HYDROGEOLOGICAL INVESTIGATIONS OF THE DECCAN TERRAIN OF THE KOYNA SUB-BASIN, INDIA

A THESIS

submitted in fulfilment of the
requirements for the award of the degree
of

DOCTOR OF PHILOSOPHY
in
APPLIED GEOLOGY

By

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Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **"HYDROGEOLOGICAL INVESTIGATIONS OF THE DECCAN TERRAIN OF THE KOYNA SUB-BASIN, INDIA"** in the fulfilment of the requirement for the award of the degree of **Doctor of Philosophy**, submitted in the **Department of Earth Sciences** of the University, is an authentic record of my own work carried out during a period from November, 1986 to November, 1994 under the supervision of Prof. A.K. Awasthi and Prof. P.C. Mohan.

The matter embodied in this thesis has not been submitted by me for the award of any other degree.

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Abstract

The western margin of the Indian Peninsula is characterised by hilly terrain, known as Western Ghats (hills). The Koyna sub-basin (a part of Krishna River basin) is located east of the main ridge, locally called the Sahyadri Hill Range. Trending north-south in general, this sub-basin with Koyna river and its tributaries covers an area of 2036 sq km in the Deccan Terrain of the district of Satara, Maharashtra State, India.

This sub-basin drew attention of geoscientists after the Koyna earthquake (magnitude 7) of 1967. Since then, detailed geological, tectonic and seismic investigations of the sub-basin have been carried out by several workers to work out the causative factors which triggered the earthquake. Despite these investigations, very little studies have been done on the hydrogeological aspects of this sub-basin. The present work, therefore, is an attempt in this direction to evaluate the hydrogeological framework of the sub-basin and assess its groundwater potential.

The annual normal rainfall, due mainly to monsoon, decreases steadily from western (6024 mm) to eastern parts (745 mm) in the area and shows wide variation due to orographic influence of the Western Ghats.

The sub-basin is underlain by basaltic lava-flows capped by laterites on the flat topped hills at higher elevation. In the lower reaches of the river valleys alluvium is found. The soils are basically of two types, viz. lateritic soils and black cotton soils. Four distinct geomorphic units, viz. plateau (flat), dissected plateau, shallow buried pediment and deep buried pediment have been identified on the basis of thematic mapper data. The major lineaments, identified on the satellite imageries and aerial photographs, are found to trend northeast-southwest, north-south and northwest-southeast. The drainage, mostly controlled by lineaments, shows a sub-dendritic pattern. The Koyna river flows along a north-south trending lineament in the upper reaches. It trends east-west along several lineaments in the middle and lower reaches. Morphometric analysis puts Koyna as a 6th order stream with bifurcation ratio of 5.08 which also indicates structural control of the drainage network.

The aquifers are found to be associated with the basalts, laterites, alluvium, soil and talus deposits. The upper vesicular unit of the basaltic flows, unlike the lower massive part, exhibits primary porosity and permeability and is weathered in most parts even at depth. However, at many places, the non-vesicular (massive) unit has developed secondary porosity due to fracturing, jointing and weathering. The laterites and talus deposits are highly porous and permeable, but have very low specific retention of groundwater. The water bearing properties of the clay- rich alluvium are largely controlled by sand/clay ratio. The lateritic soils have better potential then that of black cotton soils. Based on the analysis of 545 wells, the shallow aquifers are found upto a maximum depth of 25 m. The laterites, alluvium, soil, talus deposits and the weathered uppermost basalts from shallow aquifers in the area. The deeper aquifers are found below the zone of weathering in basalts, due mainly to fracturing.

The groundwater in deeper aquifers occurs at the contact between the basaltic flows, within the vesicular and amygdaloidal section at the lava-flow top or within the fractured and jointed section. It occurs under semi- confined condition when the productive horizon is separated by fractured and or jointed basalt. Confined aquifer conditions are found when the water bearing horizon lies at the contact of two lava-flows--the upper one occurring as massive basalt and the lower one as vesicular or fractured basalt. At many places shallow aquifers are connected to deeper aquifers through fractures.

Well yields of groundwater are found to be related with the lineaments and the geomorphic features. While the lineaments have a better control over the yields of the borewells tapping deeper aquifers, the geomorphic features have greater control over the shallow aquifer system. Deep buried pediments and the NE-SW tending lineaments are highly potential areas for dugwells and borewells respectively. Borewells in deep buried pediments with NE-SW lineaments have yields as high as 39,000 lph.

Surface-water is lifted extensively for irrigation from the Koyna river through a number of lift-irrigation schemes which run throughout the year. In the command area of these lift-irrigation schemes, therefore, groundwater is poorly extracted due to easy availability of surface-water for irrigation. Because of continual recharge due to irrigation, the water levels in this area are rising steadily. Thus, this is leading to near water-logging conditions in the lower reaches of the sub-basin.

The non-command area, on the other hand, indicates a gradual decline of water levels due to overdraft for irrigation. The decline in water level is more pronounced in the southern parts away from the Command area, due not only to overdraft but also to the general declining trends of rainfall since 1974. In fact, drought occurs in this area once in every four years. This part of the sub-basin, therefore, calls for artificial recharge of the aquifers to augment the existing groundwater regime.

