GROUND WATER BALANCE OF JAMNAGAR DISTRICT

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ABSTRACT

With the ever increasing demand of water and inadequate surface water in drought prone areas, more attention is given on ground water reserve. The present study forms a part of the development of a model to forecast the availability of drinking water in Jamnagar district. Drinking water availability has to be assessed both from surface water sources and from ground water reserve. The ground water balance study has been carried out for Jamnagar district for the period 1981-82 to 1985-86 and the percentage of rainfall that gets recharged to the ground water storage, has been estimated from the water balance study

1.0 INTRODUCTION

Ground water balance is carried out for a quantitative evaluation of ground water resources and their change under the influence of man s activities. The study of water balance in a ground water basin forms a basis for the rational use, control and redistribution of ground water resources in time and space. Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of ground water basins With water balance data, it is possible to compare individual sources of water in a system over different periods of time, and to establish the degree of their effect on variations in the water regime. Further, the initial analysis used to compute individual water balance components, and the coordination of these components in the balance equation, make it possible to identify deficiencies in the distribution of observational stations and discover systematic errors of measurement. Finally, water balance study enables evaluation of one unknown component of water balance from all other known components.

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2.0 DESCRIPTION OF THE STUDY AREA

The district of Jamnagar lies between 21°47 and 22°57 north latitudes and 68°57 and 70°37 east longitudes in the peninsular region known as Saurashtra in the north-west of Gujarat. In the north the district is bounded by the Gulf of Kutch and the Rann of Kutch, on the east by Rajkot district, on the south by Junagadh district and on the west by the Arabian Sea. The geographical area of the district is 10143 sq.km. The location of Jamnagar district in Gujarat state is presented in figure 1.

The district has an uneven topography broken at places by hill ranges, the Rann in the north-east and ranges of sand dunes along the coast on the north and west. In general, the district can be divided into three physical regions namely (i) the hills, (ii) the coastal plains, including the islands offshore and (iii) the plains.

The principal hill ranges are the Barda hills and the isolated hill of Gop. The district has about 351 km. coast, of which 93 km. from Meda creek to Okha tidal station are washed by the Arabian Sea in the west, while the rest 258 km. form the front of the Gulf of Kutch in the north. The district does not have any large perennial stream. Most of the rivers are small and flow lazily through the low lying lands into the marsh and sand of the sea. The district is drained from south to north and from south-east to north-west to the Gulf of Kutch. The principal rivers are the Aji, Und, Vartu, Venu, Ghee, Rangmati, Nagmati, Fulzar, Phuljar, Sasoi, Sihan, Ruparel, Demi and Jhijhora as shown in figure 2.

The climate of the district is characterized by four seasons, namely summer, monsoon, autumn and winter. The south-west monsoon season begins in the month of June and goes upto September. The temperature rises steadily in the district from March to May. The average maximum daily temperature during May is 36.3°C. In the western coastal region, the maximum temperature recorded in the district is 44.4°C and the minimum temperature 17.0°C. The relative humidity of the air is about 80 % during the south-west monsoon and about 60 to 75 % in the rest of the year. The evaporation and evapotranspiration losses in the district vary between 245.4 mm per month in summer and 94.4 mm per

