CHAPTER : VII

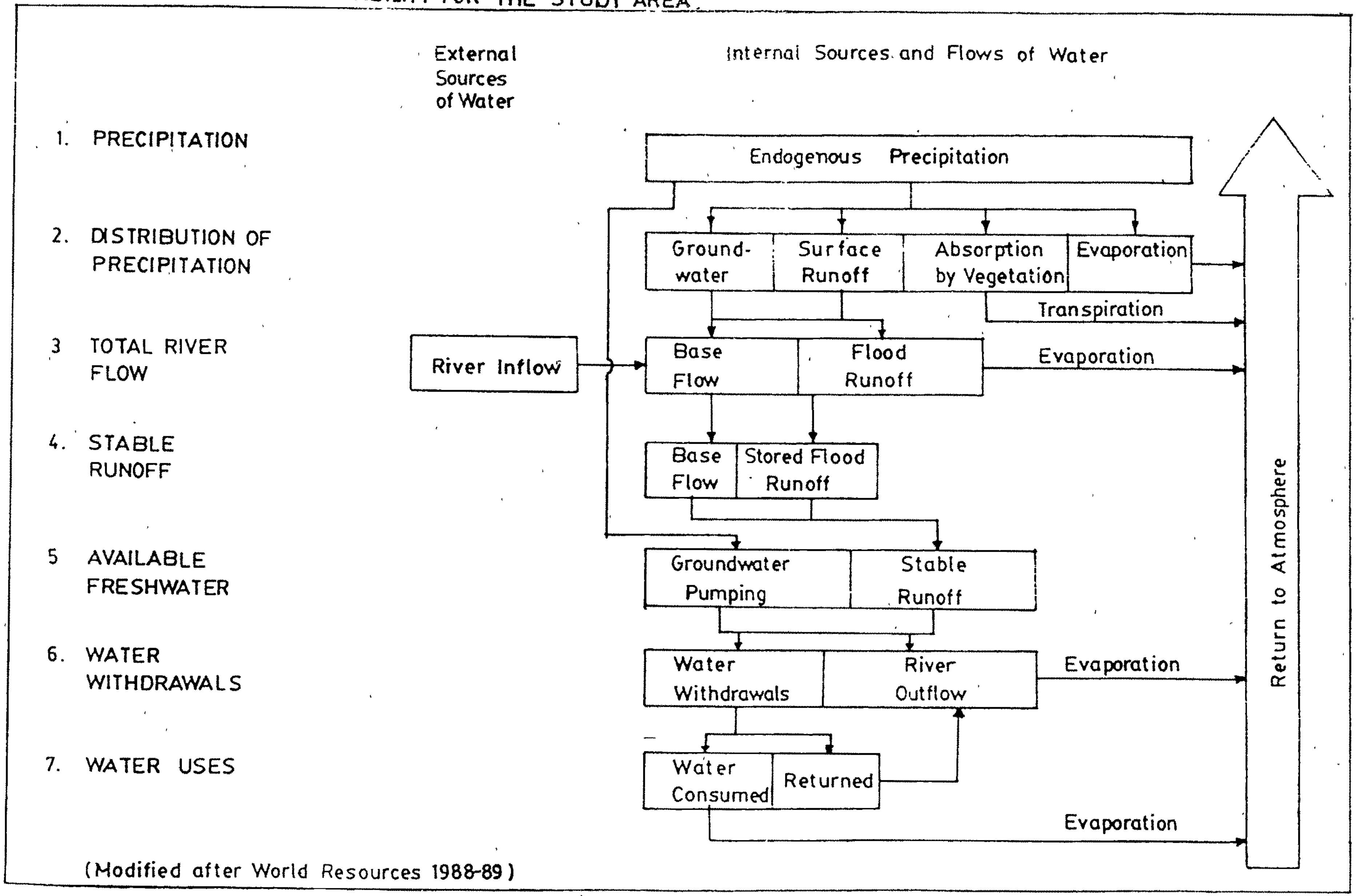
SURFACE AND SUB-SURFACE WATER, ITS QUALITATIVE AND QUANTITATIVE ASSESSMENT

PREAMBLE :

Earth is the water planet : over 70 percent of its surface is covered by water, most of it the saltwater of the oceans. Freshwater, upon which land-based animals and most plants depend, is only a small fraction [3 percent] of the water on the planet. Nevertheless, the total amount of freshwater [36 million cubic kilometers] is more than enough to sustain all life forms on Earth. The supply is continuously renewed by the endless cycling of water, driven by sun energy. Freshwater falls as precipitation. When it infiltrates the soil, it aids plant production and recharges groundwater, or it may run off the surface into lakes, streams and rivers. Freshwater returns to the atmosphere by transpiration from plants or by evaporation, either from land and inland water bodies or after flowing to the sea [Fig. 19].

This global abundance, however, is not distributed evenly. In many areas of the world limited precipitation, high population density, or both make available fresh water barely adequate for or present substantial limits to human uses. Asia and Africa are the continents facing the greatest water stress. Supplies for each Asian today are less than half the global average, and the continent's run-off is the least stable of all major land masses. Lofty mountain ranges and a monsoon climate make rain fall and run off highly variable.

FIG. 19. FRESHWATER AVAILABILITY FOR THE STUDY AREA



Like energy, fresh water is essential to virtually every human endeavor. Its availibility is vital to feeding the world's growing population, producing the material goods that raise living standards, and preserving the integrity of natural systems upon which life itself depends. The scarcity of anything so fundamental is bound to disrupt economic and social activity. Not surprisingly, after the sudden hardships wrought by oil price increases the 'energy crises' of the seventies, many people wonder is there might next be a crisis in water.

Always on the move, seemingly ubiquitous, and often hidden underground, water has long escaped the accounting books of many nations. Remarkably little is known with certainity about how much water is used where, when, and by whom. Although virtually every political leader could quote the current price a barrel of oil, few would know the cost of securing an additional thousand cubic meters of water.

Unlike oil, metals, wheat, and most other vital commodities, water is usually needed in vast quantities that are too unwieldy to be traded internationally. Rarely is it transported more than several hundred kilometers from its source. Thus, while fresh water everywhere is linked to a vast global cycle, its value and adequacy as a resource is determined by the supplies available locally or regionally, and the way they are used and managed.

The "availability" of water for human use, even in a relatively small area, is difficult to define and measure. It depends not only upon climate and precipitation but also on the timing of precipitation, river flows, availability of groundwater, and human interventions either to increase the total supply [e.g. by importing water from another area] or to use the existing water supply more efficiently.

Rapidly increasing populations in many parts of the world place growing demands on water for irrigation, domestic use and industrialization. Responses to these increased demands include not only such traditional steps as well drilling and dam construction, but also improved management of available freshwater. These non-engineering approaches include more effective allocation of freshwater and more effective allocation of freshwater and more efficient use through water conservation.

The quality of water strongly affects to usefulness. Although human activities have long polluted freshwater, governments all around the globe have made significant efforts to control specific "point sources" of pollution such as industrial facilities and urban sewage systems. However, many major sources of pollution remain largely uncontrolled because they are "scattered". Important categories of these "non-point sources" are agricultural runoff and urban/industrial runoff.

THE STUDY AREA :

In the study area, the lithology as seen in Chapter : IV, consists mainly of a thick pile of alluvivm. In order to assess the quality of surface and sub-surface water, extensive field-work, sampling, followed by laboratory analysis of water samples from 68 tube wells [Table : 33 and Fig. 31] was made. This was correlated with the quality parameters from the same wells, for the years 1979-80, 1982-83, 1985-86 [Source : Public Health Engineearing Laboratory [PHEL], Baroda] was done, to evalute any decrease in quality of water. In some cases previous data was not available from PHEL for evaluation.

QUALITY ANALYSIS METHODOLOGY :

The chemical parameters viz. pH, Total dissolved solids [T.D.S], Total hardness, calcium, magnesium, chlorides, sulphates, nitrates, fluorides, chemical oxygen demand [COD], biological oxygen demand [BOD] and total coliform were selected for analysis, to assess the suitability of surface and groundwater for drinking and irrigation purposes. The determination of nitrates, fluorides, chemical oxygen demand [COD], biological oxygen demand [BOD] and coliform was done in 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.

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. The majority of water are slightly basic due to the presence of carbonate and bi-carbonate. A departure from the norm 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.

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°C to 105°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.

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.

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.

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 lying 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. Ericrome black-T is added to the solution, a red colour is formed. EDTA is then slowly addod, 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.

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 highly 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.

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 bariumchloride 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.

Nitrates :

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 attain high levels in some groundwater. In excessive amounts it contributes to the illness known as infant methemoglobinema. 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 phenoldisurfonic 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_2SO_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.

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 is done in PHEL Laboratory, Baroda using standard SPADNS method recommended by American Public Health Association [1975].

Chemical Oxygen Demand :

The chemical oxygen demand [COD] determination provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant. It is an important rapidly measured parameter for stream and industrial waste studies and control of waste treatment plants.

The dichromate reflox method has been selected for the COD determination because it has advantages over other oxidants in oxidizability, applicability to a wide variety of samples.

Principle and Procedure :

Most types of organic matter are destroyed by a boiling mixture of chromic and sulphuric acids. A sample is refluxed with known amounts of potassium dichromate and sulpuric acid, and the excess dichromate is tritrated with ferrous ammonium sulphate. The amount of oxidizable organic matter measured as oxygen equivalent, is proportional to the potassium dichromate consumed.

0.4g H_2SO_4 is placed in a refluxing flask 20.0 ml of sample, 10 ml of standard potassium dichromate solution and few glass beads are mixed.

Flask is connected to the condensor and 30 ml conc. sulphuric acid containing silver sulphate is slowly added through the open end of the condensor. Mixture is refluxed for 2 hours, and then it is diluted to about 150 ml and excess dichromate is titraded with standard ferrous ammonium sulphate, using ferroin indicator. End point is taken on the sharp colour change from blue green to reddish brown.

In the same manner a blank solution is reflux consisting of 20 ml distilled water together with the reagents.

Calculations :

$$\text{mg/l COD} = \frac{[a - b]N \times 8000}{\text{ml sample}}$$

where

COD = chemical oxygen demand from dichromate

a = ml of $Fe[NH_4]_2\ [SO_4]_2$ used for blank solution

b = ml of $Fe[NH_4]_2\ [SO_4]_2$ used for sample

N = normality of $Fe[NH_4]_2\ [SO_4]_2$

Biological oxygen demand [BOD] :

It is defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions. [Sawyer and Mc Carty 1967]. The BOD test is widely used to determine the pollutional strength of domestic and industrial wastes in terms of the oxygen that they will require if discharged into natural watercourses in which aerobic conditions exists.

Procedure :

The BOD test is based upon determination of dissolved oxygen, consequently the accuracy of the results is influenced greatly by the care given to its measurement. BOD may be measured directly in a few samples, but in general, a dilution procedure is required.

The method is based upon the fundamental concept that the rate of biochemical degradation of organic matter is directly proportional to the amount of unoxidised material existing at the time. According to this concept, the rate at which oxygen is used in dilutions of the wastes is in direct ratio to the percent of wastes in the dilution provided that all other factors are equal.

A synthetic water is prepared from distilled water for BOD testing and the pH condition is maintained by means of phosphate buffer solution at about pH 7.0.

The potassium, sodium, calcium and magnesium salts are added to give buffering capacity and proper osmotic conditions for the metabolism and growth of micro-organism.

The dilution water is "seeded" to ensure a uniform population of organisms. Finally, the dilution water is aerated to saturate with oxygen before use.

Correction is made by letting the 5 day dissolved oxygen value of the blank represent the o-day corrected value, it serves as the reference value from which all calculations of BOD are made.

Three different dilutions were prepared of 0.1 %, 1.0 % and 2.0 %. Bottles of dilution water and samples are kept for incubation period and the calculation are made from the equation.

$$\text{BOD in mg/l} = [Do_b - Do_i] \frac{100}{\%} - [Do_b - Do_s]$$

Where Do_b and Do_i are the dissolved-oxygen values found in the blanks and the dilutions of the sample, respectively at the end of the incubation period and Do_s is the dissolved oxygen originally present in the undiluted sample.

Total coliform and fecal coliform :

The Coliform group comprises of the aerobic and facultative anerobic gram-negative, nonspore-forming, rodshaped bacteria which ferment lactose with gas formation within 48 hour at 35°C.

The test is carried out in the stages :

Stage I : Total coliform presumptive test
Stage II : Confirmed coliform test and fecal coliform test.

For analysis liquid media [broth] are used and the technique used is known as three dilution five tubes technique which gives the most probable number [MPN] per 100 ml of sample.

Procedure :

Stage I : Presumptive total coliform test :

For this test Mac Conkey's broth in double and single strength is used.

[a] Single strength Mac Conkey's broth

Mix bile salts	5.0 gms
Peptone	20.0 gms
Sodium chloride	5.0 gms
Lactose	10.0 gms

All the ingradients are mixed in 1000 ml of distilled water, and is properly warmed for dissolution. pH is adjusted to 7.4 using 1N HCl 1N NaOH. Neutral red dye is added.

[b] Double strength Mac Conkey's broth :

Concentration of all the ingradients is doubled and is mixed in 1000 ml of distilled water, with 10 ml of 1% neutral red dye.

15 tubes are filled with 10 ml of double strength medium and 15 tubes with single strength medium with inverted Durham tubes and the mouth of each tube is pluged with cotton and is sterilized in autoclave at 121°C for 15 minutes.

Innoculation for presumptive total coliform test :

10 ml sample in 5 big tubes is innoculated in presence of flame to avoid aerial contamination with the help of sterilized pipettes. Likewise 1 ml and 0.1 ml of sample is added in another 5 tube series. This is called as three dilution five tubes technique.

These tubes are innoculate at 37°C temperature and colour change [Red to Yellow] and gas formation in inverted vial after 24 hours of incubation is observed. Gas formation in inverted vials constitute positive result. MPN coliform is counted from MPN-index. This gives presumptive number of total coliforms.