The hilly region is dotted by many cold-water springs. The high rate of precipitation and the terrace-like topographic features found in the hills facilitate recharge of the aquifers through weathered/fractured/jointed rocks. These aquifers, whenever are dissected by fractures, joints and exposed to hill face, are drained in the from of springs. Based on the examination of 121 springs, it is found that they generally emerge through fractures or the contact between (i) laterite and lithomargic clay or poorly lateritised basalt, (ii) vesicular basalt and massive basalt, (iii) highly weathered massive basalt and moderately or poorly weathered massive basalt or redbole, (iv) talus deposits and hard massive basalt or laterite or lateritised basaltic flow. They are mostly distributed at an elevation range of 600 to 1350 m above MSL with maximum concentration (47%) in between 900 to 1000 m elevation. The mean discharge of the individual springs in winter is about 46 m^3/day as against the mean discharge of 28 m^3/day in summer. As per Meinzer's classification (1923), mostly the springs of magnitude 5 and 6 are found in the area. The springs have a recharge area of 722 sq.km and an yearly discharge of 14 MCM. Based on the nature of their emergence the springs could be classified as contact springs (89%) and fracture springs (11%). However, since the emergence of groundwater in the form of springs is largely controlled by the water-bearing properties of the formations in the study area, these springs can also be classified on the basis of their source-aquifers. Thus, a simple classification has been proposed which classifies the springs into five different types such as, (i) laterite springs (9%), (ii) talus springs (23%), (iii) vesicular basalt springs (20%), weathered non-vesicular basalt springs (37%) besides fracture springs (11%) associated with any type of aquifer. The first four types comes under the category of 'contact springs'.

The transmissivity of the shallow aquifers as estimated through the Papadopulos-Cooper method (1967), Boulton-Streltsova method (1976) and Mishra-Chachadi method (1985) is found to be of the order of 128 m^2/day for talus deposits, 64 to 135 m^2/day for the highly weathered and jointed basalt and 57 m^2/day for the poorly weathered and poorly jointed basalt. The dugwells were tested in terms of productivity with the help of their specific capacity, unit area specific capacity and specific capacity index values as suggested by Slichter (1906), Naresimhan (1965), Walton (1962) and Singhal (1973) respectively. The unit area specific capacity is found to be better parameter as compared to others. For the dugwells tapping talus deposits, black cotton soils, alluvium and basalts, it is found to be of the order of 1.2, 0.7 to 1.3, 1.4 and 0.3 to 6.7 (exceptional 25.2) lpm/m/m^2 respectively. In the dugwells tapping basalts alone it is found to be of the order of 0.3 to 1.3 lpm/m/m^2 for the poorly weathered and poorly jointed basalts, 0.7 to 1.2 lpm/m/m^2 for the poorly weathered and highly jointed basalts and 0.9 to 6.7 (exceptional 25.2) lpm/m/m^2 for the highly weathered and jointed basalts. On the basis of these parameters, it is concluded that the highly weathered and jointed basalt forms the most potential water-bearing horizon in the area.

With a view to classify the water resources of the Koyna sub-basin and assess their suitability both for drinking and irrigation purposes, a total of 147 water samples (76 from dugwells, 24 from borewells, 29 from springs and 18 from the Koyna river) were chemically analysed. Based on modified Hill-Piper diagram (Romani, 1981) the waters from the shallow aquifers are found, in general, to be calcium-bicarbonate type (53%) and calcium-magnesium-bicarbonates type (27%). In case of deeper aquifers they are mostly calcium-magnesium-bicarbonate type (29%), sodium-bicarbonate type (24%), calcium-bicarbonate type (19%), calcium-magnesium-sodium-bicarbonate type (19%) and sodium-calcium-bicarbonate type (9%). The analysis indicate that both the surface and groundwaters are fit for drinking and domestic purposes as per the criteria fixed by Govt. of India (1983). Based on Wilcox diagram (1955), USSL diagram (1954), these waters are also found fit for irrigation purposes. However, in the lower reaches of the Koyna river, the water quality has deteriorated due to use of fertilizers and water-logging conditions. The groundwater in this area shows salinity hazard.

With the erection of the Koyna dam, the Koyna sub-basin, stands divided into two parts — Area I (954.20 sq.km) to the north of the Koyna dam which covers the entire catchment area of the dam and Area II (1081.80 sq.km.) downstream of the Koyna dam. These two divisions have defined basin boundaries and have been treated as two separate watersheds. Area I is mostly hilly and the inhabitants mostly depend on spring water while Area II forms relatively plain valley. Groundwater development through dugwells and borewells is mostly confined to Area II only and hence the assessment of the groundwater resources was made for this part of the Koyna sub-basin only.