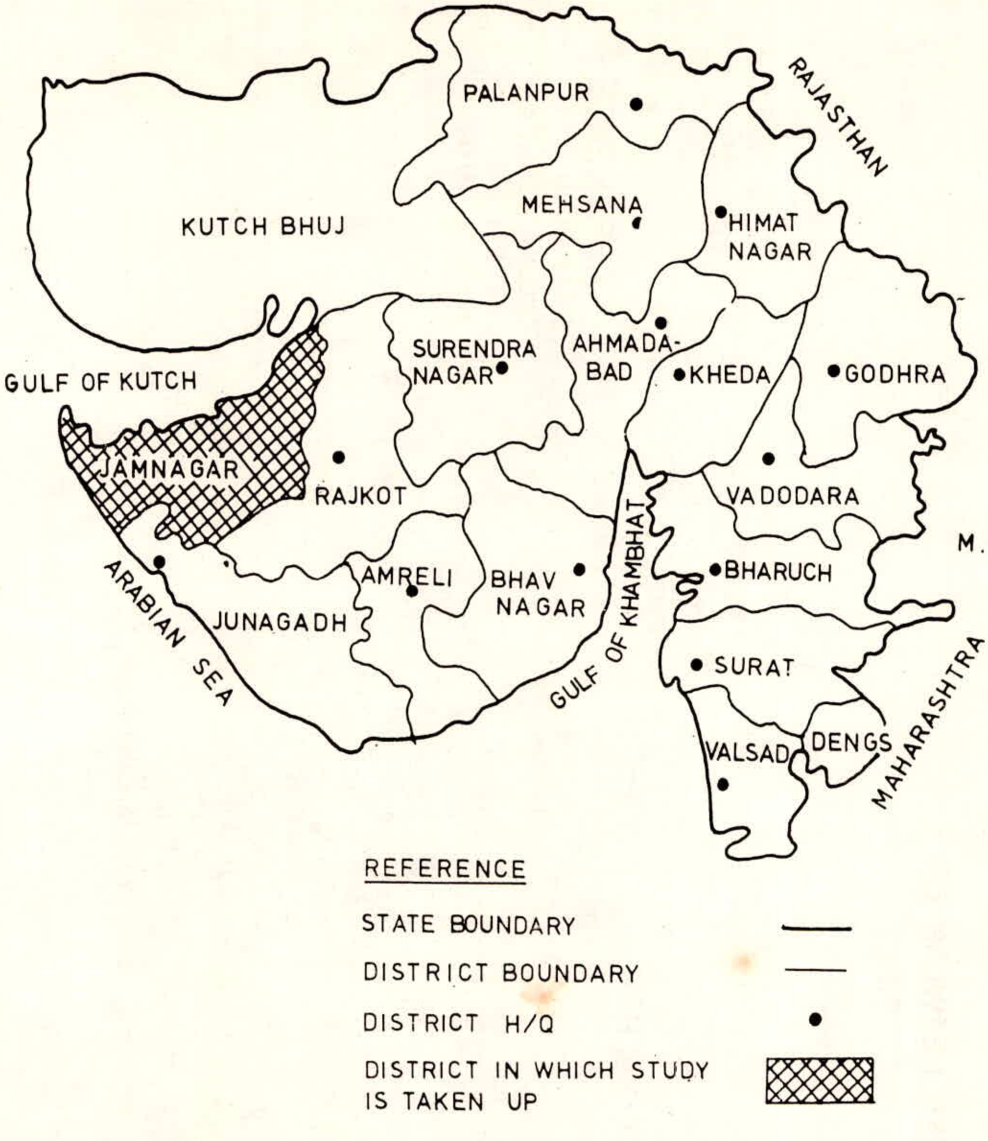

FIG. 1 – INDEX MAP SHOWING JAMNAGAR DISTRICT IN STATE OF GUJARAT

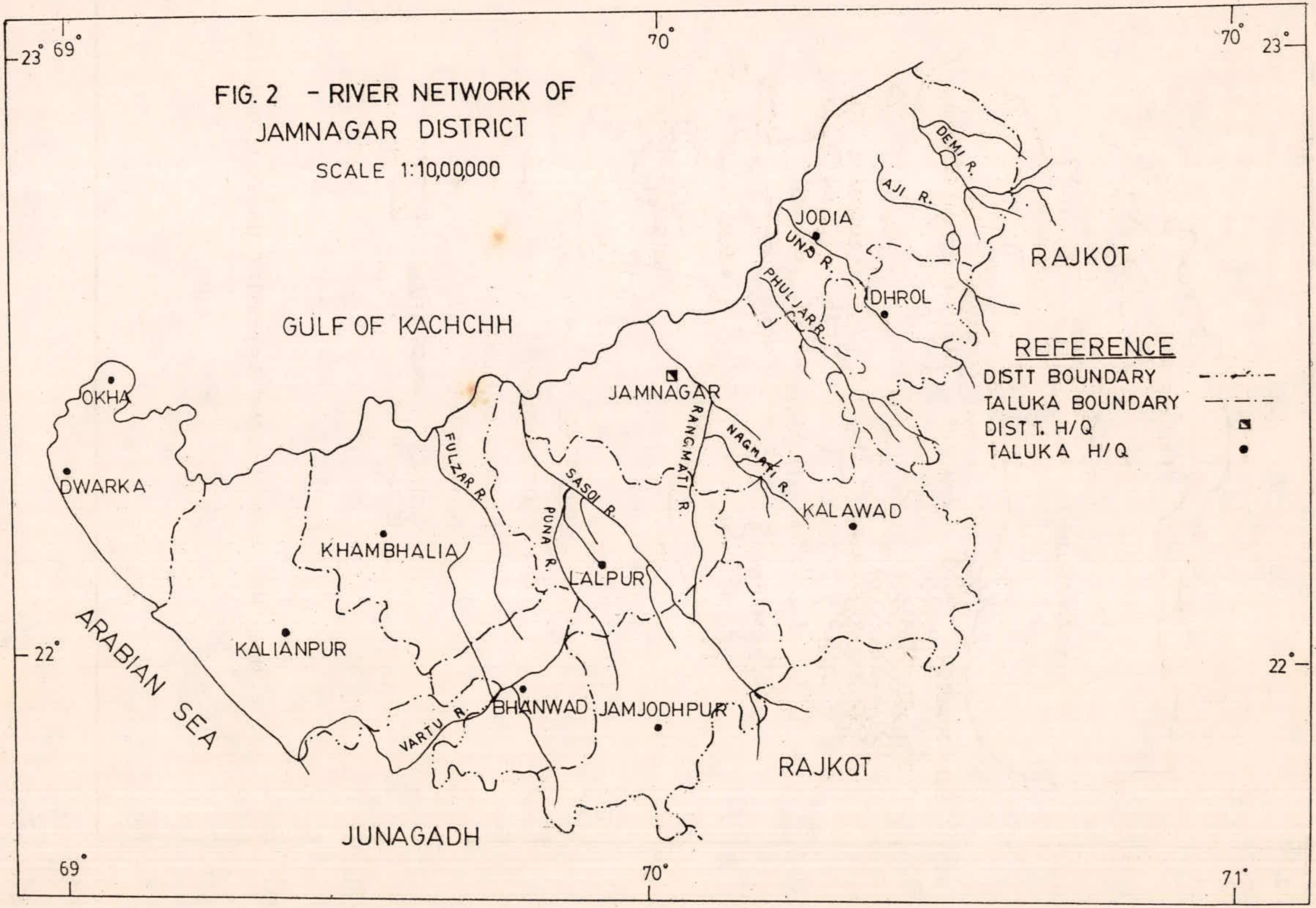

FIG. 2 - RIVER NETWORK OF JAMNAGAR DISTRICT

SCALE 1:10,00,000

month in the winter season.

The district receives rainfall mainly from south-west monsoon with an annual average rainfall of 459.60 mm. It has been estimated that around 93 % of the annual rainfall takes place during monsoon season. The rainfall is erratic and not dependable. The total water resources of the district comprise both the surface water and the ground water resources. The locations of raingauge stations and observation wells in Jamnagar district are presented in figure 3 and 4 respectively

3.0 COMPONENTS OF GROUND WATER BALANCE EQUATION

The basic concept of water balance is:

Inflow to the system-Outflow from the system = Change in storage of the system, over a period of time.