Stage II : Confirmative test for total coliforms and fecal coliforms [i.e. E coli] :

First brilliant green lactose bile broth is prepared

Peptone	10.0 gms
Dehydrated	20.0 gms
Ox-bile lactose	10.0 gms

All the above ingradients except lactose is mixed in 1000 ml

TABLE : 18

MPN INDEX AND 95% CONFIDENCE LIMITS FOR VARIOUS COMBINATIONS OF POSITIVE RESULTS WHEN FIVE TUBES ARE USED PER DILUTION [10 ml, 1.0 ml, 0.1 ml]

Combination of Positives	MPN Index/ 100 ml	95% Confidence Limits		Combination of Positives	MPN Index/ 100 ml	95% Confidence Limits	
		Lower	Upper			Lower	Upper
0-0-0	2	-	-	4-2-0	22	9	56
0-0-1	2	1.0	10	4-2-1	26	12	65
0-1-0	2	1.0	10	4-3-0	27	12	67
0-2-0	4	1.0	13	4-3-1	33	15	77
				4-4-0	34	16	80
1-0-0	2	1.0	11	5-0-0	23	9	86
1-0-1	4	1.0	15	5-0-1	30	10	110
1-1-0	4	1.0	15	5-0-2	40	20	140
1-1-1	6	2.0	18	5-1-0	30	10	120
1-2-0	6	2.0	18	5-1-1	50	20	150
				5-1-2	60	30	180
2-0-0	4	1.0	17	5-2-0	50	20	170
2-0-1	7	2.0	20	5-2-1	70	30	210
2-1-0	7	2.0	21	5-2-2	90	40	250
2-1-1	9	3.0	24	5-3-0	80	30	250
2-2-0	9	3.0	25	5-3-1	110	40	300
2-3-0	12	5.0	29	5-3-2	140	60	360
3-0-0	8	3.0	24	5-3-3	170	80	410
3-0-1	11	4.0	29	5-4-0	130	50	390
3-1-0	11	4.0	29	5-4-1	170	70	480
3-1-1	14	6.0	35	5-4-2	220	100	580
3-2-0	14	6.0	35	5-4-3	280	120	690
3-2-1	17	7.0	40	5-4-4	350	160	820
4-0-0	13	5.0	38	5-5-0	240	100	940
4-0-1	17	7.0	45	5-5-1	300	100	1300
4-1-0	17	7.0	46	5-5-2	500	200	2000
4-1-1	21	9.0	55	5-5-3	900	300	2900
4-1-2	26	12.0	63	5-5-4	1600	600	5300
				5-5-5	≥2500	-	-

[From American Public Health Association, 1975] of distilled water, mixture is warmed and then cooled, lactose is added and pH is adjusted to 7.5 and 13 ml of 0.1 % brilliant green dye is added.

5 ml of brillant green lactose bile broth is poured in small tubes and is sterilized having inverted Durham tubes.

With the help of a wire loop medium from presumptive positive tubes are transfored to brilliant green lactose bile broth tubes. Two sets are prepared from which one set is incubated at 37°C temperature and another set at 44°C temparature. Gas formation is observed at 24 hours of incubation. Tubes having gas formation at 37°C constitute the confirm test for total coliforms and gas formation at 44°C temperature constitute the confirm test for fecal coliform or escherichia coliforms. MPN index is found out from the standard table [American Public Health Association 1975] [Table : 18].

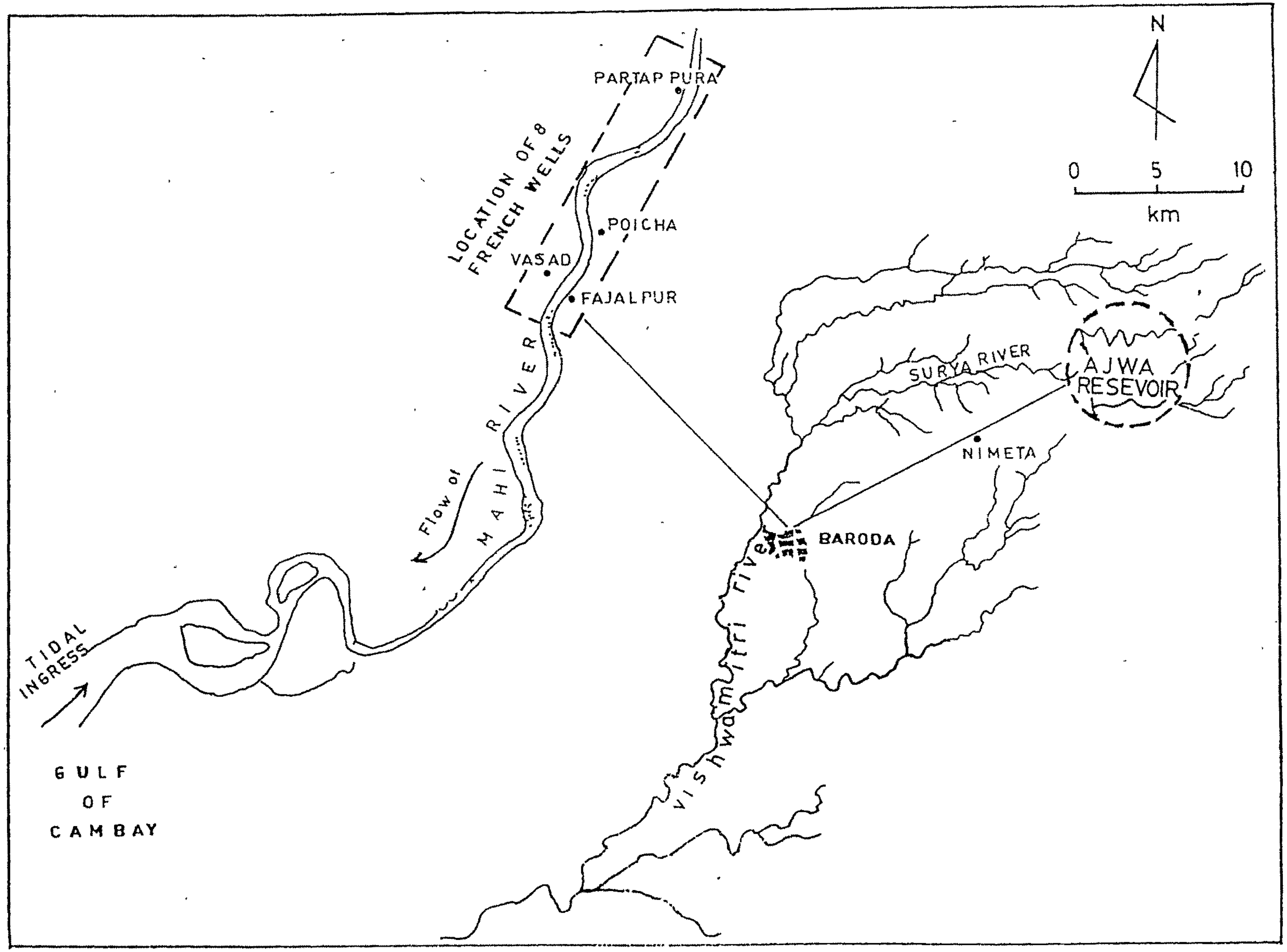
For purpose of evaluation, the entire study of water has been divided into two viz. surface and sub-surface.

SURFACE WATER :

Baroda and its surroundings have 2 large surficial water bodies from which drinking water for the city is procured viz. the Mahi river and the Ajwa reservoir.

Upto the sixties, Baroda used to have a single drinking water source viz. Ajwa reservoir [Plate : 23], which lies 17 km north east of Baroda [Fig. 20]. This reservoir was built some 100 years back to cater to a small population, which increased at a very small pace upto the sixties. With the onset of industrialization, the demand for drinking and industrial water mushroomed, causing the authorities to look for an alternate source. The nearest source was the Mahi river, flowing

FIG. 20:-LOCATION MAP OF TWO MAIN WATER RESOURCES OF BARODA CITY.



to the NW of Baroda. French-wells [Plate : 26] were dug in the Mahi river bed at Fajalpur [Fig. 20]. There are 8 French-wells at present, out of which 6 supply water to the industries and 2 supply water to the western side of Baroda city. The Mahi river which is an important perennial river of western India, enters Gujarat near Kadana [Fig. 21] and follows a continuous NE-SW course to finally merge into the Gulf of Cambay at Dabka. The mouth of this river, in the Gulf of Cambay, is supposed to suffer from one of the highest tidal fluctuations in the world, causing sea water to ingress upstream. This tidal ingress, is hypothecatically supposed to reach upto Fajalpur, where the French-wells supplying water to Baroda are located. This would impede the natural flow of the water and also cause pollution of the water at Fajalpur. To assess the effective range of the tidal ingress, and its influence on the water quality vis. a vis. Baroda city, a complete analysis of spatial and temporal variation in water quality of the Mahi river in Gujarat was done as per the methodology given under.

Fig. 21 is a map of Gujarat, India, showing the Mahi river and the location of eleven sampling stations which will be referrred throughout this description. These stations and their numbers are [1] Harod, [2] Thanasavli, [3] Kund river, [4] Sewalia, [5] on Meshri river, [6] Kanora, [7] Vasad, [8] Mini river at Sherkhi, [9] Jaspur, [10] Dabka, [11] Kavi.

TECHNIQUES :

Monthly sampling of water for the year 1988 from all the above mentioned 11 stations was carried out. The time interval of sampling between station 1 to 11 was 3 days. During the months of July, August and September sampling was not done due to high flow of the river which did not afford access to the fixed sampling points. Further, the monsoon of the year 1988 was an exceptionally active one, causing flooding of the low-lying areas.

FIG. 21. MAP OF **MAHI** RIVER SHOWING LOCATION OF WATER QUALITY MONITORING STATIONS MENTIONED IN THE TEXT AND REFERRED TO IN OTHER FIGURES.

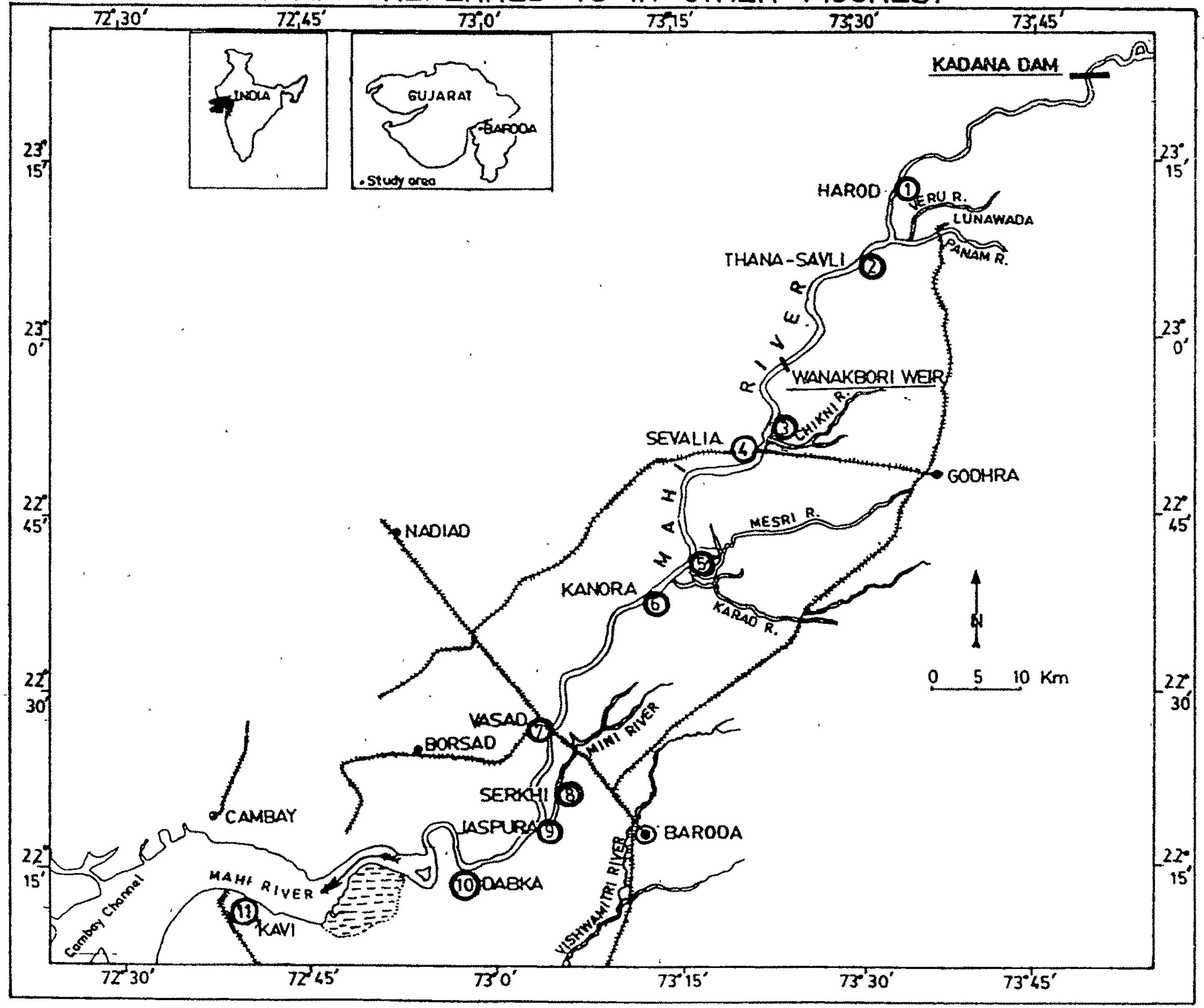
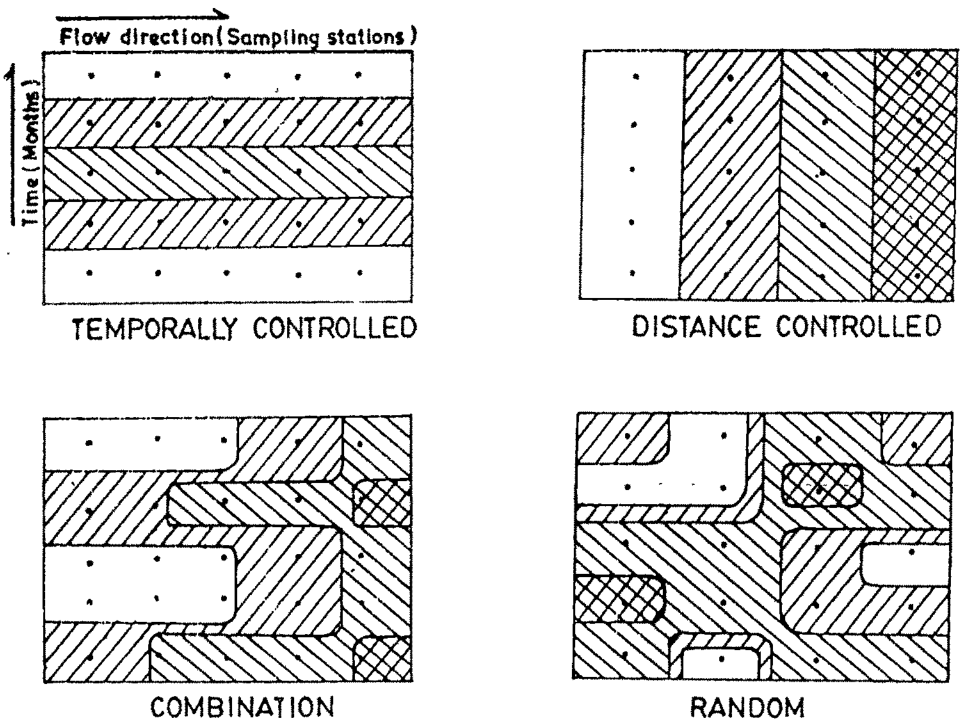


PLATE 26 : VIEW OF ONE OF THE FRENCH-WELL DUG IN THE MAHI-RIVER BED AT FAJALPUR FOR THE SUPPLY OF WATER TO BARODA CITY AND INDUSTRIES. THE MEAGRE WATER QUANTITY IN THE RIVER IS CONSPICUOUS.