The regional specific yield for Area II has been estimated to be 1.20%. On the basis of water level fluctuation method, the annual groundwater recharge has been estimated to be 60 MCM, out of which 30 MCM is due to monsoon rainfall and the rest 30 MCM is due to induced recharge from the surface water tanks (3MCM) and water applied for irrigation (27 MCM). The safe-yield has been estimated to be 60 MCM, out of which 22 MCM is being used for domestic/stock and irrigational needs, 30 MCM is unutilised baseflow and 3 MCM is spring flow. Thus, there remains a balance of only 5 MCM for further groundwater development. Assuming that at least 25% of the unutilised baseflow (i.e 8 MCM) can be brought to fruitful use, the total amount of groundwater available for further groundwater development amounts to 13 MCM. Taking a unit draft of 0.021 MCM per well per year at the existing hydrogeological set-up, about 620 wells can be constructed in the Command area alone. Similarly, at least 25% of the spring flow (i.e. about 1 MCM) can be tapped through pipe-lines for drinking, irrigation and afforestation.

The Koyna sub-basin is characterised by both scarcity and abundance of water-scarcity in the dissected plateau which calls for artificial recharge of the aquifers, and abundance in the command area of the Koyna lift-irrigation schemes which calls for consumptive use of the water resources. For optimal development of the available groundwater resources it is but imperative to practice both these vital aspects. The areas having NE-SW trending lineaments should be looked for greater success of the borewells where more number of dugwells may be constructed in the deep buried pediments due to their high groundwater potential. The command area of the lift-irrigation schemes may be expanded further to the adjoining scarcity areas for effective development of the available surface water potential. The springs form very important source of water which could be harnessed effectively in the hilly tracts without disturbing the existing natural system.

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Chapter 1

Introduction

The western margin of the Indian Peninsula is characterised by hilly terrain, known as Western Ghats (hills). The Koyna sub- basin (a part of Krishna River basin) is located east of the main ridge, locally called the 'Sahyadri Hill Range'. Trending north- south in general, this sub-basin with Koyna river and its tributaries covers an area of 2036 sq km in the Deccan Terrain of the district of Satara, Maharashtra State, India.

This sub-basin drew attention of geoscientists after the Koyna earthquake (magnitude 7) of 1967. Since then, detailed geological, tectonic and seismic investigations of the sub-basin have been carried out by several workers to work out the causative factors which triggered the earthquake. Despite these investigations, very little studies have been done on the hydrogeological aspects of this sub-basin. The present work, therefore, is an attempt in this direction to evaluate the hydrogeological framework of the sub-basin and assess its groundwater potential.

1.1 GEOGRAPHICAL LOCATION

The Koyna sub-basin lies in the Satara district of Maharashtra State, India (Fig. 1.1). It is bounded between the North latitudes 17° 07'35" and 17° 58' 00" and East longitudes 73° 33' 20" and 74° 12' 00" and falls in parts in the Survey of India toposheet nos. 47 G/9, 47 G/10, 47 G/11, 47 G/13, 47 G/14, 47 G/15, 47 G/16, 47 K/3 and 47 K/4. On its west lies the Coastal tracts and on its east is the Krishna river system.

1.2 ACCESSIBILITY

The Koyna sub-basin lies about 50 kms southwest of the district headquaters of Satara.Mahabaleshwaris a hill station located in the north (Fig. 1.2) and is well connected by National Highway No. 4 (Pune-Bangalore) and National Highway No. 17 (Bombay-Goa). NH-4 passes through Karad where the Koyna meets the river Krishna (Fig. 1.2). A State Highway(SH) passes through the middle of the area and connects the two National Highways. Karad is also connected by rail. Although the road network is poor due to adverse physiographic conditions and rugged topographic features in the sub-basin important villages are connected by motorable roads. Fig. 1.2 shows the important roads and railway lines connecting the study area with the adjoining region.

1.3 CLIMATE

The area experiences sub-tropical monsoon type of climate. The winter season lasts from November to February and the summer extends from March to May. The monsoon starts from June to September. During October and November the monsoonhas a retreating period.

1.3.1 Temperature

January is the coldest month and the daily mean monthly minimum temperature ranges from 10°C to 14°C. May is the hottest month and the daily mean monthly maximum temperature varies between 31°C to 37°C.

1.3.2 Humidity

The air is highly humid during the monsoon months. The relative humidity ranges between 79 to 96% in the morning (830 hrs) and 72 to 100% in the evening (1730hrs) during this period. It is lowest in the month of March and ranges between 31 to 36% in the morning and 17 to 43% in the evening. The dryness is more marked in the plains than in upland regions.

1.3.3 Wind

The winds are strong particularly in the hills during monsoon season. In the rest of the year they are light to moderate.