Considering the various inflow and outflow components, the terms of the ground water balance equation can be written as:

$$R_i + R_c + R_r + R_t + I_g + S_i = T_p + E_t + O_g + S_e + \Delta S$$

where,

R_i = recharge from rainfall;

R_c = recharge from canal seepage;

R_r = recharge from field irrigation

= R_{rs} + R_{rg}

R_{rs} = recharge from surface water irrigation,

R_{rg} = recharge from ground water irrigation;

R_t = recharge from reservoirs and tanks;

I_g = sub-surface inflow to the study area;

S_i = influent seepage from rivers;

T_p = draft from ground water;

E_t = evapotranspiration losses,

= E_{tf} + E_{tw},

E_{tf} = evapotranspiration losses from forested area,

E_{tw} = evapotranspiration losses from water-logged area;

O_g = sub-surface outflow from the study area;

S_e = effluent seepage to rivers; and

ΔS = change in ground water storage (positive for increase and negative for depletion)

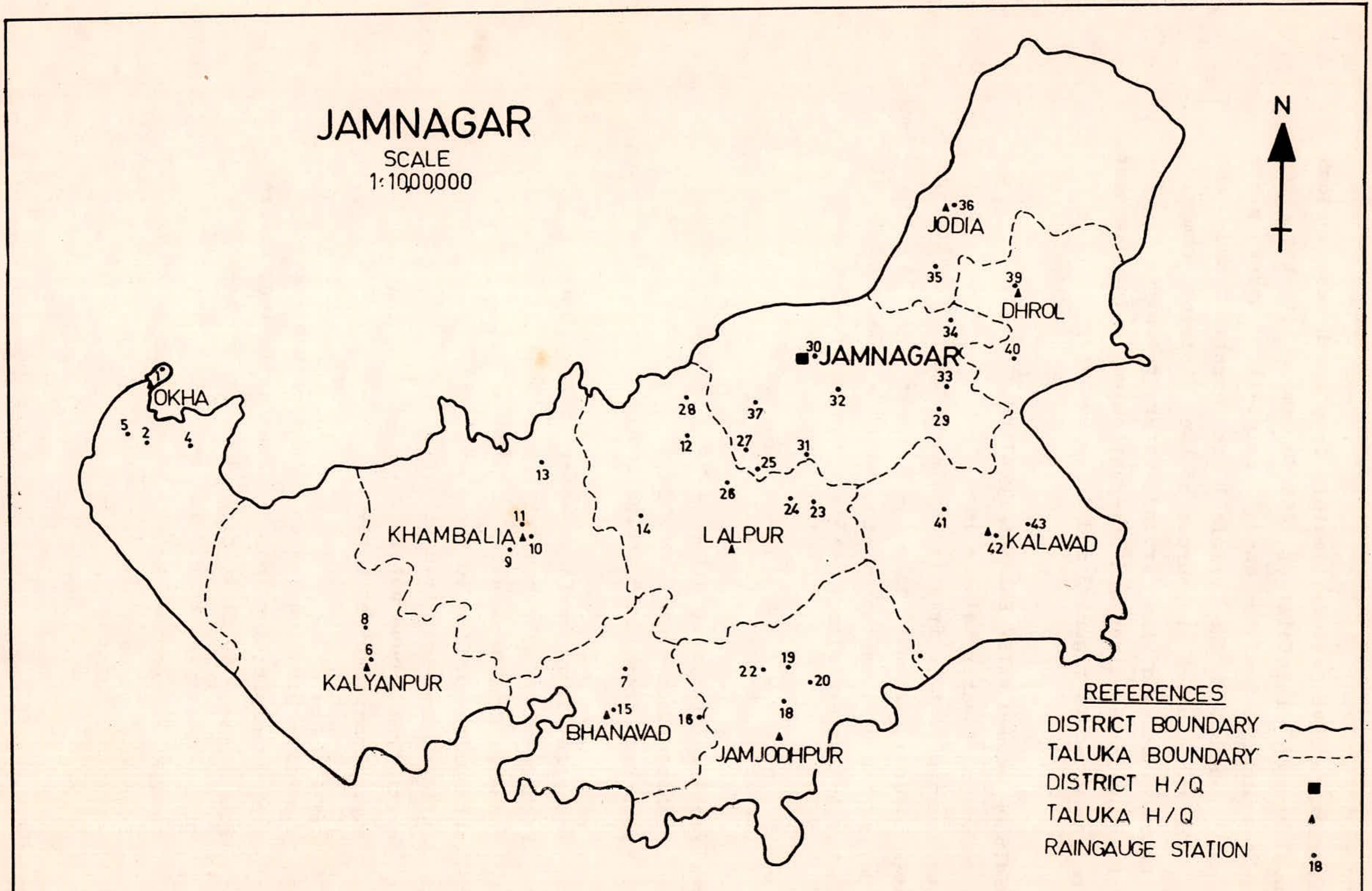

FIG. 3 : LOCATION OF RAINGAUGE STATIONS IN DISTRICT JAMNAGAR

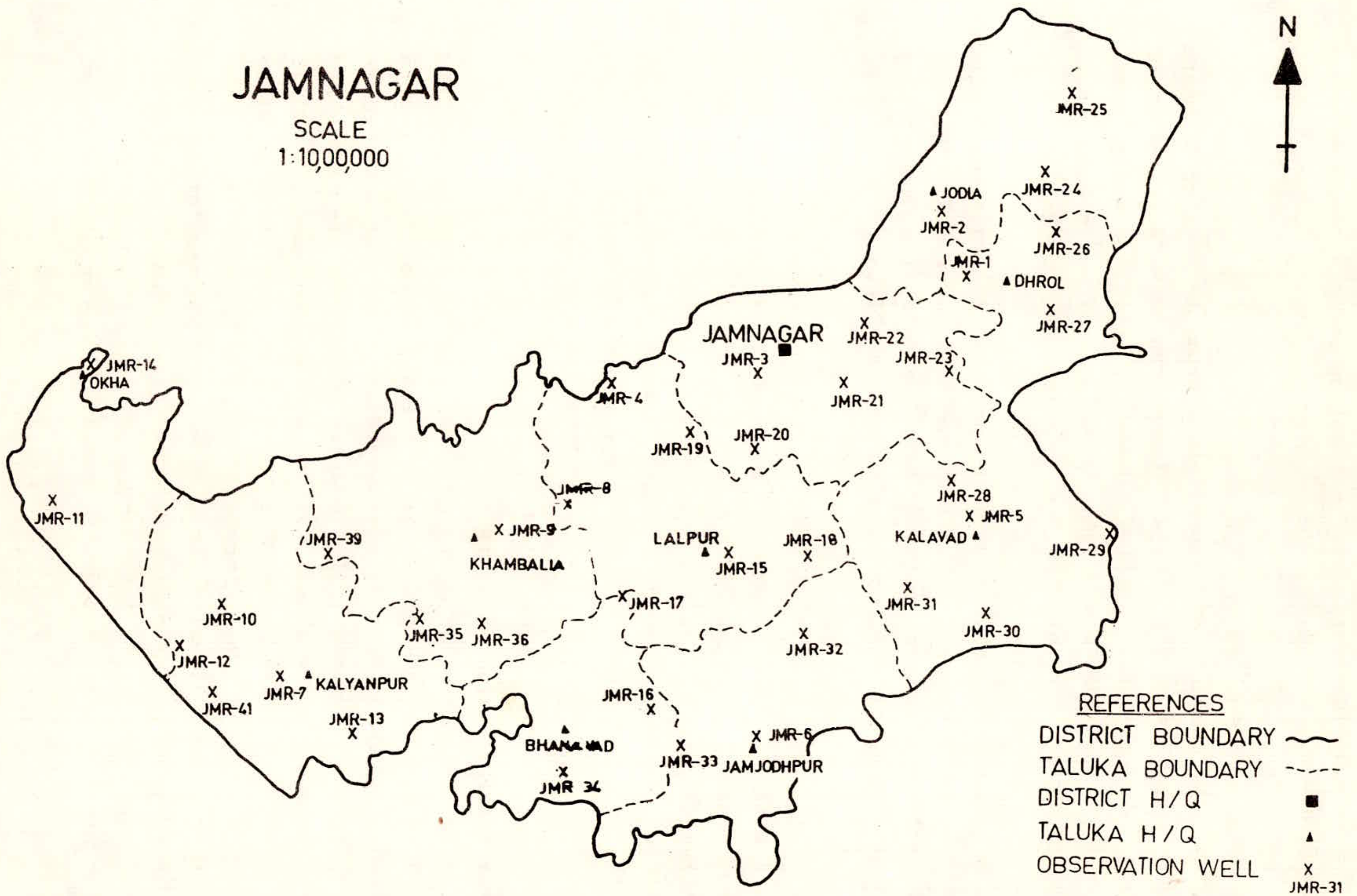

FIG. 4 -LOCATION OF OBSERVATION WELLS IN DISTRICT JAMNAGAR

The estimation of the various outflow and inflow components and the methodology adopted for estimating each component are discussed below.

3.1 Draft from Ground Water (T_p)

Draft is the amount of water lifted from the aquifer by means of various lifting devices.The withdrawal can be made by means of (i) deep tubewells, (ii) shallow tubewells, (iii) pumping sets, (iv) rahats and other means. An inventory of wells and sample survey data are pre-requisites for computation of ground water draft.

The data pertaining to number and type of devices are available for the period 1981-82 to 1984-85. For 1985-86, the growth rate has been assumed as 2.5 %. The following values of unit draft have been adopted (as given by GWRDC Ltd.):

Dug well = 0.0037 MCM/Year,

Dug well with pump set (alluvium) = 0.018 MCM/Year ;

Dug well with pump set (hard rock) = 0.012 MCM/Year ,