FIG. 22- FOUR GRAPHS ILLUSTRATING THE BASIC PRINCIPLES OF TIME-DISTANCE PLOTS

(AFTER HANOR 1988)



FOR EACH PLOT THE HORIZONTAL AXIS REPRESENTS DISTANCE DOWN STREAM AND THE VERTICAL AXIS REPRESENTS TIME OVER A PERIOD OF A YEAR. DOTS SHOW SAMPLE CONTROL. INCREASING DENSITY OF SHADING REPRESENTS INCREASING CONCENTRATION. CAPTIONS IDENTIFY DOMINANT CONTROLS ON COMPOSITION.

The following quality parameters were selected for detailed evaluation; dissolved chloride; dissolved nitrate; temperature; biological oxygen demand [5-day] [BOD]; and chemical oxygen demand, high level [COD].

The goal of this study was to investigate spatial and temporal controls on the above water quality parameters. A highly effective graphical method for representing changes in river composition consist of plotting variations in chemical composition as a function of both time and distance for a given water year. The four graphs in Fig. 22 [after Hanor, 1988] illustrate the basic principles of the process. In each of the four graphs, the horizontal axis represents distance downstream, and the vertical axis represents time of the year. The dots show when and where samples were collected for analysis. If there is sufficient sample control, contours of equal concentration can be drawn across the surface of the graph. In the examples shown, progressively dark areas represent times and segments of the river where there were progressively higher concentrations of particular component during the period of time represented.

The variations in concentration over a period of a year are shown for four hypothetical constituents : A, B, C and D. The concentration of constitutent A at any given time shows no change in the downstream direction, it would be reasonable to conclude that there are no significant sources or sinks of this component within this particular reach of the river. There is however a pronounced temporal or seasonal variation in the concentration of A as river water enters the study reach. The processes which are controlling are obviously operating upstream from the study area. In contrast, there is no temporal variation in the concentration of B in the water entering the study area. There is, however, progressive increase in B with distance downstream. There are thus processes or activities within the study area which are resulting in increased concentration of B at all seasons of the year.

Component C exhibits both temporal spatial variations in composition. Processes both upstream and within the study area are affecting its concentration. The variation in the concentration of D is apparently random. As a working hypothesis, one might conclude in the absence of evidence for low analytical precision that the concentration of D is controlled by dynamic short-term processes.

DISCUSSION :

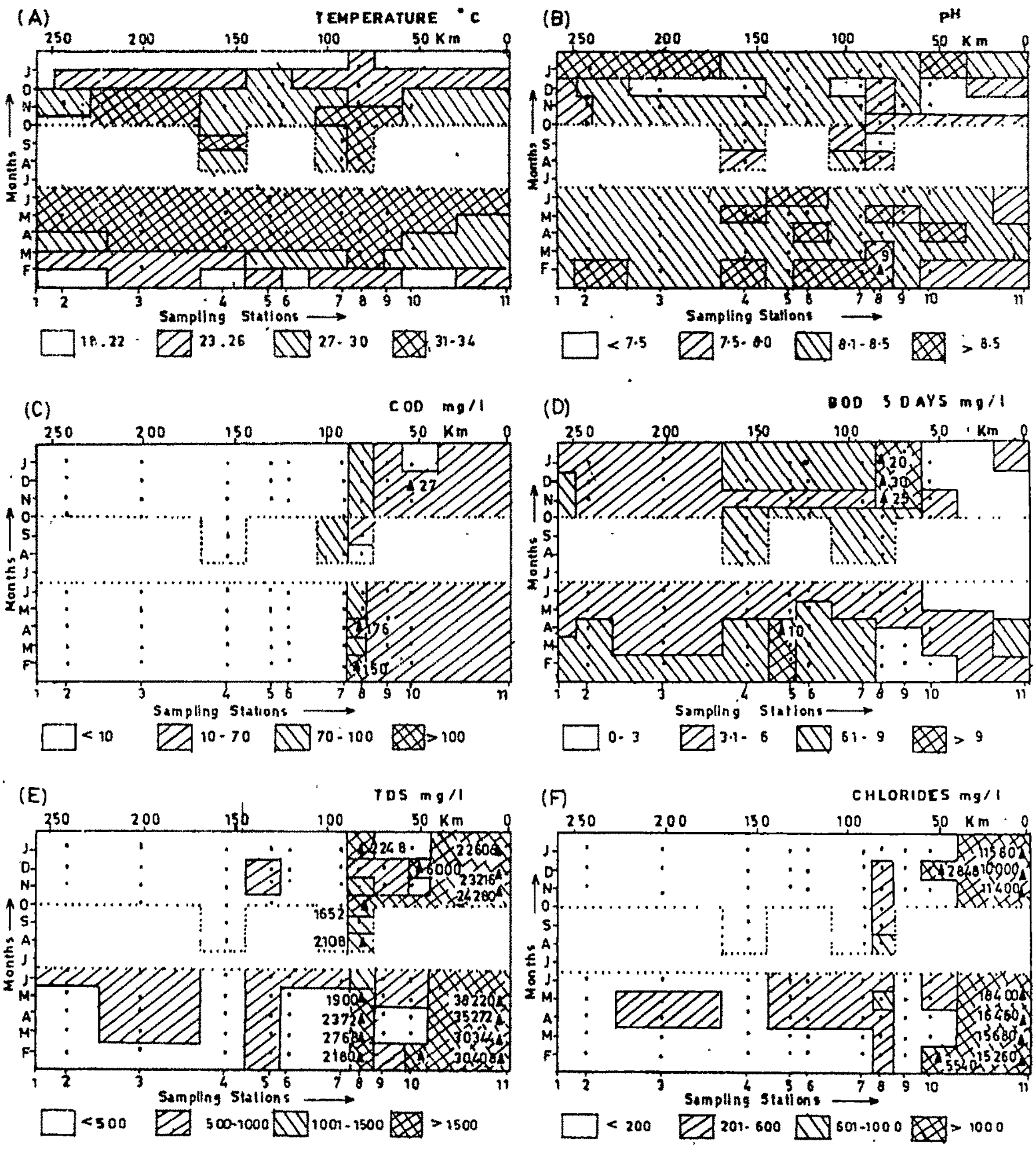
Time-distance plots were made for each water quality parameter mentioned for the year 1988. All of these plots serve as the basis for the discussions and conclusions generated in this research. Fig. 23 and 24 show time distance plots and variations of the water quality parameters. A detailed discussion of the behaviour of each parameter is given below.

Temperature and pH [Fig. 23.A, 23.A and Table : 19, 20] :

There is a strong seasonal variation in water temperature. The lowest temperature [22°C] occur in January and February, while the highest temperatures [30°C] are recorded at nearly all stations in the months of March, April, May, June. In October, stations Nos. 7, 8 and 9 show temperatures higher by at least 3°C in comparison to other stations. In fact, the temperatures near that of peak summer time. A close look at the data also reveals that all round the year Stations 7, 8 and 9 show higher temperatures in comparison to the other stations. This can be attributed to the high level of pollution in this part of the river.

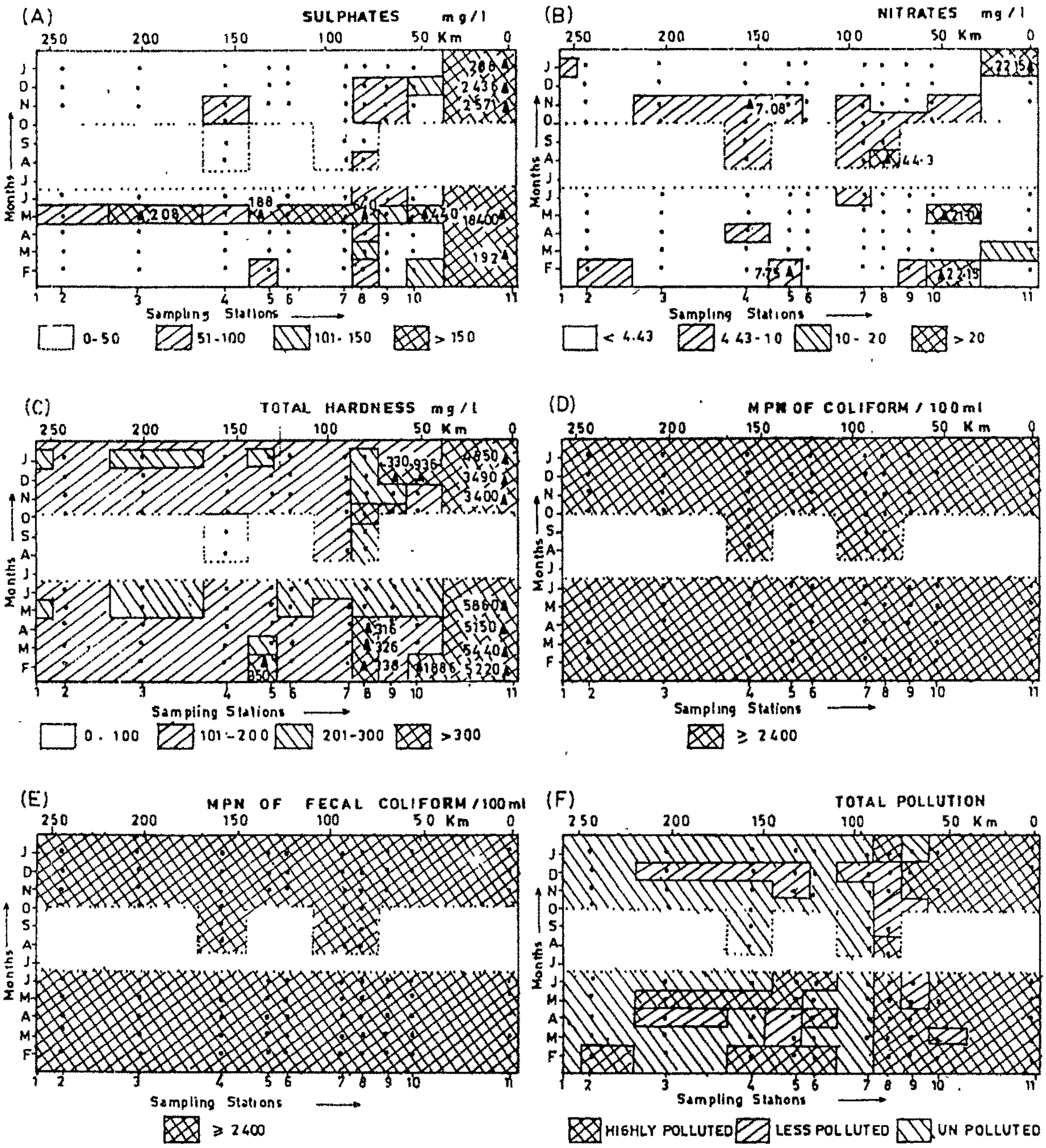
The variation in pH can be split into two broad classes, viz. months showing basic pH [between 9.0-7.5] at a majority of the stations, and months showing less basic and nearly neutral pH [between 7.5 and 7.0]. The second class is distinctive in the month of October especially around stations 8, 9, 10 and 11.

FIG.-23 TIME-DISTANCE PLOTS FOR TEMPERATURE, P^H, CHEMICAL OXYGEN-DEMAND (COD), BIOLOGICAL OXYGEN DEMAND (BOD), TOTAL DISSOLVED SOLIDS (TDS) & CHLORIDES FOR THE WATER YEAR-1988



(BLANK SPACE (JULY TO SEPTEMBER) IN THE SAMPLE ARRAY REPRESENTS LACK OF DATA)

FIG. 24 TIME DISTANCE PLOTS FOR SULPHATES, NITRATES, TOTAL HARDNESS, COLIFORM BACTERIA, FECAL COLIFORM BACTERIA & TOTAL POLLUTION FOR THE WATER YEAR 1988.