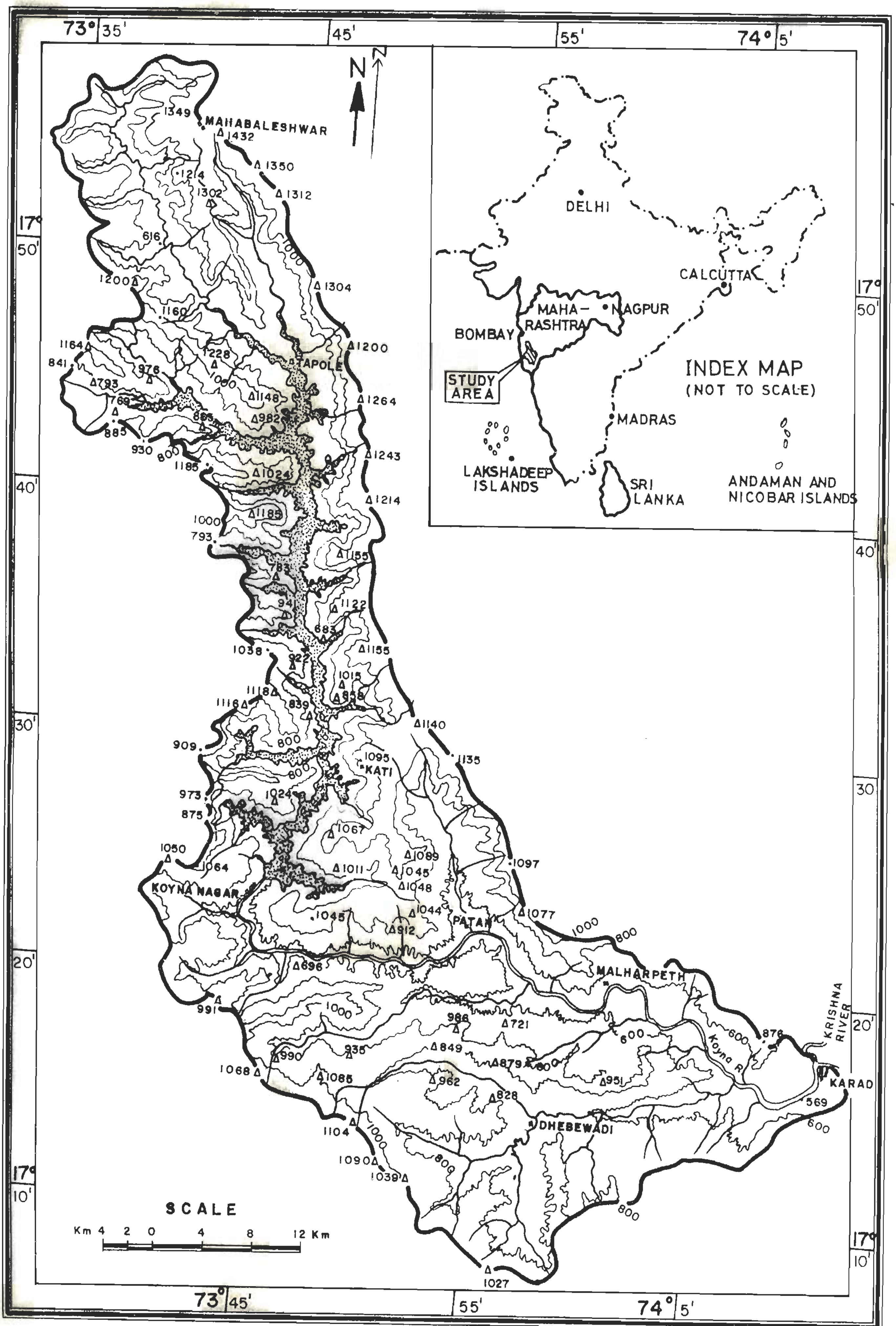

FIG. 1·1 LOCATION MAP OF THE KOYNA SUB-BASIN

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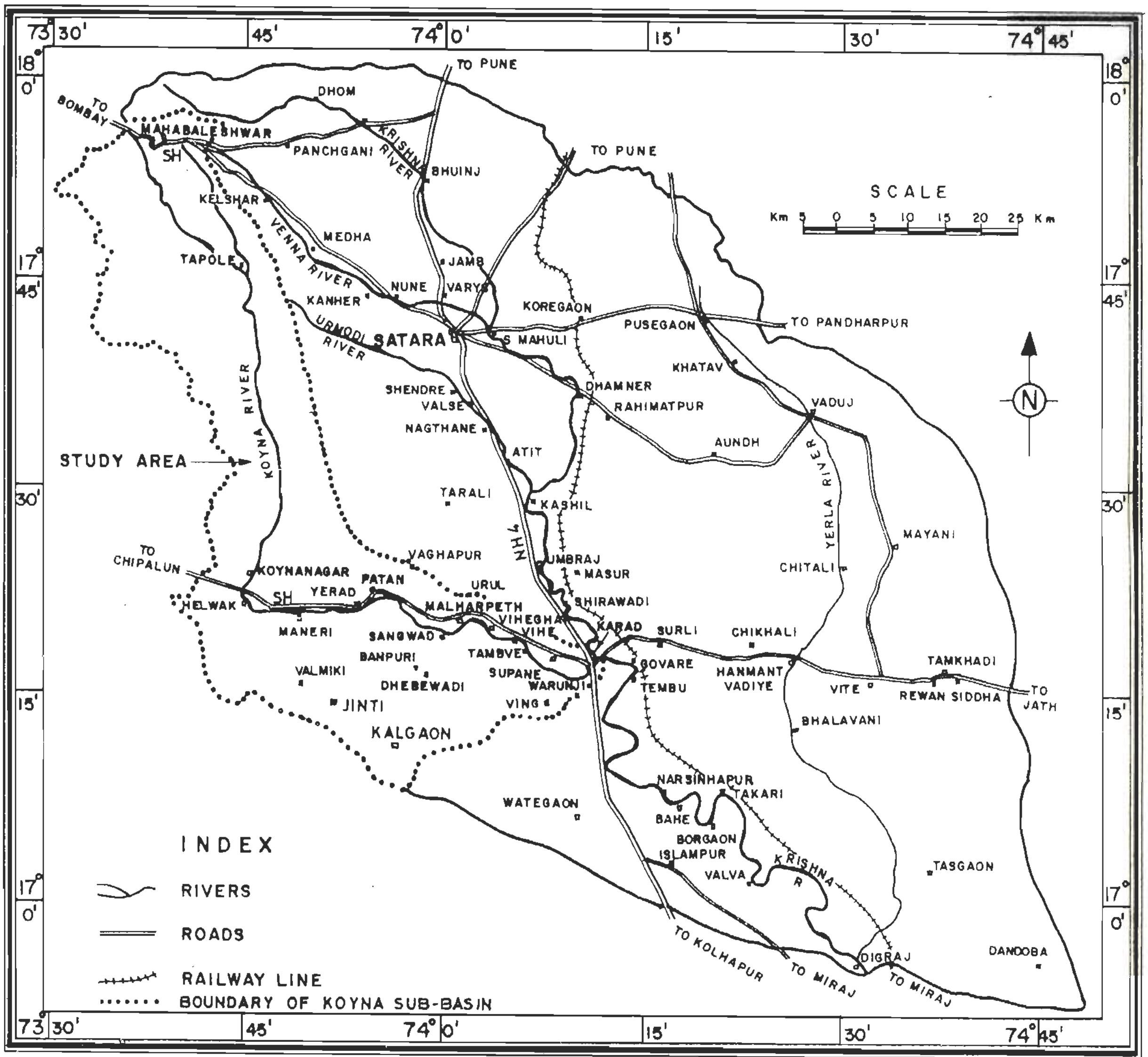


FIG. 1·2 LOCATION MAP OF THE STUDY AREA SHOWING COMMUNICATION NETWORK

P. K. NAIK

1.3.4 Evaporation

It varies between 18.8 mm in August to 159.4 mm in April as per the long-term monthly average evaporation data at Koynanagar.

1.3.5 Rainfall

There is a wide variation in the distribution of rainfall in the area due to orographic influence of the Western Ghats (Fig 1.3). The annual normal rainfall due mainly to monsoon decreases steadily from the western to the eastern parts. Highest annual average rainfall is recorded at Mahabaleshwar (6024mm) in the north while the lowest is received at Karad (745mm) in the east. The probability of occurrence of normal rainfall (i.e. $\pm$25% of the annual normal) varies from 0.53 at Gudhe to 0.86 at Koyna. Analysis of the long-term data of the rainfall indicates that about 88% of the annual rainfall is received during the monsoon period (June to September). In the winter, rainfall contribution is only 8% while during summer it is only 4% of the total annual rainfall. With the help of time-series analysis of the long-term annual rainfall, it is observed that since 1974, the rainfall pattern shows a marked declining trend at Gudhe in the south (Fig. 1.4). Frequency of drought ($<$ 25% of the annual normal rainfall) varies between once in 4 years at Gudhe to once in 19 years at Koynanagar.

1.3.6 Evapotranspiration