Shallow tubewell = 0.001 MCM/Year ,

Deep tubewell = 0.05 MCM/Year.

Hence, the yearly draft is computed by multiplying unit draft with the number of devices of each type. Seasonal draft values for monsoon and non-monsoon seasons have been taken as 20 % and 80 % respectively of the yearly draft values.

3.2 Evapotranspiration Losses (E_t)

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from the plants will be at the maximum possible rate i.e. at potential rate. This potential evapotranspiration will take place in a water-logged tract due to the rise in the water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone.The evapotranspiration from such area can be worked out by usual methods of computing evapotranspiration using the known data.

Since the present study area does not have any significant forested area, the evapotranspiration losses from forested areas (E_{tf}) have been taken as zero. Also from the observed water level data, it was found that depth to water table below ground level was more than 2.0 metre throughout the study area. Therefore, considering no water-logged area, the evapotranspiration losses from water-logged areas (E_{tw}) have also been taken as zero.

3.3 Effluent and Influent Seepage (S_e and S_i)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent).
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reaches and computations made for each segment. For every reach, at least one observation station nearest to the middle of reach has been selected. The hydraulic gradient is computed as ratio of the difference between the river stage at the point where the normal from the observation well meets river and the water level in the observation well, to the distance between the points under reference. Similarly observation wells are taken on the other side of the river and the hydraulic gradients computed. Transmissivity of the aquifer has been taken as 110 m^2/day as provided by GWRDC Ltd., Gandhinagar. The effluent or influent seepage has been estimated as:

$$S_e (\text{or } S_i) = \Sigma\, T I \Delta L$$

where, T is the transmissivity, I is the hydraulic gradient and ΔL is the length of the reach. By considering proper signs, the influent and effluent seepages have been estimated for all rivers coming in the study area.

3.4 Sub-surface Inflow and Outflow (I_g and O_g)

Sub-surface inflow and outflow is governed mainly by the hydraulic gradient and the transmissivity of the aquifer The boundary of the study area is divided into small segments and the gradient of water table is determined by using the ground water levels near the boundary for each segment. Net flows are estimated for each segment by using the relationship

$$I_g (\text{or } O_g) = Ti\Delta L$$

where, I_g is the discharge passing through a particular segment, T is the transmissivity, i is the hydraulic gradient averaged over a length ΔL and ΔL is the length of the segment concerned. To get the total discharge passing across the study area boundary, the discharge values for each segment are summed up

3.5 Recharge from Canal Seepage (R_c)

Seepage refers to the process of water movement from a canal into and through the bed and wall material. Seepage losses from surface water bodies often constitute a significant part of the total recharge to ground water system. Hence, it is important to properly estimate these losses for recharge assessment to ground water system

The data related to running days in monsoon and non-monsoon seasons for canals in the study area are available for the study period However, wetted areas for different irrigation schemes are available for the year 1984 only Therefore, the same values of wetted areas have been adopted for other years also. Assuming seepage factor to be 2.5 cumecs/million square metres of wetted area, the recharge from canal seepage in monsoon and non-monsoon seasons for different irrigation schemes have been estimated as:

Recharge from canal seepage = Seepage factor x Wetted area x Running days.