(BLANK SPACE (JULY TO SEPTEMBER) IN THE SAMPLE ARRAY REPRESNTS LACK OF DATA)

TABLE : 19

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

TEMPERATURE 0°C AT POINT

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No.10 Dabka	Point No.11 Kavi
February	22	22	24	22	23	21	23	26	26	20	23
March	25	26	26	25	30	27	28	32	28	27	27
April	29	30	31	31	32	33	33	34	34	30	29
May	32	32	31	31	32	33	34	32	32	32	30
June	32	32	32	33	33	34	34	32	32	32	32
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	30	-	-	30	31	-	-	-
September	-	-	-	31	-	-	30	31	-	-	-
October	30	30	31	28	30	30	33	34	33	29	28
November	30	30	31	30	30	30	30	25	26	29	29
December	22	25	23	23	30	30	24	24	24	25	24
January	21	20	21	21	22	20	20	24	22	20	18

TABLE : 20

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

pH AT LABORATORY

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	8.4	8.7	8.3	8.6	8.5	8.8	8.6	9.0	8.5	7.5	7.5
March	8.2	8.4	8.2	8.2	8.4	8.5	8.3	8.8	8.5	8.5	8.2
April	8.4	8.4	8.2	8.5	8.4	8.6	8.5	8.1	8.3	8.7	8.2
May	8.5	8.4	8.3	8.6	8.5	8.4	8.5	8.8	7.7	8.1	7.9
June	8.5	8.5	8.1	8.5	8.7	8.6	8.5	8.5	8.4	8.2	7.8
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	7.7	-	-	8.5	8.0	-	-	-
September	-	-	-	8.2	-	-	7.8	7.5	-	-	-
October	7.9	7.8	8.1	8.2	8.2	8.1	8.0	7.2	7.1	7.0	7.3
November	8.0	8.0	8.1	8.1	8.2	8.5	8.2	8.0	8.4	7.0	7.4
December	7.6	8.1	7.2	7.3	8.2	8.5	7.3	7.9	8.4	7.2	7.8
January	8.6	8.6	8.6	8.5	8.2	8.3	8.2	8.1	8.4	8.6	8.1

TABLE : 21

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

CHEMICAL OXYGEN DEMAND mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	-	-	-	-	-	-	-	150	16	20	35
March	-	-	-	-	-	-	-	80	26	30	65
April	-	-	-	-	-	-	-	176	16	21	35
May	-	-	-	-	-	-	-	100	40	16	25
June	-	-	-	-	-	-	-	80	16	34	41
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	80	6	-	-	-
September	-	-	-	-	-	-	75	12	-	-	-
October	-	-	-	-	-	-	89	10	26	23	27
November	-	-	-	-	-	-	-	75	15	19	20
December	-	-	-	-	-	-	-	80	13	27.72	15
January	-	-	-	-	-	-	-	81	13	4	40

TABLE : 22

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

BIOLOGICAL OXYGEN DEMAND 5 DAY DO mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	7.0	7.0	6.7	7.3	9.7	7.3	7.8	1.3	0.2	0.56	5.3
March	7.3	6.2	4.9	7.3	9.5	7.7	7.7	1.7	2.3	5.9	6.1
April	5.7	6.9	3.5	7.4	10.0	6.7	6.6	3.5	3.8	3.4	7.0
May	5.2	5.5	3.9	5.8	5.7	6.1	3.6	4.6	6.0	5.6	2.1
June	4.6	6.0	3.9	5.6	5.5	4.8	5.0	5.2	5.8	2.1	1.9
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	6.4	-	-	8.5	8.0	-	-	-
September	-	-	-	6.2	-	-	7.2	7.2	-	-	-
October	6.7	4.9	5.7	6.3	7.2	6.2	6.5	7.3	6.3	5.8	2.2
November	6.4	6.0	5.7	5.8	5.3	5.0	6.0	25	10	4.6	2.6
December	7.8	5.8	3.8	7.2	6.1	6.6	7.5	30	11	2.0	2.2
January	3.3	3.3	6.0	6.7	7.1	7.6	6.6	20	9.3	2.2	3.7

Chemical Oxygen Demand [COD] [Fig. 23.C and Table 21] :

Chemical oxygen demand [COD] is a measure of the total amount of material that can be degraded with a strong chemical oxidant. All year round, stations 1-6 show no COD values, thereby indicating the absence of industrial wastes. This is logical, as this stretch of the river passes through a rural and agricultural country-side. From station 8 onwards in the downstream direction, high values of COD are seen throughout the year. The explanation for this lies in the dumping of untreated industrial wastes into the Mahi and Mini rivers by the major industrial complexes around Baroda.

Biological Oxygen Demand [BOD] [Fig. 23.D and Table : 22] :

Bacteria need oxygen for the reduction of carbonaceous - organic matter present in the water. The higher the amount of these materials, the greater the utilization or depletion of oxygen dissolved in the water, that is, there would be a greater biological demand for oxygen [BOD]. It is the dissolved oxygen that sustains life within the water, and its depletion would have adverse effects on the health and survival of aquatic life. The discharge from effluents contributes greatly to the organic content of the river and thus increases the BOD rendering the water unfit for aquatic life. Potable water should have no BOD value or count. In short, BOD is a measure of the concentration of organic material which can be biodegraded through aerobic bacterial action.

BOD values varying between 0.2 - 30 are seen all round the year. Stations 1-7, show values ranging from 3.6 to 10 all round the year, while stations 8-11 show a wider range from 0.2 - 30. The high values of BOD shown by stations 1-7 which are located in an agricultural setting, can be attributed to municipal wastes being dumped into the river, as well as the human and animal excreta, which is a common phenomenon here as all the human morning rituals are done at the river side. Further,

TABLE : 23

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

TOTAL DISSOLVED SOLIDS mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	272	248	364	224	888	332	324	2180	576	10788	30408
March	428	384	516	352	668	332	412	2768	396	364	30344
April	320	328	536	320	756	336	360	2372	400	396	35272
May	364	340	640	344	662	460	432	1900	780	936	38220
June	664	784	588	392	940	600	552	1268	580	720	18400
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	132	-	-	156	2108	-	-	-
September	-	-	-	128	-	-	284	1112	-	-	-
October	280	324	360	212	432	284	284	1612	1612	2768	35644
November	252	316	472	284	504	300	320	1196	570	312	24280
December	284	469	320	280	745	300	340	960	554	6000	23216
January	274	264	480	240	490	272	280	2248	408	260	22608

TABLE : 24

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

CHORIDE AS CI. mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No.10 Dabka	Point No.11 Kavi
February	48	32	144	36	320	40	40	568	164	5540	15260
March	48	48	176	40	160	44	44	504	64	44	15680
April	60	52	216	60	215	200	209	428	84	72	16460
May	64	60	208	64	205	202	230	640	144	440	18400
June	80	48	196	68	228	216	204	372	180	208	10000
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	16	-	-	28	836	-	-	-
September	-	-	-	24	-	-	24	360	-	-	-
October	30	27	140	28	130	48	52	580	170	88	15660
November	28	24	110	28	112	46	38	340	175	60	11400
December	40	115	64	32	184	52	48	261	69	2848	10000
January	40	32	140	36	124	36	36	132	52	52	11580

due to the present of the Kadana dam in the upstream direction, the flow of the water is controlled and meagre, unable to wash downstream, the pollutants.

The wide range of BOD values [0.2 - 30] shown by stations 8-11, are indicative of various intensities of flushing present near and around the mouth of the river. These values can be attributed to the dumping of industrial wastes in the Mini and Mahi rivers.

Total Dissolved Solids [TDS] [Fig. 23.E and Table : 23] :

There is a seasonal or temporal variation in T.D.S. concentration with highs at all stations during the months of May-June, and high values during all the months in the downstream stations, 9, 10 and 11. The exceptionally highs at stations 9, 10 and 11 and to a certain extent even at station 8 can be attributed to the tidal ingress which occurs due to one of the world's highest tidal fluctuations in the Gulf of Cambay, where the Mahi river has its mouth.

Another derivative from the T.D.S. data, is the overwhelming inefficiency of a fluvial regime to flush away material brought in by the tidal ingress. The natural flow of the Mahi river is impeded by the gigantic Kadana dam [Fig. 21] in the upstream.

Chloride [Cl] [Fig. 23.F and Table : 24] :

One salient feature which is noticed about chloride data is the highs shown at all stations during the pre-monsoon months of April, May and June. This can be attributed to the meagre flow in the river due to flow impedence by the Kadana dam and the acute heat [44° - 47°C] during this period.

Stations 8, 9, 10 and 11, show highs throughout the year, which is due to the regular tidal ingress.

TABLE : 25

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

SULPHATE AS SO_4 mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	27	-	35	12	72	22	-	89	20	104	288
March	5	-	21	-	3	-	-	101	37	1	192
April	19	20	26	30	15	10	24	97	50	30	1140
May	64	60	208	64	188	202	230	640	144	440	18400
June	-	-	12	-	16	-	-	66	67	22	5220
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	5	80	-	-	-
September	-	-	-	-	-	-	-	10	-	-	-
October	36	42	46	66	40	29	35	84	74	31	590
November	25	35	41	99	45	20	34	65	70	24	2571
December	30	31	10	2	14	17	12	55	71	108	2436
January	-	-	17	-	-	-	-	19	25	-	288

TABLE : 26

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

NITRATE AS NO_3 mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	3.544	4.430	2.658	0.886	7.753	1.107	1.994	1.107	8.544	22.150	2.880
March	2.215	3.544	2.215	1.329	3.101	2.215	2.215	3.101	1.772	2.215	13.733
April	1.329	1.329	0.443	4.430	3.101	1.772	1.772	1.772	1.772	0.443	2.215
May	2.658	0.886	1.329	2.215	0.443	1.329	2.658	0.443	0.443	21.042	2.658
June	2.215	0.886	1.329	3.544	1.329	3.544	5.316	0.886	0.443	2.215	3.101
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	4.430	-	-	7.088	44.300	-	-	-
September	-	-	-	4.430	-	-	4.430	4.430	-	-	-
October	3.101	0.886	4.430	4.430	4.439	2.215	4.430	4.430	4.430	7.753	3.544
November	3.544	1.329	4.430	7.088	4.430	3.740	4.430	1.300	1.500	4.430	1.329
December	1.772	2.100	1.772	0.443	2.658	3.987	2.215	0.990	1.360	2.215	2.215
January	4.430	0.886	3.544	0.443	0.443	1.329	1.107	1.107	3.544	2.880	22.150

Sulphate [SO_4] [Fig. 24.A and Table : 25] :

There is no fixed pattern for the concentration levels at all stations. Sulphate forms an essential component of any fertilizer. Thus, sporadic highs and lows at all points can be attributed to implementation of fertilizers, and the consequent flushing of it into the river, from the river bank [Peskin, 1986].

Exceptionally high values at point 11, especially during the month of May is another indicator of the sluggishness of the river flow and its inefficiency to flush away the various pollutants.

Nitrate [NO_3] [Fig. 24.B and Table : 26] :

The variation in concentration resembles that of SO_4, which is explicable as nitrate is also present in fertilizers.

Total Hardness [$CaCO_3$] [Fig. 24.C and Table : 27] :

The inherent hardness present in the flowing water is marked by highs in the summer months at all stations. Stations 8, 9, 10 and 11 show highs all year round, which again can be attributed to the tidal ingress.

Coliform and Fecal Coliform Bacteria [Fig. 24.D, 24.E and Table : 28, 29] :

There is a constant intensity of both coliform and fecal coliform count at all stations and through out the year. This is indicative of intensive local pollution all along the river course, caused by human and animal excreta and municipal wastes. Further, it also points towards the inefficiency of the fluvial system in removing the pollutants.

Time-distance plots permit an evaluation to be made of the relative importance of various processes which control water quality in the

TABLE : 27

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

TOTAL HARDNESS $CaCO_3$ mg./l.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	174	124	182	150	350	172	150	338	194	1886	5220
March	190	176	180	176	212	164	160	326	188	174	5440
April	190	200	200	162	180	174	186	316	186	180	5150
May	216	170	214	158	200	218	188	254	252	254	5860
June	186	154	254	188	178	202	220	296	258	256	3496
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	74	-	-	108	220	-	-	-
September	-	-	-	98	-	-	108	276	-	-	-
October	164	188	170	146	156	186	164	422	372	196	5440
November	142	138	162	132	166	162	154	300	260	150	3400
December	156	200	102	130	164	152	170	250	330	936	3496
January	218	170	236	182	220	146	142	280	196	198	4850

TABLE : 28

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

MPN OF COLIFORM / 100 ml.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No. 10 Dabka	Point No. 11 Kavi
February	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
March	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
April	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
May	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
June	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	2400	-	-	2400	2400	-	-	-
September	-	-	-	2400	-	-	2400	2400	-	-	-
October	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
November	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
December	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
January	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400

All figures are $\geqslant$ 2400

TABLE : 29

ANALYSIS OF WATER SAMPLES OF MAHI RIVER

MPN OF FECAL COLIFORM / 100 ml.

Months	Point No. 1 Harod	Point No. 2 Thana-Savli	Point No. 3 Chikni River	Point No. 4 Sevalia Bridge	Point No. 5 Meshri River	Point No. 6 Kanora	Point No. 7 Vasad	Point No. 8 Sherkhi	Point No. 9 Jaspura	Point No.10 Dabka	Point No.11 Kavi
February	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
March	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
April	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
May	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
June	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
July	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	2400	-	-	2400	2400	-	-	-
September	-	-	-	2400	-	-	2400	2400	-	-	-
October	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
November	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
December	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
January	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400

All figures are $\geqslant$ 2400

Mahi river and its main tributaries. Many water quality parameters are influenced to varying degrees both by human activity in the upriver portion [viz. Kadana dam], and by natural processes and events which occur in the downstream [viz. tidal ingress]. The absolute concentration of COD, BOD, total dissolved solids, chloride, sulphate, nitrate, total hardness, coliform and fecal coliform bacteria in the lower reaches of the Mahi river are all strongly dependent on the relative magnitude of processes which are occurring in the upstream and downstream directions [Fig. 23, 24 and Table : 19 to 29]. These processes undoubtedly include runoff and infiltration from atmospheric precipitation, cooling and warming of surface waters, influx of agricultural wastes, influx from decay of natural vegetation, influx of upstream municipal wastes, and most importantly, the tidal ingress which brings back all the pollutants from the downstream area [i.e. from stations 8-11], right upto as far as station 7.

The high values shown by all parameters between stations 7 and 11 are the result of the dumping of industrial wastes, municipal sewage and tidal ingress which does not allow the meagre flow of the river to flush away the pollutants.

The purpose of this study was to evaluate the effects in the downstream direction by the building of a large dam [Kadana] on the Mahi river. This is important, since nearly half of Baroda's domestic as well as industrial water requirement is met by 8 French-wells dug in the river bed at Vasad [Point 7]. Though water for domestic utilization is properly treated to get rid of bacterial contamination, it is possible that any source of upstream or downstream viral infection, a distinct possibility, as the river is used by local people both for their vital body rituals, bathing cattle and for the dumping of municipal wastes, would be brought upto Vasad by the tidal ingress. Thus in turn would contaminate the river bed aquifers, as the fluvial regime is incapable of flushing away the pollutants. The problem would be even more acute in the summer as the flow would be in the form of a trickle. Any water brought in

TABLE : 30

AVERAGE ANNUAL WATER QUALITY OF AJWA RESERVOIR

CHEMICAL PARAMETERS	MINIMUM	MAXIMUM
pH	7.1	7.4
Total Alkalinity	25	140
Total Hardness	86	162
Ca. Hardness as $CaCO_3$	41	76
Mg. Hardness as $CaCo_3$	45	119
Chloride as Cl.	20	78
Total Solids By E.C.	92	254

All the values are expressed in mg/l except PH

Source : Baroda Municipal Corporation

TABLE : 31

ANALYSIS OF WATER QUALITY OF VISHWAMITRI RIVER NEAR SAYAJIBAUG [SOCLEEN, 1988]

PHYSICO-CHEMICAL PROPERTY	COUNT	COUNT
Date	11.01.88	18.01.88
Type of sample [grab/composite]	grab	grab
Time	15.05	13.10
pH	7.56	7.16
Total dissolved solids [in ppm]	2180	1980
Dissolved solids [in ppm]	960	1160
Suspended solids [in ppm]	1220	820
Dissolved oxygen [in ppm]	1.40	0.90
Biological oxygen demand [in ppm]	175	250
Chemical oxygen demand [in ppm]	664	840
Sulphates [in ppm]	800	560

by the tidal ingress would immediately infiltrate into the dry river bed, eventually finding its way into the aquifers.

