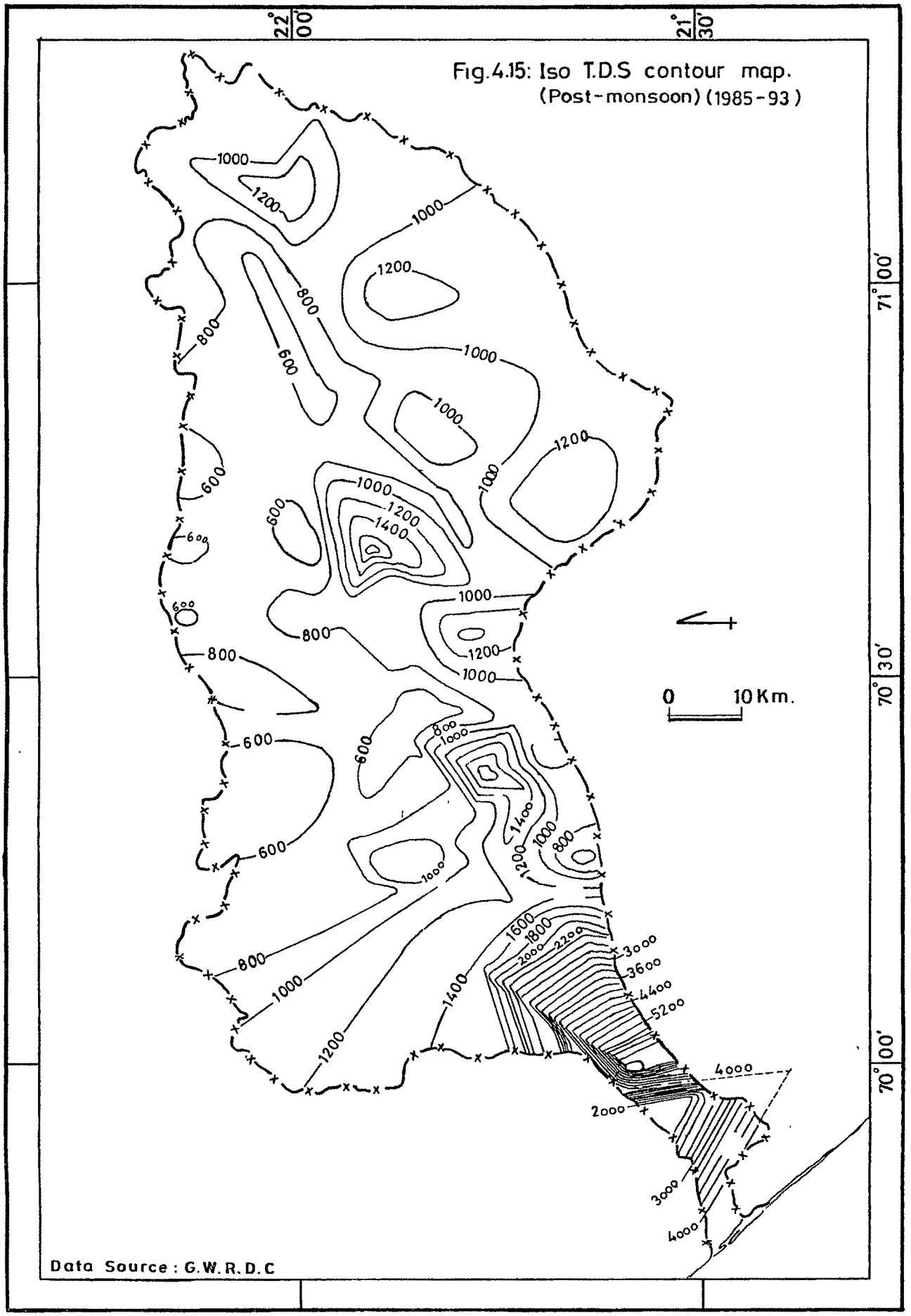
Lithology, structure and geomorphology have controlled the occurrence of ground water in the unconfined aquifers of the basin. Precipitation, recharge and discharge have played vital role in the water table level fluctuations. Figure 4.8 and 4.9 reflects that the zones of water level rise (Kamlapur, Bhadui, Gogavader, Shapar, Gondal, Shivrajgadh, Jetpur, Vegdi, Gundasari, Sodavadar, Patanvav, Srinathgadh and Kotda Sangani) are the favourable sites for exploitation. But an imbalance in draft and recharge may lower down the level. The water table level, which follows the topographic expression, having a east-west movement, are met at a lower depth in the coastal tracts (Fig. 4.6 and 4.7). In these regions, the quality of water is of great concern on account of salinity.

Water quality in the basin, irrespective of the season, assessed on the basis of chloride and total dissolved solids (secondary data- observatory wells, 1985-1993), revealed that their concentration increases with the near viscinity to the sea (Fig. 4.12, 4.13, 4.14, 4.15).


22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
Fig. 4.12 : Iso-Chloride contour map.
(Pre-monsoon) (1985-93)
N
0 10 Km
ARABIAN SEA
Data Source : G.W.R.D.C.


22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
Fig.4.13: Iso Chloride contour map.
(Post-monsoon) (1985-93)
N
0 10 Km
ARABIAN SEA
Data Source : G.W.R.D.C.


22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
Fig.4.14: Iso T.D.S. contour map.
(Pre-monsoon) (1985-93)
N
0 10 Km
ARABIAN SEA
Data Source : G.W.R.D.C.


22° 00'
21° 30'
71° 00'
70° 30'
70° 00'
Fig.4.15: Iso T.D.S contour map.
(Post-monsoon) (1985-93)
0 10 Km.
Data Source : G.W.R.D.C