3.6 Recharge from Field Irrigation (R_r)

Water requirements of crops is met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated fields for growing crops is lost in consumptive use and the balance infiltrates to recharge the ground water. Infiltration from applied irrigation water, derived both from ground water and surface water sources, constitutes one of the major components of ground water recharge. For a correct assessment of the quantum of recharge by applied irrigation, studies are required to be carried out on experimental plots under different crops, in different seasonal conditions.

(a) Recharge from surface water irrigation (R_{rs})

Recharge from surface water irrigation has been taken as 35 percent of water delivered for application in the field. Data on irrigated areas in monsoon and non-monsoon seasons are available for the study period. Average water depths are available for the year 1984 and the same are assumed for other years also. Recharge from surface water irrigation is; then computed as:

Recharge from surface water irrigation = Seepage factor x Area irrigated x Average water depth.

(b) Recharge from ground water irrigation (R_{rg})

Recharge from ground water irrigation has been taken as 40 percent of the water delivered (i.e 40 percent of the ground water draft)

3.7 Recharge from Reservoirs and Tanks (R_t)

Studies have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity However,as data on live storage capacity of large number of tanks may not be available, the seepage from the tanks may be taken as 44 to 60 cm per year over the total water spread. For the present study, seepage factor has been taken as 36.67 mm/month (corresponding to 44 cm/year).

Monthly water level data for tanks are available for the study period. The corresponding water spread areas have been estimated from the area-elevation curves available. Then the monthly recharge values are computed by multiplying the seepage factor with the water spread areas.

3.8 Change in Ground Water Storage (ΔS)

The change in ground water storage is an indicator of the long term availabilities of ground water. The change in ground water storage between the beginning and end of the non-monsoon season indicates the total quantity of water withdrawn from ground water storage, while the change between the beginning and end of monsoon season indicates the volume of water gone into the ground water reservoir. During the monsoon season, the recharge is more than the extraction and hence the ground water storage increases, which can be utilized in the subsequent non-monsoon season.

To assess the change in ground water storage, the water levels are observed through a network of observation wells spread over the area, as shown in figure 4. The water levels are highest immediately after monsoon in the month of October or November and lowest just before monsoon in the month of May or June. The change in ground water storage can be computed from the following equation :

$$\Delta S = \Sigma \Delta h A S_y$$

where,

ΔS = change in ground water storage,

Δh = change in water level,

A = area influenced by the well under consideration, and

S_y = specific yield.

For the present study, pre-monsoon and post-monsoon water level data are available for the study period. Thiessen polygons have been drawn for the observation wells and the change in ground water storage in monsoon and non-monsoon seasons have been estimated by using the above relation. The values of specific yield were used as provided by GWRDC Ltd., Gandhinagar.

3.9 Recharge from Rainfall (R_i)

Part of the rain water, that falls on the ground, is infiltrated into the soil. This infiltrated water is utilized partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions, nuclear methods and the water balance approach.

The monthly rainfall data is available for 24 raingauge stations in the study area. Thiessen polygons have been drawn and mean seasonal rainfall values are computed for the study period. The recharge to ground water from rainfall is estimated by water balance approach. In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information.The rainfall recharge for monsoon season is calculated by substituting these estimates in the water balance equation. Recharge coefficient i.e. recharge per unit rainfall is thus estimated. Since most of the rainfall occurs in the monsoon season only, it is assumed that in non-monsoon season,all the rain water is used by the crops and absorbed in the soil moisture zone with no recharge to ground water reservoir. Hence the recharge from rainfall has been taken as zero in the non-monsoon season.