In contrast, the quality of the Ajwa reservoir water remains more or less constant throughout the year as the body of water remains a closed one. The only inflow is during the monsoon. The average annual quality of the water is given in Table : 30 [Baroda Municipal Corporation records].

Discussions with general medical practitioners in Baroda city have revealed that people consuming water supplied from the Mahi river are more prone to enteric diseases than those consuming Ajwa water [Barodawala and Patel, in Press].

The other river flowing in the study area is the Vishwamitri, which bisects the city of Baroda into two. This river is a seasonal one, with flow only during the monsoon. It serves as a receptacle for municipal wastes and effluents from minor industries. The water is black in colour [Plate : 27] and gives of a pungent smell. The physico-chemical analysis of water samples from the Vishwamitri near the Sayajibaug [formerly known as Kamatibaug] is given in Table : 31.

From the Table : 31, it is clear that the Vishwamitri river is a very polluted one and incapable of supporting any form of life. The water percolating downwords would also have a deleterious effect on the underground aquifers. This would possibly be the cause of the decrease in groundwater quality along the reaches of this river in Baroda city. Hence this river cannot possibly be considered as a source of drinking water.

The Mini river, a seasonal one, has for the past 3 decades served as a receptacle of effluents from various industries [Plate : 28]. The water which is present during the non-monsoon months is derived from effluent dumping. During the summer cattle resort to the drinking of

PLATE 27 : VIEW OF THE VISWAMITRI RIVER FLOWING THROUGH BARODA. BLACK AND VISCOUS WATER IS CONSPICUOUS. THE PLANETAURIUM IN SAYAJI BAUG IS SEEN IN THE BACKGROUND.

PLATE 28 : SEASONAL NATURE OF THE MINI RIVER, WITH THE PARTIAL PRESENCE OF EFFLUENT WATER WHICH IS DARK GRAY, VISCOUS AND GIVES OF A PUNGENT ODOUR.

the effluent ridden water [Plate : 29].

From the above discussions it can be deduced that with a mushrooming population, the Baroda city authorities will have to augment the daily water supply from the Mahi river bed at Fajalpur. This of course, solves the problem of quantity, but the problem of quality as discussed above, still looms large.

SUB-SURFACE WATER :

The entire area is composed of Pleistocene and sub-recent alluvium consisting of sand, silt, clay and kankar. Pre-monsoon and post-monsoon static water table levels for the year 1988-89 [Gujarat Water Resources Development Corporation, 1989] show that the water table is very deep towards the Mahi and Mini rivers, while occurring at a shallow depth near the Vishwamitri river [Fig. 30]. A number of groundwater mounds and troughs with multi-directional flow have been observed in the area. The water table gradient is steep at many places. This irregular behaviour of the water table suggests, besides the deeper entrenchment of the Mahi river, an irregular, discontinuous disposition of the water bearing formations. This can possibly be attributed to irregular concentrations of calcareous and ferruginous concretions within the sediments and also to the lateral discontinuty of the sediment phases due to gullying, valley cutting and subsequent filling by sediments of lateral phases.

Data from Gujarat Water Resources Development Corporation [unpublished reports] show that the shallow water bearing formations in the east of the study area are mainly composed of finer clastics, indicating low groundwater potentiality. The deeper aquifers west of the Vishwamitri river, are composed of coarse sand and gravels having comparatively better potentials for groundwater development. The groundwater occurs mainly as unconfined aquifers.

The average annual water table fluctuation is between 1.5 - 2 m [Fig. 30].

PLATE 29 : CATTLE RESORTING TO THE DRINKING OF THE EFFLUENT WATER OF THE MINI RIVER .

TABLE : 32

INDIAN STANDARD SPECIFICATION FOR DRINKING WATER

SR. NO.	WATER QUALITY PARAMETERS	PERMISSIBLE VALUE AS PER IS : 10500/1983	
		DESIRABLE LIMIT [FIT]	RELAXABLE IN ABSENCE OF ALTERNATE SOURCE [ABS]
1	Total dissolved solids [TDS] mg/l	500 to 1500	3000
2	pH	6.5 to 8.5	9.2
3	Total hardness mg/l	300	600
4	Calcium mg/l	75	200
5	Magnesium mg/l	30	100
6	Chlorides mg/l	250	1000
7	Sulphates mg/l	150	400
8	Nitrate mg/l	45	-
9	Fluoride mg/l	0.6 to 1.2	1.5
10	Chemical oxygen demand in flowing river [COD]	100	-
11	Biological oxygen demand in flowing river [BOD]	30	-
12	MPN of total coliform	10/100 ml	-
13	MPN of fecal coliform	2/100 ml	-

WATER QUALITY :

In order to asses the quality of sub-surface water, 68 wells [Fig. 31, Table : 33] were selected for sampling during 1988-89. Data for the years 1979-80, 1982-83 and 1985-86, wherever available, were got from the reocrds of Gujarat Water Resources Development, for comparison purposes. The water quality parameters were analysed as per the methodology described earlier. The usability of water was determined using IS:10,500/ 1983 [Indian Standard : Specification for drinking water] as the index [Table : 32].

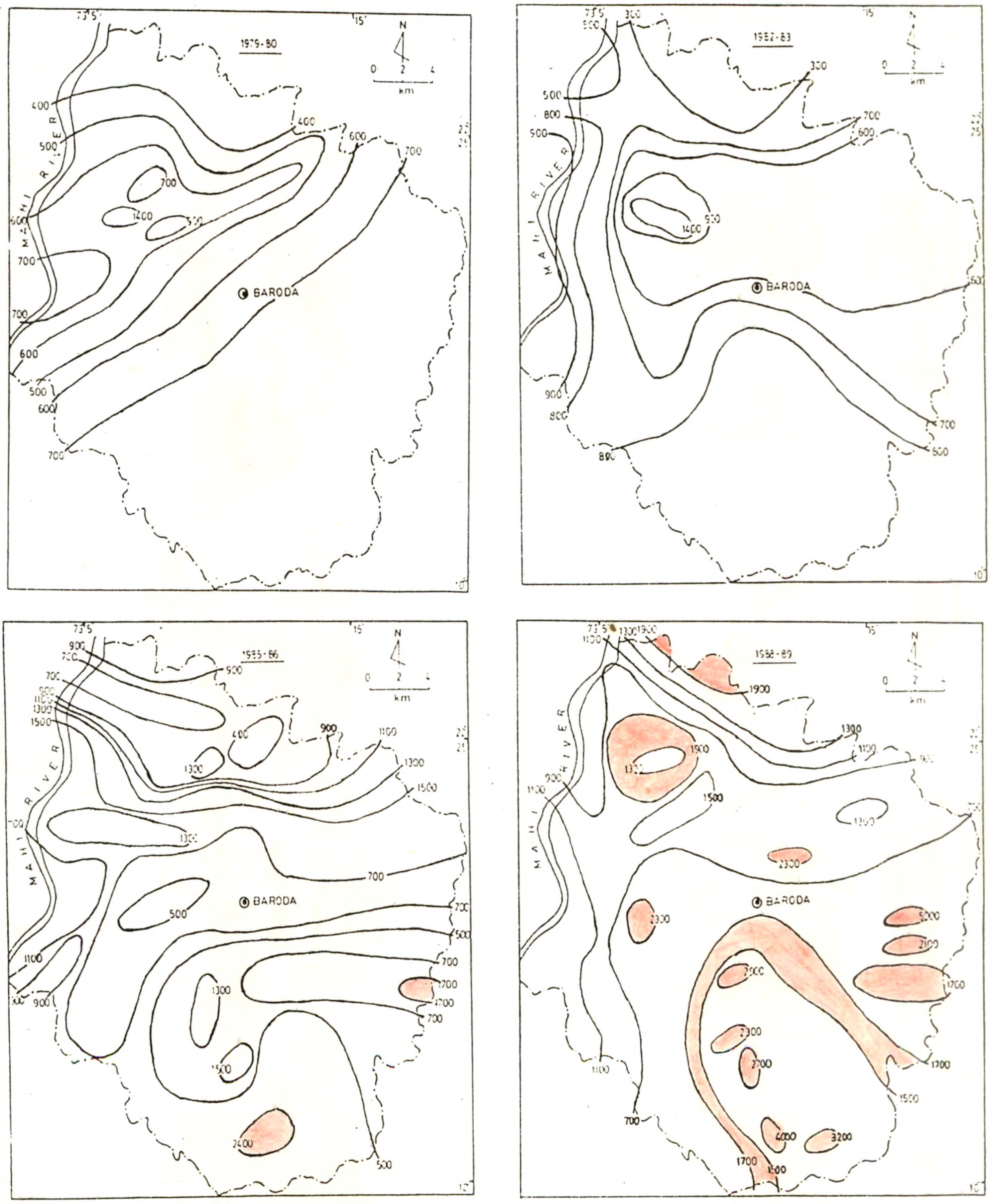
Table : 33 shows the comparison of water quality parameters for the years 1979-80, 1982-83, 1985-86 [data collected from the records of the GWRDC] and 1988-89 [samples collected and analysed].

DISCUSSION :

From Table : 33 it is clear that values of all water quality parameters are on the increase, some nearing critical values, while others have crossed the permissible limits. In order to have a picture of the extent of deterioration of water quality parameters, iso-curves of several parameters, including total dissolved solids [TDS], total hardness, chloride, sulphate, nitrate and fluoride have been made. From Figs. 25, 26, 27, 28, 29 and 30 it is very clear that the area of land having impermissible sub-surface water quality parameters is on the increase. No fixed pattern of increase is seen in all the parameters, hence an influence regarding the possible causes of deterioration would be difficult to make.

Fig. 31 shows the comparison of water usability for the years 1979-80, 1982-83, 1985-86 and 1988-89, based on data described in Table : 33. Out of the 68 wells monitored, in 1988-89, 34 are found to be unfit for human consumption, 24 are considered potable in the absence of a better alternate source [ABS], and 10 are found to be fit. As per

FIG.-25. CONCENTRATION (mg./l.) OF TOTAL DISSOLVED SOLIDS (T.D.S.) IN SUBSURFACE WATER (TUBE WELLS) BETWEEN 1979 AND 1989 IN THE STUDY AREA



Values exceeding desirable limit.