The long-term potential evapotranspiration varies between 66.1mm in August to 167.7mm in April at Mahabaleshwar and 103mm in August to 194mm in May at Karad.

1.4 PHYSIOGRAPHY AND DRAINAGE

The Koyna sub-basin is characterised mainly by the hilly tracts of the north-south trending Western Ghats. The sub-basin has an elevation range of 550 to 1460m abvoe MSL and represents a typical physiographic set-up characteristic of the Deccan Plateau. The vast landscape of the Sahyadri Hill Range (local name of the main ridge of the Western Ghats) is made up of crenulated hills with deep winding valleys and interfingering gullies (Fig. 1.5).

The hilly tracts, in general, are highly rugged and closely dissected. The ridges are mostly flat-topped with steep flanks. The basaltic flow contacts have given rise to terraces at many places (Fig.1.6). When the streams descend through such terraces they form water-falls to the extend of about 100m. The area around Mahabaleshwar in the north bears a thick capping of laterite with undulating topography. A columnar jointed glomeroporphyry (Thorat and Ravi Kumar, 1987) basaltic flow forms prominent scarps around Mahabaleshwar. It is the site of many well known points (viewing sites) attracting thousands of tourists annually. Other topographic features include vertical cliffs (Fig. 1.7), V'-shaped valleys, vertical and mushroom-like outcrops of columnar basalts (Fig.1.8), step-like terraces etc. Near Mahabaleshwar there are several natural caves formed probably due to undercutting and erosion of soft lithomargic material below the laterites. These caves are called 'Robbers Caves' and are the main tourist attractions of Mahabaleshwar.