4.0 GROUND WATER BALANCE

Water balance study for monsoon (June to October) and non-monsoon (November to May) periods is carried out separately. The former yields an estimate of recharge coefficient and the latter determines the degree of accuracy with which the components of water balance equation have been estimated.

Substituting all other components in the ground water balance equation, the recharge from rainfall has been calculated for monsoon seasons of the study period and shown in table 1. Recharge coefficients (based upon the rainfall in monsoon season) are also calculated for the monsoon seasons of the study period and given as recharge/rainfall ratio. These are found to vary from 0.02 to 0.04 for the study area For non-monsoon seasons, unaccounted water has been computed as (Inflow-outflow-change in ground water storage), the discrepancy being less than 40 MCM in all cases. Keeping in view the large study area (around 10,000 sq km.) and the total quantity of water involved, this amount of unaccounted water seems to be quite reasonable and within limits.Therefore, overall water balance can be considered to be in order, although individual components may have some errors.

TABLE 1 - GROUND WATER BALANCE OF JAMNAGAR DISTRICT

S.No.	Component	1981-82 Monsoon	1981-82 Non-monsoon	1982-83 Monsoon	1982-83 Non-monsoon	1983-84 Monsoon	1983-84 Non-monsoon	1984-85 Monsoon	1984-85 Non-monsoon	1985-86 Monsoon
1.	Draft from Ground Water	86.78	347.10	89.00	356.03	91.29	365.15	93.63	374.53	97.08
2.	Evapotranspiration Losses	0	0	0	0	0	0	0	0	0
3.	Net Outflow to other Areas	-0.53	-0.74	-0.16	-0.37	-0.86	-0.41	-0.65	3.37	2.99
	(A) Outflow=(1)+(2)+(3)	86.25	346.36	88.84	355.66	90.43	364.74	92.98	377.90	100.07
4.	Seepage Losses from									
	(a) Canals and Distributories	3.76	21.59	4.14	14.99	2.24	18.55	3.21	13.23	0.52
	(b) Surface Water Irrigation	10.71	60.47	8.78	38.63	3.43	45.61	7.52	45.71	0.00
	(c) Ground Water Irrigation	34.71	138.84	35.60	142.41	36.52	146.06	37.45	149.81	38.83
	(d) Reservoirs and Tanks	5.29	7.03	5.14	5.59	6.26	5.25	4.50	4.73	2.52
5.	Net Influent Seepage	4.81	7.46	5.25	6.83	4.97	6.47	4.06	4.22	2.02
	(B) Inflow = (4)+(5)	59.28	235.39	58.91	208.45	53.42	221.94	56.74	217.70	43.89
6.	Change in Ground Water Storage	143.35	-95.02	53.00	-110.94	149.25	-169.04	121.35	146.09	-7.48
7.	Rainfall	7415.20	613.99	3206.26	25.76	9138.89	0.00	3971.79	17.85	1823.80
8.	Recharge from Rainfall = (6)+(A)-(B)(Monsoon)	170.32	0.00	82.93	0.00	186.26	0.00	157.59	0.00	48.70
9.	Recharge Coefficient = (8)/(7) (Monsoon)	2.30%		2.59%		2.04%		3.97%		2.67%
10.	Unaccounted Water = (B)-(A)-(6)(Non-monsoon)		-15.95		-36.27		+26.24		-14.11	

5.0 CONCLUSIONS

Water balance approach, essentially a lumped model study, is a viable method of establishing the rainfall recharge coefficient and for evaluating the methods adopted for the quantification of recharge and discharge from other sources. The present study has been conducted to obtain the seasonal ground water balance (monsoon and non-monsoon) for the period 1981-82 to 1985-86 for the Jamnagar district. The recharge from rainfall during the monsoon seasons have been computed from the water balance equation. The unaccounted water in the non-monsoon seasons has been found to be within reasonable limits, thereby indicating a reasonable degree of accuracy in quantification of the various components.

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