FIG-26. CONCENTRATION (mg/l) OF TOTAL HARDNESS IN SUBSURFACE WATER (TUBEWELLS) BETWEEN 1979 AND 1989 IN THE STUDY AREA

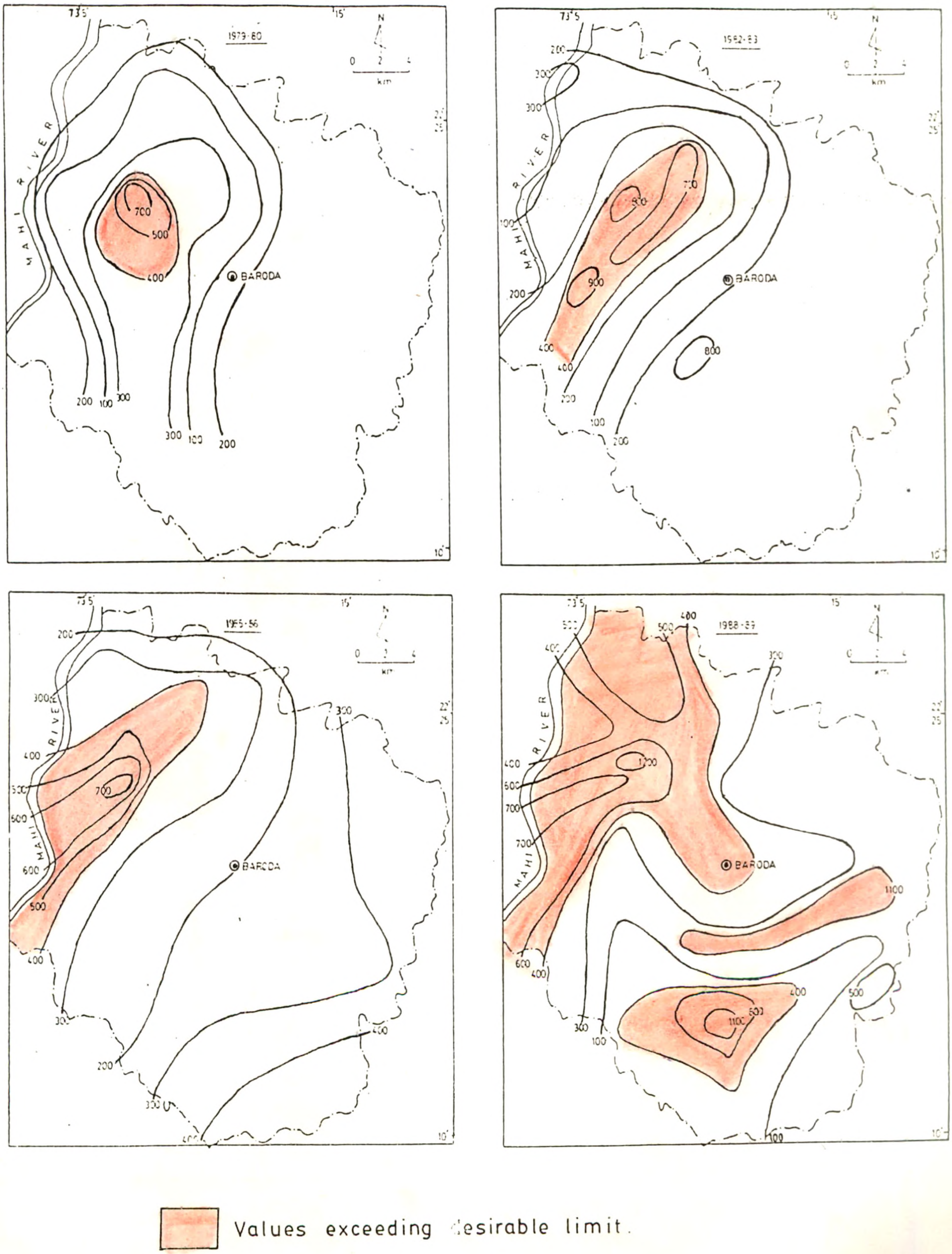
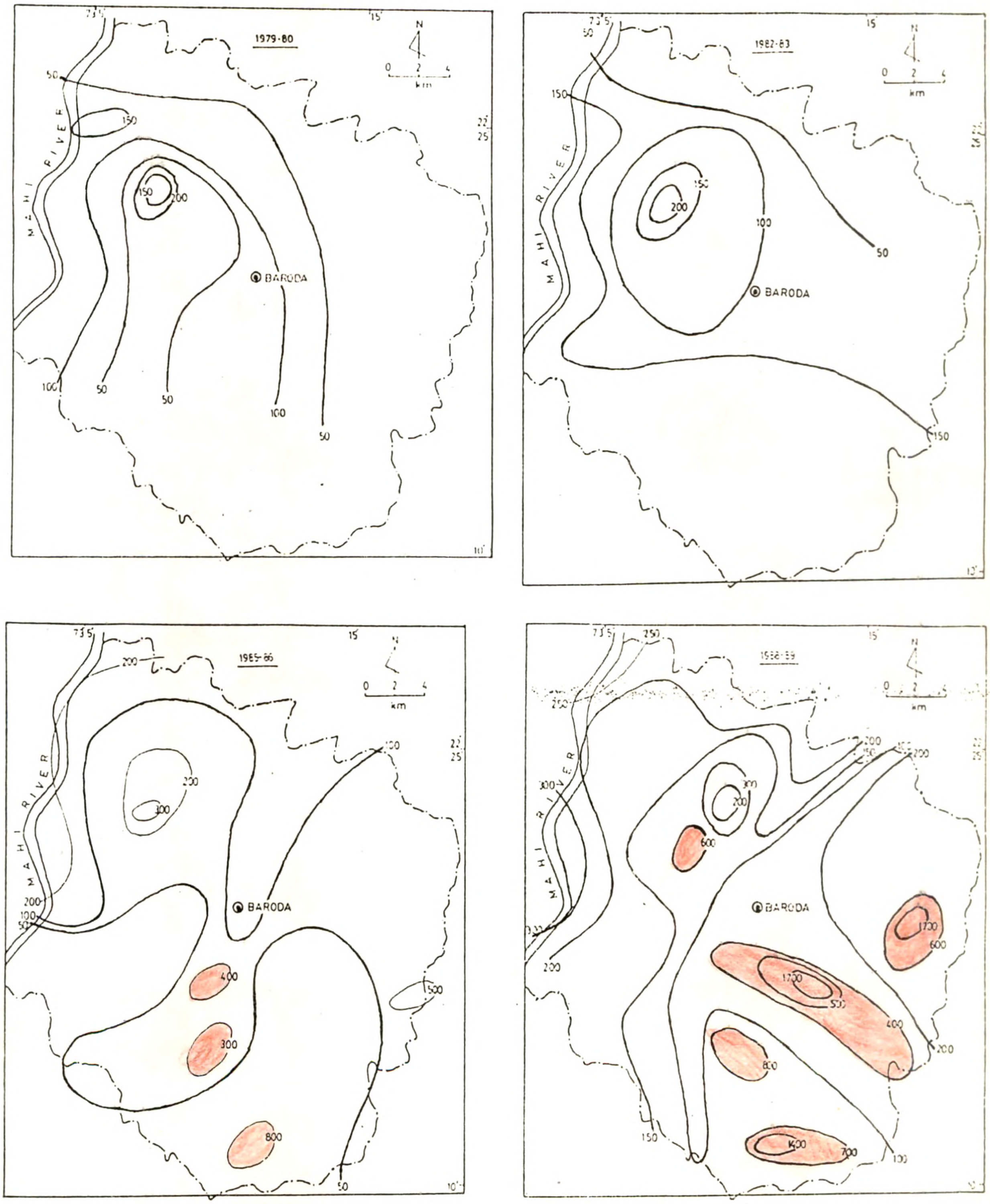


FIG:-27. CONCENTRATION (mg/l.) OF CHLORIDE IN SUBSURFACE WATER (TUBEWELLS) BETWEEN 1979 AND 1989 IN THE STUDY AREA

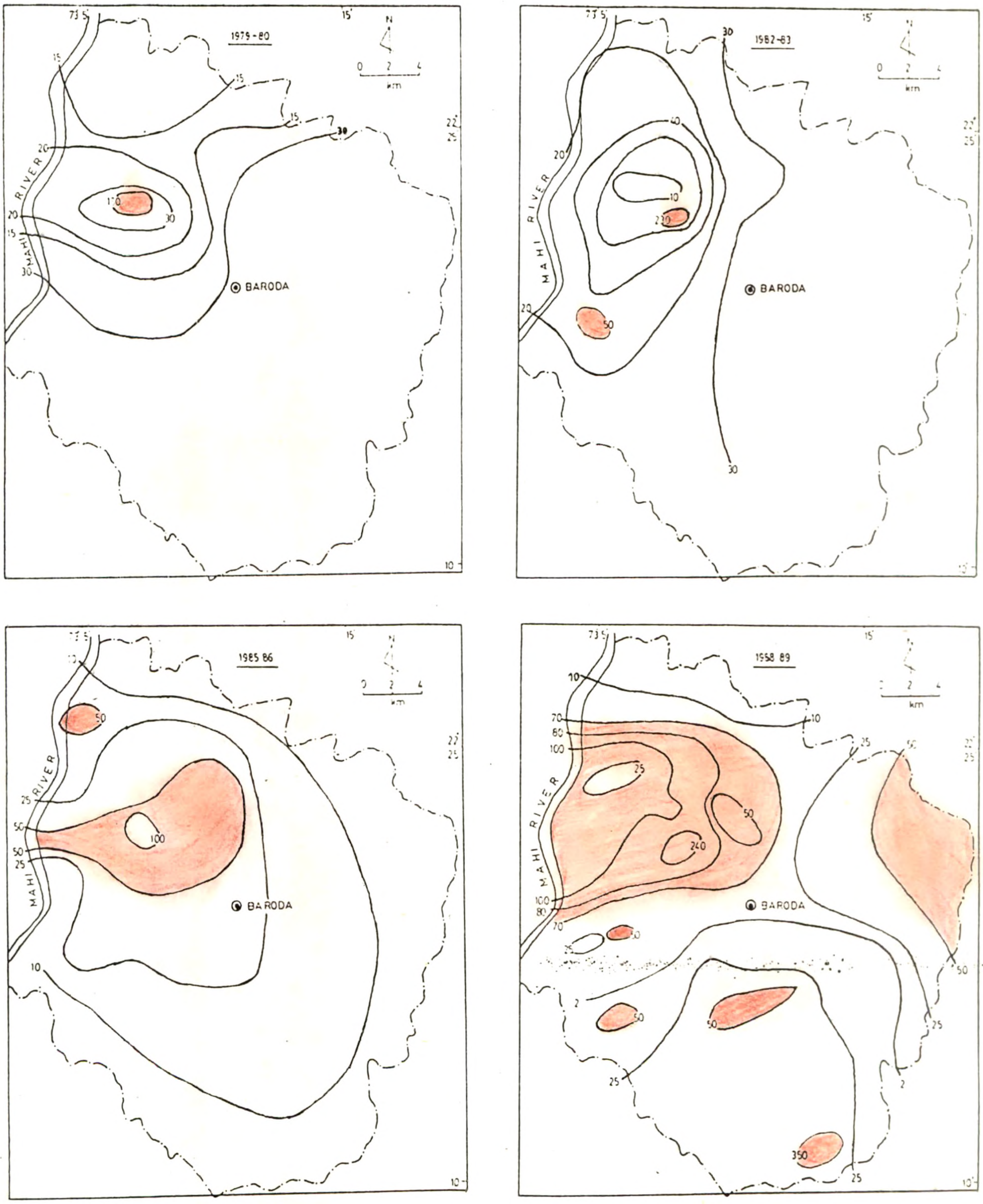


Values exceeding desirable limit.

FIG:-28. CONCENTRATION (mg./l.) OF SULPHATE IN SUBSURFACE WATER (TUBEWELLS) BETWEEN 1979 AND 1989 IN THE STUDY AREA

Values exceeding desirable limit.

FIG:-29. CONCENTRATION (mg/l.) OF NITRATE IN SUBSURFACE WATER (TUBEWELLS) BETWEEN 1979 AND 1989 IN THE STUDY AREA



Values exceeding desirable limit.

FIG : 30

CONCENTRATION OF FLUORIDE (A) (mg/l) IN SUBSURFACE WATER, PRE-MONSOON (B) AND POST-MONSOON (C) (in m) STATIC WATER LEVEL IN THE STUDY AREA (FOR 1988 - 89)

FIG. 31. QUALITY OF SUB-SURFACE (TUBE-WELLS) WATER BETWEEN 1979-80 & 1988-89 IN AND AROUND BARODA CITY

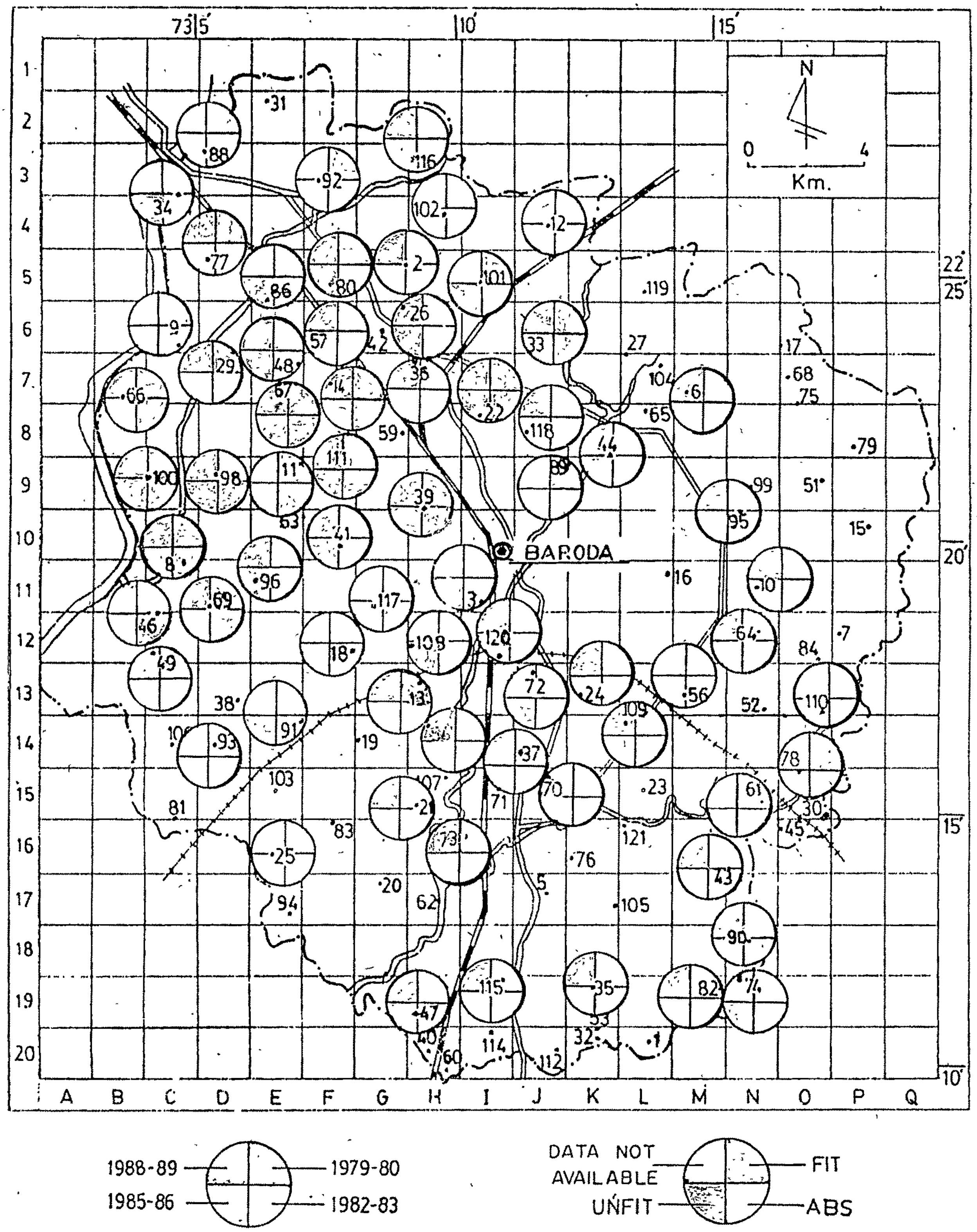


TABLE : 33

COMPARATIVE SUB-SURFACE WATER QUALITY OF THE STUDY AREA

[YEARS 1979-80, 1982-83, 1985-86 AND 1988]