The area is drained by the trunk stream Koyna and its tributaries (Fig. 1.9). The Koyna, in its north-south course, is seldom broader than 30-35m, but in its easterly course it widens upto 150m. After its southerly flow for about 65 kms it is dammed by the Koyna dam forming the Shiv Sagar Reservoir (popularly known as the Koyna Reservoir) (Fig. 1.9).After this, the river abruptly turns eastward to join the river Krishna at Karad. The important left bank tributaries include the river Solashi and the river Ker. These follow a general NNW-SSE direction. The right bank tributaries are the river Mornaand the river Vang. These follow a general E-W direction and then SW-NE direction.

The overall drainage pattern of the sub-basin is sub- dendritic. The drainage is mostly controlled by lineaments (Fig. 2.1). The Koyna river flows along a north-south trending lineament in the upper reaches. It trends east-west along several lineaments in the lower and middle reaches.

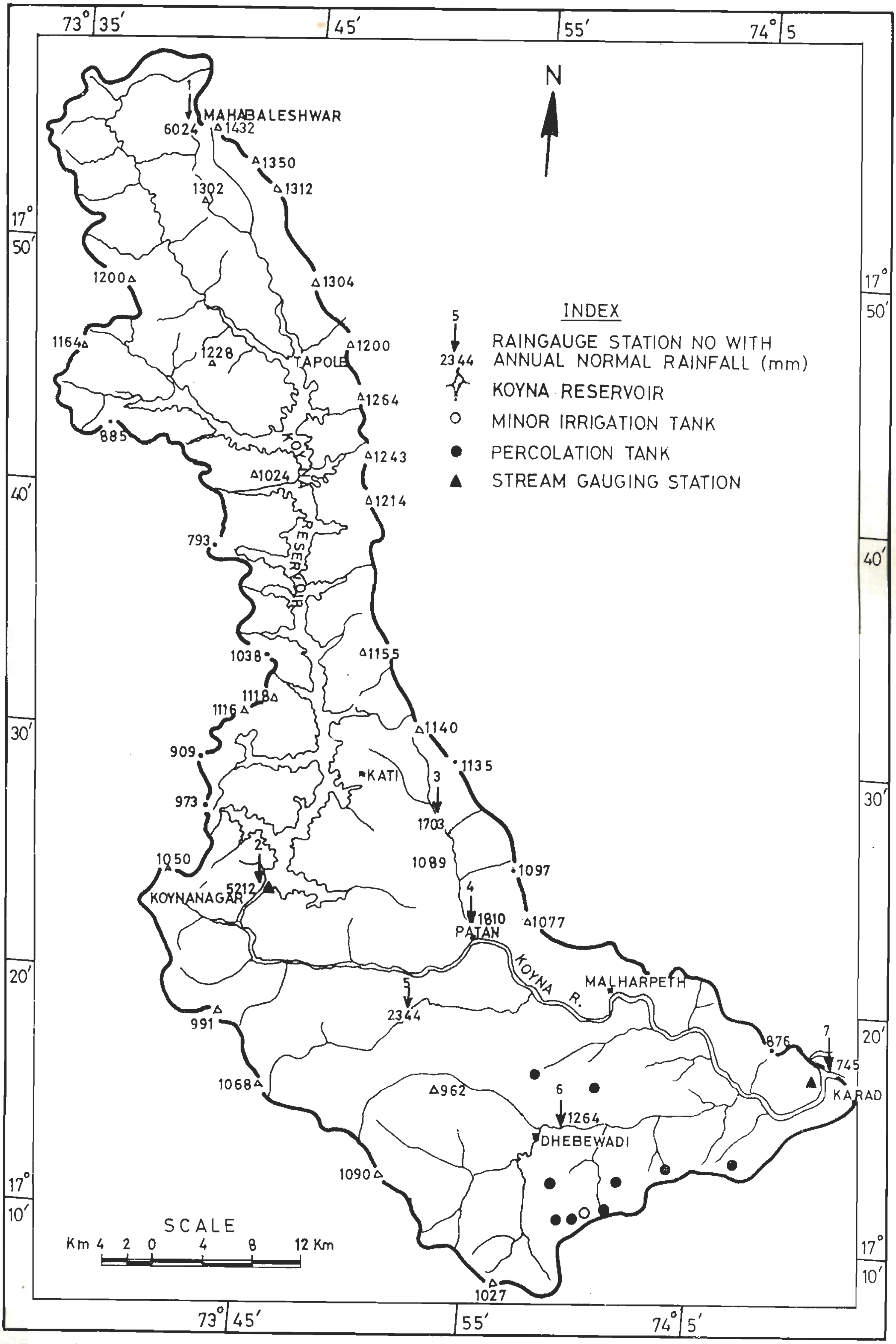
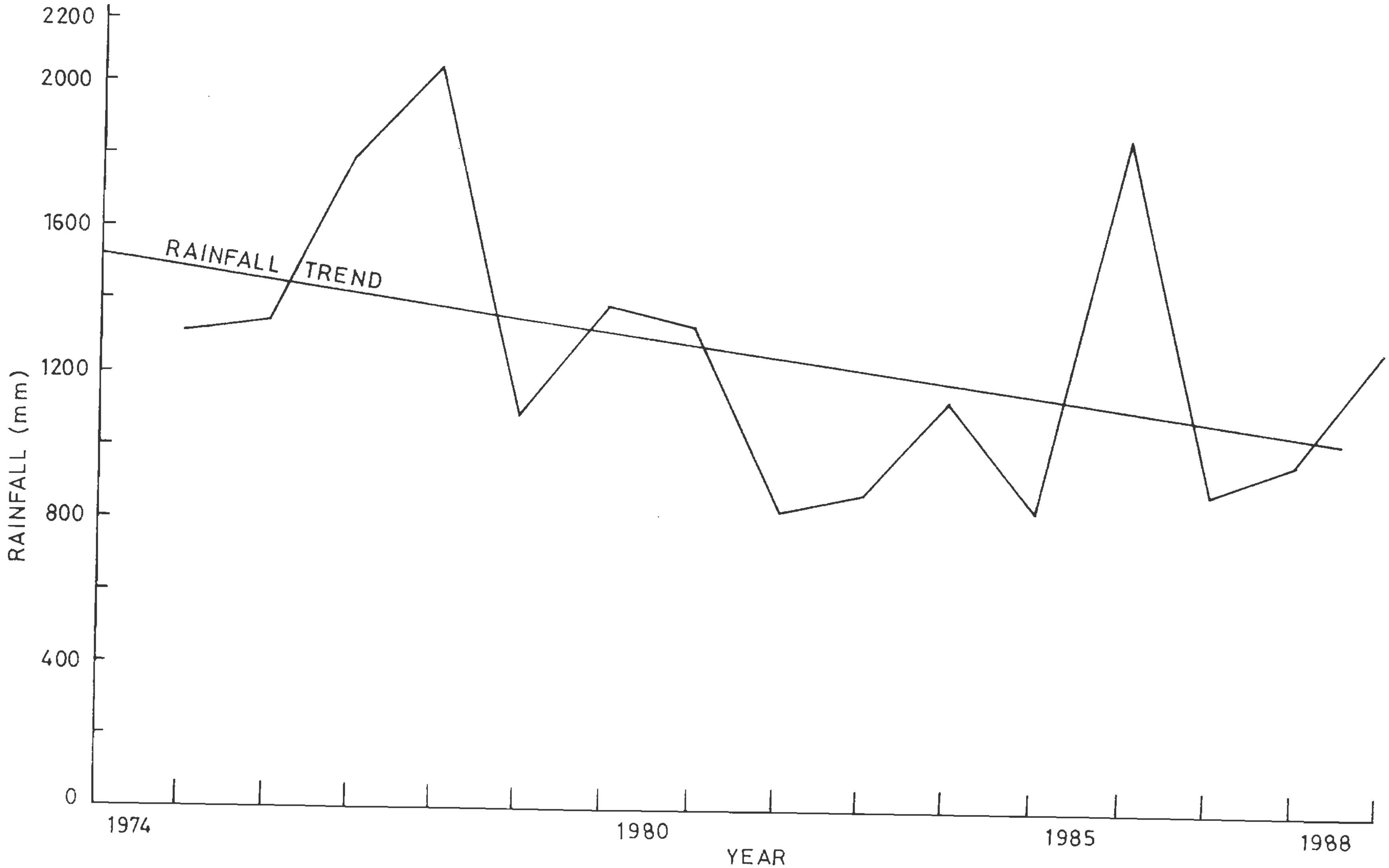