NO.	NAME OF VILLAGE/ TOWN/ LOCATION	REF. NO. [as per Fig. 1]	HEIGHT OF GROUND FROM M.S.L. [m]	STATIC WATER LEVEL [m]		pH [6.5 - 8.5]				TOTAL DISSOLVED SOLIDS [TDS] mg/l [500 - 1500]				TOTAL HARDNESS [AS $CaCO_3$] mg/l [300]				CALCIUM [AS Ca] mg/l [75]			
				PRE-MONSOON	POST-MONSOON																
1	2	3	4	5	6	7				8				9				10			
						A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
2	Ajod	G/5	39	17	16				7.6				846				546^{+}				90^{+}
3	Akota	I/11	33	15	9			7.8	7.7			788	1612^{+}			272	402^{+}			22.4	60
6	Amaliyara	H/7	39	12	11				8.2				1448				162				32
8	Ampad	C/11	32	27	23	8.0	8.2	7.5	8.2	714	982	1001	1188	111	124	396^{+}	656^{*}	17.3	20.8	19.2	54
9	Angadh	C/6	35	25	25	8.0	7.7	8.0	7.9	698	808	770	880	469^{+}	588^{+}	465^{+}	498^{+}	20.4	45.6	30.7	105^{+}
10	Ankhol	N/11	34	12	11				7.8				4934^{*}				1108^{*}				250^{+}
11	Ankodiya	E/9	33	25	19	7.8	7.9	8.1	8.4	610	662	700	702	205	202	305^{+}	368^{+}	26.0	32.8	29.0	36
12	Asoj	J/4	42	12	11	7.7	8.6^{+}	7.7	8.5	350	396	462	632	250	270	290	310^{+}	45.0	49.6	35.0	34
13	Atladara	H/13	32	17	7	7.8	8.4	8.1	7.7	770	872	1412	2994^{+}	105	350^{+}	556^{+}	1054^{*}	24.0	37.6	95.0^{+}	111^{+}
14	Bajwa	F/7	36	23	19	7.5	8.1	8.5	7.5	410	520	1210	1450	260	210	263	460^{+}	26.0	33.0	37.0	44
18	Bhayli	F/12	32	19	19			8.1	8.2			434	894			196	456^{+}			24.0	68
21	Chapad	H/15	27	19	16			7.8	7.3			1296	2264^{+}			500^{+}	882^{*}			46.4	95^{+}
22	Chhani	I/8	34	19	17	7.3	7.9	7.5	7.9	500	594	738	810	250	278	326^{+}	346^{+}	70.0	71.2	61.0	63
24	Danteshwar	K/13	32	4	3				7.5				5018^{*}				1564^{*}				120^{+}
25	Darapura	E/16	29	25	21				8.1				764				402^{+}				79^{+}
26	Dashrath	G/6	37	20	17	7.5	7.5	7.5	8.2	580	660	1320	1500	275	266	518^{+}	250	30.0	24.0	57.0	20
29	Dhanora	D/6	31	26	25	7.9	8.8^{+}	7.9	8.5	650	732	1590^{+}	1922^{+}	65	78	592^{+}	615^{*}	13.0	10.4	41.0	91^{+}
33	Dumad	J/6	39	17	14	7.4	8.4	7.6	7.9	665	694	926	970	103	142	248	301^{+}	21.0	20.8	30.4	34
34	Fajalpur	C/4	32	25	23	7.8	7.9	8.3	8.0	475	584	804	837	315^{+}	324^{+}	376^{+}	460^{+}	45.0	53.6	50.1	60
35	Fatepura	K/19	31	12	9				7.8				3294^{*}				118				26
36	F'nagar	H/7	39	23	17			8.5	8.0			1110	1690^{+}			290	390^{+}			14.4	57
37	G.I.D.C.	J/14	30	11	6				8.2				306				172				34
39	Gorwa	H/9	33	19	18	7.8	7.9	8.2	7.6	320	420	500	680	101	136	214	224	35.0	27.0	41.6	47
41	Gotri	F/10	30	25	25			8.2	7.7			554	1014			192	136			31.0	22

Table : 33 contd.

NO..	MAGNESIUM [AS Mg] mg/1 [30]				CHLORIDE [AS Cl] mg/1 [250]				SULPHATE [AS SO_4] mg/1 [150]				NITRATE [AS NO_3] mg/1 [45]				FLOURIDE mg/1 [0.6-1.2]				OPINION			
1	11				12				13				14				15				16			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
2				77.0+				138				28				84.2*				0.46				UF
3			51.8+	60.0+			114	850+			26	130			13.3	8.9				0.78			ABS	ABS
6				20.0				256				23								1.14				F
8	14.4	17.2	21.0	37.0+	155	188	160	184	30	37	31	5	13.0	31.0	20.0	21.0				0.84	F	F	ABS	UF
9	29.0	31.2+	40.1+	51.0+	105	114	139	172	10	8	9	11			21.2	26.6				0.54	ABS	ABS	ABS	ABS
10				116*				1760*				1040*								1.20				UF
11	19.0	28.8	27.9	31.2+	70	72	39	62		11	16	4	5.3	17.2	18.9					1.01	F	F	ABS	ABS
12	31.0	35.0+	41.2+	54.0+	30	38	98	200			5	4	10.9	13.3	10.9	11.1	0.1			0.54	F	ABS	ABS	ABS
13	11.0	61.4+	76.0+	186+	70	184	478+	606+		32	54	132	23.0	37.7	22.2	13.3				0.88	F	ABS	ABS	UF
14	34.0	30.2	57.4+	60.0+	80	82	128	178	71	82	132	188	6.4	8.8	36.0	124*	0.1			1.44*	F	F	ABS	UF
18			30.9+	68.6+			95	120			11	79			16.6	21.0				0.74			ABS	ABS
21			92.0+	155+			382+	824+			20	22			2.2	4.4				0.82			ABS	UF
22	21.0	24.0	40.0	46.0+	95	104	124	150	35	32	95	83	35.5	37.7	73.1*	48.7*	0.1			0.70	F	F	UF	UF
24				303*				1760*				322+				57.0*				0.70				UF
25				49.0+				166								31.0				0.95				ABS
26	43.0+	49.4+	89.7+	48.0+	75	76	226	354+	11	26	104	78	14.4	17.7	88.6*	93.0*	0.1			0.65	ABS	ABS	UF	UF
29	15.0	12.4	19.0	39.0+	45	88	124	184	12	10	9	51		2.2	4.2	11.1				0.78	F	ABS	ABS	UF
33	21.0	21.6	41.3+	51.0+	50	58	158	175	17	19	66	43		26.6	26.5	71.0*	0.2			0.30	F	F	ABS	UF
34	30.0	45.6+	43.2+	47.0+	51	72	158	166	14		19	34	16.5	17.2	66.5*	2.2				1.46+	ABS	ABS	UF	ABS
35				13.0				704				184+				354*				4.30*				UF
36			61.0+	90.0+			120	215			86	150				40.5				4.10*			ABS	UF
37				21.0				58				6				6.7				0.74				F
39	29.0	23.0	18.2	28.8	17	32	38	88		10	11	23	14.6	11.1						0.20	F	F	F	F
41			27.0	19.0			106	156			61	80			4.4	4.4				1.00			F	F

Table : 33 contd.

1	2	3	4	5	6	7				8				9				10			
						A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
43	Hansajipur	N/17	30	12	10				7.9				1520^{+}				266				35
44	Harni	K/8	36	5	4				7.9				670				212				40
46	Hinglot	C/12	31	28	25	7.9	8.0	7.7	7.5	663	912	970	1350	312^{+}	418^{+}	450^{+}	402^{+}	40.0	49.6	19.7	71
47	Itola	H/19	30	16	14				8.5				226				148				24
48	I.P.C.L.	E/7	36	24	19	7.7	7.6	7.6	8.0	715	900	1270	1958^{+}	414^{+}	498^{+}	$626^{\bullet}$	$1208^{\bullet}$	69.0	107^{+}	85.6^{+}	167^{+}
49	Jaspur	C/12	26	28	25				8.4				1144				178				31
54	Kalali	H/14	32	17	8				7.8				652				154				14
56	Kapurai	N/13	32	5	3				7.8				1736^{+}				148				24
57	Karachia	F/6	36	21	19	7.9	7.3	7.9	7.9	725	922	848	876	270	334^{+}	458^{+}	$660^{\bullet}$	67.0	66.4	52.8	57
61	Kelanpur	N/15	34	12	10				7.9				1622^{+}				550^{+}				51
64	Khatamba	N/12	34	11	9			7.4	7.9			636	2138^{+}			280	$1088^{\bullet}$			40.0	168^{+}
66	Kotna	B/7	29	25	24	7.5	7.9	8.0	7.8	665	966	1324	1196	143	186	547^{+}	$656^{\bullet}$	37.0	31.2	121^{+}	111^{+}
67	Koyali	E/7	36	24	19	7.6	7.5	7.6	7.8	1465	1464	1698^{+}	1652^{+}	$785^{\bullet}$	$818^{\bullet}$	$714^{\bullet}$	$710^{\bullet}$	119^{+}	$220^{\bullet}$	134^{+}	$226^{\bullet}$
69	Mahapura	D/11	32	27	24	7.8	7.9	8.2	7.9	490	596	702	746	122		326^{+}	330^{+}	30.0		43.2	29
70	Makarpura	J/15	28	8	6			8.3	7.7			404	706			208	422^{+}			24.0	112^{+}
72	Manjalpur	J/13	32	8	5			7.8	8.3			824	1520^{+}			196	296			28.0	63
73	Maretha	I/16	25	13	13			7.9	7.6			1690^{+}	2608^{+}			356^{+}	$1102^{\bullet}$			41.3	187^{+}
74	Mastupura	N/19	36	14	12			7.6	8.2			562	590			190	156			36.0	22
77	Nandesari	D/5	35	25	24	7.6	7.6	8.5	8.6^{+}	660	884	1690^{+}	1932^{+}	203	254	279	390^{+}	33.3	42.4	64.0	70
78	Navapura	O/15	43	13	12	7.8	8.2	7.9	7.5	680	700	890	900	105	190	356^{+}	568^{+}	13.0	12.0	54.0	66
80	Padmala	F/5	39	21	19	7.9	8.1	8.3	8.0	650	702	994	1016	196	268	434^{+}	590^{+}	41.0	52.0	69.4	62
82	Patarveni	H/19	36	14	11				8.1				1082				186				46
86	Ranoli	E/5	36	25	25	7.3	7.9	7.9	8.1	670	686	1220	1284	155	250	558^{+}	444^{+}	96.0^{+}	108^{+}	68.0	29
88	Rayaka	D/3	33	23	20	7.5	7.6	7.9	7.8	470	522	597	986	254	304^{+}	325^{+}	598^{+}	37.5	50.4	11.2	120^{+}
89	Sama	K/9	34	5	5			8.3	7.3			886	2316^{+}			274	322^{+}			31.2	65
90	Samastpura	N/18	36	14	12				8.3				868				194				32
91	Samiyala	E/14	28	22	21			8.2	8.5			435	476			194	286			26.0	41
92	Sankarda	F/3	36	19	19	7.8	8.4	7.7	7.6	209	304	600	1090	140	150	356^{+}	502^{+}	21.0	32.0	52.8	77^{+}

Table : 33 contd.

1	11				12				13				14				15				16			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
43				31.0^{+}				392^{+}				55				16.0				$1.9^{\bullet}$				UF
44				27.0				180				8								0.4				F
46	45.0^{+}	70.5^{+}	21.5	34.0^{+}	112	140	80	488^{+}	50	68	21	65	42	$53.1^{\bullet}$	21.2	24.4				0.94	ABS	UF	ABS	ABS
47				21.0				32				4				2.2				0.44				F
48	31.0^{+}	55.2^{+}	98.0^{+}	90.0^{+}	160	174	104	136	90	86	221^{+}	378^{+}	14.4	17.7	35.4	$80.0^{\bullet}$				1.10	ABS	ABS	UF	UF
49				24.0				196				18				13.3				0.44				F
54				28.3				80				8				$50.9^{\bullet}$				0.44				UF
56				21.0				184				5								0.52				ABS
57	70.0^{+}	72.0^{+}	78.2^{+}	$124^{\bullet}$	190	180	110	112		31	35	58	27	26.5		$132^{\bullet}$				1.46^{+}	ABS	ABS	ABS	UF
61				100^{+}				456^{+}				145				2.2				0.84				ABS
64			43.2^{+}	$160^{\bullet}$			94	610^{+}			28	124				2.2				0.32			ABS	UF
66	25.0	25.9	80.0^{+}	91.0^{+}	105	194	239	318^{+}	17	33	25	38	16.6	26.6	35.6	42.1				0.38	F	F	ABS	UF
67	$118^{\bullet}$	64.0^{+}	90.7^{+}	$170^{\bullet}$	215	266^{+}	322^{+}	108		84	60	75	$108^{\bullet}$	15.5	$111^{\bullet}$	$126^{\bullet}$				0.74	UF	UF	UF	UF
69	29.0		52.3^{+}	62.0^{+}	42	36	50	64	21		75	155^{+}	16.5		42.1	$55.3^{\bullet}$				0.84	F	F	ABS	UF
70			35.5^{+}	34.1^{+}			36	148			11	59			6.1	19.2				0.93			ABS	ABS
72			30.0	33.1^{+}			28	540^{+}			8	98			26.6	40.4				0.75			F	ABS
73			64.0^{+}	$112^{\bullet}$			70	834^{+}			20				3.0	8.9				0.38			ABS	UF
74			24.0	24.0			76	90			31	8			13.3	6.6				0.98			F	F
77	29.0	35.5^{+}	40.1^{+}	52.0^{+}	154	174	88	16	70	86	54	36	16.5	17.7	23.2	$100^{\bullet}$				0.99	F	ABS	ABS	UF
78	13.0	13.4	46.0^{+}	46.0^{+}	120	122	72	238		72	11	28		15.5	4.4					1.42^{+}	F	F	ABS	ABS
80	29.0	33.1^{+}	62.4^{+}	40.0^{+}	25	36	212^{+}	112	15	10	109	49	16.5	$46.5^{\bullet}$		$100^{\bullet}$				0.70	F	ABS	UF	UF
82				1.7				164				20				13.3				1.10				F
86	32.0^{+}	33.1^{+}	94.0^{+}	60.0^{+}	90	108	204	29		22	105	76	22.2	$46.5^{\bullet}$	13.3	25.0				0.65	ABS	ABS	UF	ABS
88	36.6^{+}	42.7^{+}	41.0^{+}	82.0^{+}	41	48	196	248	11	13	19	20	11.3	17.7	13.9	11.1				0.99	ABS	ABS	ABS	ABS
89			47.0^{+}	38.0^{+}			108	630^{+}			51	238^{+}			13.3	26.6				0.79			ABS	ABS
90				27.0				80				14				6.7				0.48				F
91			29.0	44.2^{+}			67	120							6.7	6.7				0.69			F	ABS
92	30.0	36.0^{+}	53.6^{+}	74.4^{+}	13	12	34	170			4	26			13.3	21.2				0.78	F	ABS	ABS	ABS

Table : 33 contd.

1	2	3	4	5	6	7				8				9				10			
						A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
93	Sangma	D/14	28	26	25			8.0	8.2			360	1004			262	306+			36.0	43
95	Sayajipura	H/10	40	11	11				7.9				590				362+				96+
96	Sevasi	E/11	32	26	24			7.7	7.3			578	2214+			282	834+			42.0	146+
98	Sherkhi	D/9	36	26	21	7.7	7.8	8.6+	7.9	735	768	1139	1380	463+	588+	651+	658+	30.0	34.0	69.0	104+
100	Sindhrot	C/9	33	26	23	7.4	8.5	8.2	7.8	785	870	1091	1188	108	154	280	292	45.0	25.6	44.0	54
101	Sisva	I/5	40	17	15	7.9	8.2	7.8	8.2	349	396	426	610	154	170	289	390+	57.5	87+	54.0	72
102	Sokhda	H/4	39	16	15			8.3	7.8			704	1300			416+	444+			88+	103+
108	Tandalja	H/12	31	18	9			8.3	7.9			256	1656+			138	286			31.2	48
109	Tarsali	L/14	31	3	3				7.9				1448				704+				123+
110	Tatarpura	O/13	34	13	11			8.4	7.7			1750+	1776+			292	186			42.4	43
111	Undera	F/8	36	21	19	7.8	7.7	7.4	8.0	910	1460	1346	1484	550+	688+	380+	600+	130+	109+	66.0	191+
115	Varnama	I/19	27	11	11			7.6	8.1			2402+	3944+			432+	464+			48.8	70
116	V'koteriya	H/3	34	15	13			7.6	8.1			892	1934+			512+	128			104+	26
117	V'saiyed	G/11	32	19	15	7.8	7.6	7.8	7.9	605	706	720	800	470+	510+	250	292	30.0	38.4	25.6	30
118	Vemali	J/8	38	15	15				8.2				944				224				34
120	V'mitri	I/12	32	12	6				7.8				1456				114				17

Table : 33 contd.

1	11				12				13				14				15				16			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
93			41.3+	47.5+			86	156			14	18				44.3				0.19			ABS	ABS
95				29.0•				62				8				50.9•				0.32				UF
96			43.0	113•			60	648+			10	286+			15.5	13.3				0.80			F	UF
98	25.3	31.2+	38.8+	138•	83	84	90	138			106	234+	20.4	46.5•	60.0•	95.2•				0.90	ABS	UF	UF	UF
100	20.0	21.6	22.1	37.0+	160	170	215	350+	14.6	30	48	25	14.6	17.7	19.0	31.0				1.74•	F	F	F	UF
101	26.5	32.2+	21.9	24.9	75	90	29	38	25	33	32	37	14.2	37.7						0.43	F	ABS	F	ABS
102			47.5+	54.0+			74	452+			55	52				11.1				0.70			ABS	ABS
108			14.4	40.0+			26	440+			21	30				29.2				0.15			F	ABS
109				95.0+				482+				43				15.5				0.43				UF
110			44.6+	19.0			550+	450+			88	17			4.5	26.6				1.44+			ABS	ABS
111	101	99.0+	52.0+	108•	40	76	160	68		92	101	136	32.8	230•	97.0•	240•				1.00	ABS	UF	UF	UF
115			74.0+	104•			820+	1472•			116	476•			4.4	4.4				1.25+			ABS	UF
116			60.4+	15.0			162	892+			26	42			93.0•					0.32			ABS	UF
117	22.0	21.60	44.6+	51.8+	70	96	98	116	15	10	28	31		11.1		2.2				0.94	ABS	ABS	ABS	ABS
118				34.0+				94				41				79.7•				0.44				UF
120				27.0				488+				64				8.9				2.60•				UF

SOURCES : Gujarat Water Resources Development
[Data for the year 1979-80, 1982-83 and 1985-86]

A = Year 1979-80
B = Year 1982-83
C = Year 1985-86
D = Year 1988

\+ = Value relaxable in absence of alternate source.
• = Value exceeding permissible limits as per IS:10500/1983.
F = Water is fit for potable use.
ABS = Water can be used in absence of alternate source.
UF = Water is unfit for potable use.

IS:10,500/1983, if any one water quality parameter exceeds that of ABS limits, then that water is deemed unfit. Further, if any one water quality parameter exceeds that of the desirable limit, then it is deemed potable in the absence of a better alternate source [or ABS] [Table : 32].

GROUNDWATER POTENTIAL :

Groundwater is a renewable resource, subjected to periodic replenishment primarily from precipitation. To have a measure of the quantum of such periodic increment to any groundwater body it is necessary to obtain precise information on the hydrogeological framework of the reservoir, the groundwater regime conditions and the factors governing the recharge to and discharge from the groundwater system.

The Central Ground Water Board has conducted detailed inter-disciplinary and integrated studies on a large number of selected basins for determining the water balance situation. In view of the large variations in the geological framework, lithological character of the wide range of rock units, hydrometeorological conditions, etc. the basins selected were typical of the region [Charlu and Dutt, 1982]. These major studies were spread upto various parts of the country and included, amongst others, the type areas of the peninsular hard rocks, the alluvial sediments of a part of Sindhu-Ganga basin and Rajasthan-Gujarat region.

For carrying out groundwater development programmes in an effective manner, it is desirable to have an idea of available groundwater potential at any given point of time. Detailed methods are based on appreciation of the acquifer parameters, etc. obtained through long duration aquifer tests. However, in the absence of knowledge of these parameters in precise terms, importance is generally given to determine the replenishable component of recharge on annual basis. The two approaches currently in vogue are [1] the water balance approach, and [2] water-table fluctuation/ specific yield approach.

For the study area the water table fluctuation/specific yield approach is found most suitable.

Water Table Fluctuation/Specific Yield Approach :

Groundwater levels rise due to rainfall or any other source of recharge. The rise during the monsoon period is, by and large, attributable to the increment to the groundwater body due to rainfall. In other words, the magnitude of the rise is in a way a measure of the recharge to the groundwater, which amongst other things is dependent on the specific yield of the formation materials comprising the zone of saturation.

From this, periods of recharge, and periods of groundwater discharge could be found out. Recharge due to rainfall could be made out from the general relation [Charlu and Dutt, 1982] :

$$R = A \times Sy \times [h_1 - h_2]$$

where

R = recharge due to rainfall

A = area under evaluation [714 sq.km. in the case of the study area]

Sy = Specific yield of the aquifer. The specific yield values for different types of geological formations in the zones of fluctuations of water table are as below [ARDC III, 1979] :

[i]	sandy alluvial areas	:	12 to 18%
[ii]	silty alluvial areas	:	06 to 12%
[iii]	granites	:	03 to 04%
[iv]	basalt	:	02 to 03%

For the study area, [i] is of relevence and can be used.

h_1 and h_2 = Monsoon and pre-monsoon groundwater levels respectively. In the case of the study area it is a generalised 1.5 m.

The estimation of recharge to groundwater by this method is as follows :

R = A [714 sq.km.] x Sy [18/100] x $h_1 - h_2$ [1.5 m]

= 192 MCM/year ..... [1]

In order to supplement the above value [1], the rainfall infiltration method [ARDC III, 1978] has also been used :

Recharge = Total area x 25% of annual rainfall
= 714 sq.km. x 25% of 950 mm
= 170 MCM/year ..... [2]

Further information has been done by using the Chaturvedi formula [in ORG, 1989].

R_p = 2.0 $[R-15]^{2/5}$ x Area under evaluation

where

R_p = Total recharge

R = Annual rainfall

R_p = 2.0 $[950 - 15]^{2/5}$ x 714

= 214 MCM/year ..... [3]

In short, the mean average of the values [1], [2] and [3] is 192 + 170 + 214 = 576/3 = 192

Thus the value of 192 is the same as the value derived by the water table fluctuation method. The annual recharge for the study area is 192 MCM/year.

GROUNDWATER DRAFT :

The groundwater draft for all types of structures [tube wells, dug wells, dug cum bore wells etc.] have been calculated taking the report given by the group on the Estimation of Groundwater Resource and Irrigation Potential from Groundwater in Gujarat State [1986]. Proposed fixed norms of draft for different structures is as follows :

Draft :

0.0037 MCM/year for dug wells
0.018 MCM/year for borewells in alluvium
0.100 MCM/year for tube-wells [private and government]

These draft rates have been estimated from their running records and have been compiled taluka-wise [GWRDC, 1986].

[a] **Draft from dug wells :**

Total number of dug wells in the area = 500
[Source : GWRDC, 1988]

Draft = 500 x 0.0037 = 1.8 MCM/year ..... [4]

[b] **Draft from bore wells :**

Total number of bore wells in the area = 2000
[Source : Baroda Municipal Corporation and Vadodara Urban Development Authority, 1988]

Draft = 2000 x 0.018 = 36 MCM/year ..... [5]

[c] **Draft from tube wells :**

Total number of tube wells in the area = 60

[Source : GWRDC and Baroda Municipal Corporation, 1988]

Draft = 60 x 0.100 = 6 MCM/year ..... [6]

[d] **Draft from French-wells at Mahi :**

Total number of French-wells in the area = 8
[6 industrial and 2 for domestic purposes]

Draft of each French-well is 0.045 MCM/day

[Source : Baroda Municipal Corporation]

Draft = 8 x 0.045 = 128.48 MCM/year ..... [7]

[e] **Surface Water from Ajwa Reservoir :**

Ajwa supplies 45.7 million litre of water per day to Baroda city [Source : Baroda Municipal Corporation].

i.e. 45.7 x 365 = 16 MCM/year ..... [8]

Total calculated water draft = [4]+[5]+[6]+[7]+[8] = 188.28 MCM/year ..[9]

Considering the water quality and groundwater pollution in the study area wherein nearly 42% of the wells are polluted [where one or more water quality parameter exceed the required limit], the difference in actual available pure drinking water is bound to be drastically less than calculated water draft which is 188.26 MCM/year [Equation : 9].

From the field observations, it has been seen that out of 500 dug wells in the study area, 166 dug wells are polluted; out of 2000 bore wells, 600 are polluted; and out of 60 tube-wells, 5 tube-wells are polluted. Thus the actual pure water draft available is as follows :

[a] **Draft from dug wells :**

Total number of fit dug wells = 334

Draft = 334 x 0.0037 = 1.2 MCM/year ..... [10]

[b] **Draft from bore wells :**

Total number of fit bore wells = 1400

Draft = 1400 x 0.018 = 25.2 MCM/year ..... [11]

[c] **Draft from tube wells :**

Total number of fit tube wells = 55

Draft = 55 x 0.1 = 5.5 MCM/year ..... [12]

Total available pure groundwater draft = [10] + [11] + [12]
= 31.9 MCM/year ..... [13]

DOMESTIC AND INDUSTRIAL WATER DEMAND :

The Environmental Hygine Committee [1987, New Delhi], in the Code of Basic Requirements of Water Supply, Drainage and Sanitation [IS:1172-1971], and the National Building Code [from Manual on Water Supply and Treatment, 2nd Edition, New Delhi, 1984] have recommended certain water requirements for domestic, non-domestic, industrial, cattle, etc. taking into account the feasibility and minimum needs.

TABLE : 34

DOMESTIC, INDUSTRIAL AND CATTLE, WATER DEMAND IN THE STUDY AREA
[FOR 1981, 1988, 1991 AND 2001]

Sr. No.	Year	Cattle population	Cattle demand [15 l/head/ day] in MCM/year	Rural population	Rural demand [55 l/head/ day] in MCM/year	Urban population	Urban demand [140 l/head/ day] in MCM/year	Total demand 4 + 6 + 8 in MCM/year	Industrial demand at 10% of a total demand in MCM/year	Grand total demand 9 + 10 in MCM/year
1	2	3	4	5	6	7	8	9	10	11
1	1981	50,000	0.27	2,55,400	5.1	7,65,175	39.0	44.3	4.4	48.80
2	1988	59,000	0.32	4,34,104	8.7	10,65,934	54.3	63.3	6.3	69.62
3	1991	60,000	0.32	5,10,692	10.0	11,94,831	61.0	71.3	7.1	78.40
4	2001	60,000	0.32	79,174	1.6	18,68,464	95.0	96.9	9.6	106.60

Source : Cattle Population : District Statistical Report, 1981, 1988.
Rural & Urban Population : Census of India, Gujarat, Dist. Baroda, 1981.
Population projection have been done on the basis of growth rate as per Census 1971 and 1981.

Requirements

urban [human]	:	140 L/Head/Day
rural [human]	:	055 L/Head/Day
cattle	:	015 L/Head/Day
industries	:	10% of total urban human, rural human and cattle requirements.

Table : 34 shows the overall water demand for the study area for the years 1981, 1988, 1991 and 2001. The projected requirement for 2001 is more than double than that of 1981.

AGRICULTURAL WATER REQUIREMENT :

The net irrigation water requirement for each district and taluka in Gujarat has been worked out by Gujarat Water Resources Development Corporation [1974-1979], depending on the depth of irrigation, types of crops in various seasons and intensity of irrigation. The data pertaining to the net irrigation water requirement in the study area [714 sq.km.] is 0.5 MCM/year [GWRDC, 1981]. This requirement would go down with passage of time, as more and more agricultural land would fall prey for either industrial or urban usage.

WATER BUDGET :

Depending on the above mentioned data and facts, an attempt has been made to work out the water budget for the year 1988, and projections for the years 1991 and 2001 [Table : 35].

The 1988 water draft for projection purposes has been kept as a constant, since it would be risky to hazard a guess as to how many dug wells, tube wells, etc. would be dug in the future.

The projections for the overall population growth rate has been made

TABLE : 35

A COMPARISON OF EXISTING AND PROPOSED WATER BUDGET IN THE STUDY AREA

	1988	1991	2001
[A] Availability of pure drinking water in MCM/year			
1. Dug well [10]	1.20	-	-
2. Bore well [11]	25.20	-	-
3. Tube well [12]	5.50	-	-
4. French well [7]	16.00	-	-
5. Ajwa reservoir [8]	16.00	-	-
6. Total	63.90	-	-
[B] Water demand in MCM/year			
1. Urban [Human]	54.30	61.00	95.00
2. Rural [Human]	8.70	10.00	1.60
3. Cattle	0.32	0.32	0.32
4. Irrigation	0.50	0.50	0.50
5. Industrial	6.30	7.10	9.60
6. Total	70.12	78.90	107.00
[C] Susplus/Deficit [in MCM/year] [A_6 - B_6]	6.2(-)	15.0(-)	43.1(-)

from data in the Census of India [Baroda district, 1971, 1981; Table : 10].

Column A shows the structure-wise draft of pure drinking water in the study area for the year 1988. The total available draft is 63.9 MCM/year.

Column B shows the structure-wise water demand for the years 1988, 1991 and 2001. The 6.2 MCM/year deficit shown for the year 1988, more than doubles in 1991, while the deficit for the year 2001 is more than 7 times. Of course, the total available draft has been kept as a constant. Despite this, the future demand for water poses one of the largest geo-environmental problems as [i] the Mahi river bed at Fajalpur, which is the potential large scale water supplier for the future, is effected by tidal ingress and pollution as discussed earlier, [ii] the number of present tube-wells and dug wells which are polluted, do not form a future source for water, unless drastic measures are taken to stop pollution, via. indiscriminate effluent dumping.

Summing up, it will require stringent measures to stop the pollution of ground and surface waters, which are so essential for the sustenance of the society as a whole.