FIG.1·3-LOCATION OF RAIN AND STREAM GAUGING STATIONS AND SURFACE WATER RESERVOIRS



SCALE :
X–AXIS 1 UNIT = 1 YEAR
Y–AXIS 1 UNIT = 200 mm

FIG.1·4 – LONG TERM ANNUAL RAINFALL TREND AT GUDHE

Fig.1.5 : The landscape of the Koyna valley at its origin.

Fig. 1.6 : A hill terrace near Mahabaleshwar.

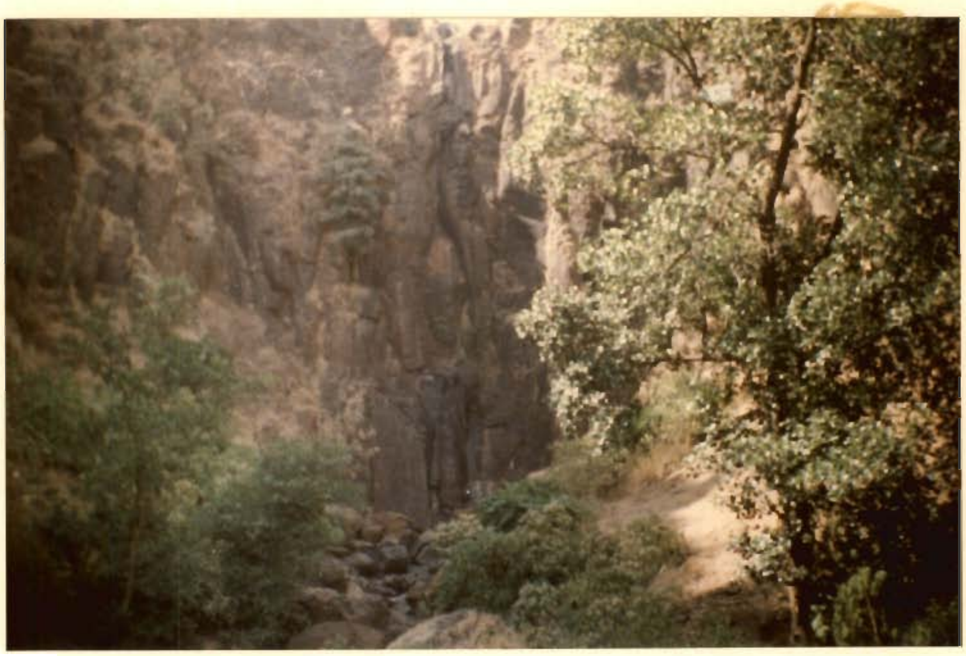


Fig. 1.7 : A vertical cliff near Koynanagar.

Fig.1.8 : Mushroom-like appearance of columnar basalt near Koynanagar.

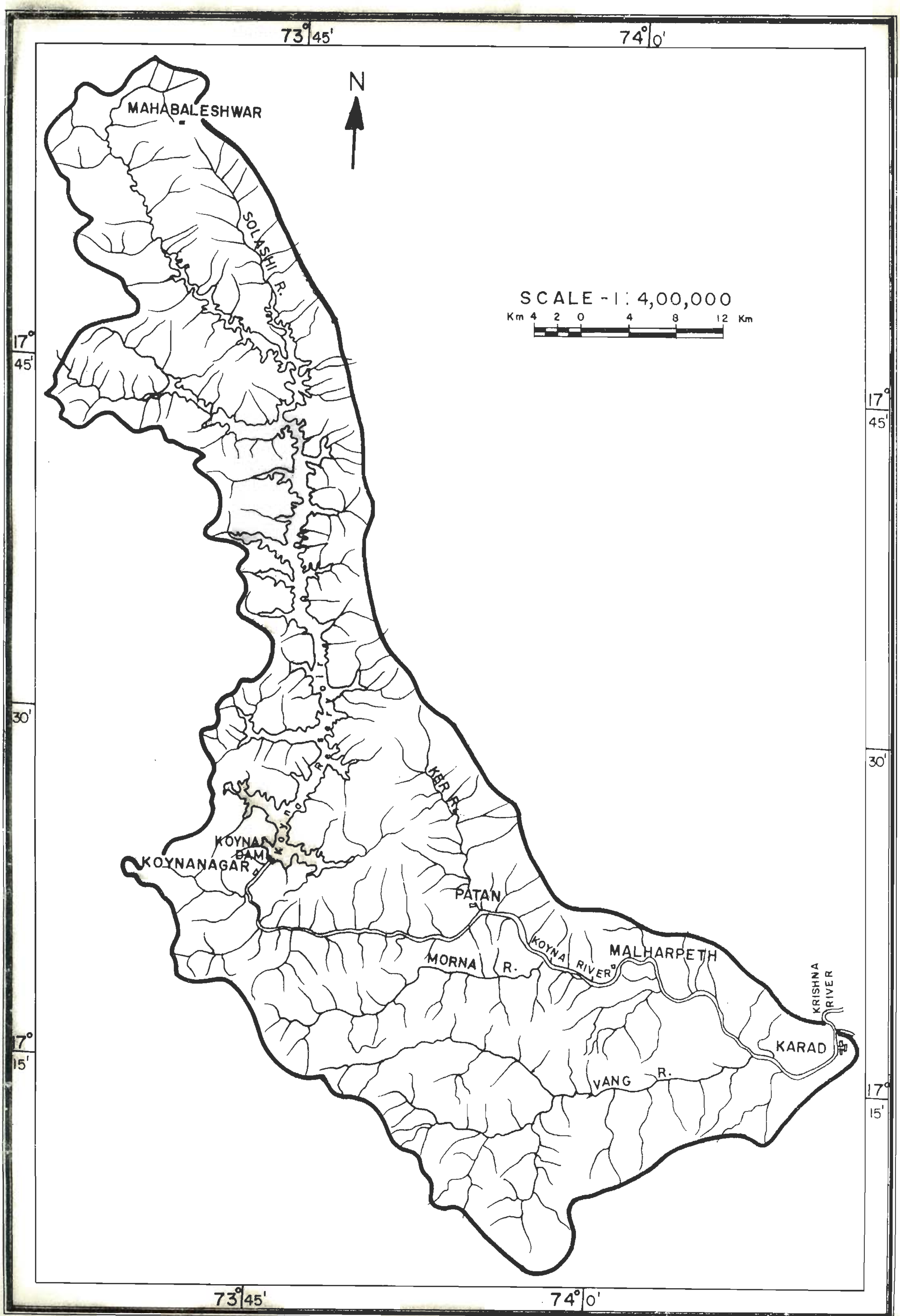


FIG.1·9 DRAINAGE MAP OF THE KOYNA SUB BASIN

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Table 1.1 Morphometric Analysis of the Koyna Sub-basin

PARAMETER	VALUE
A. Linear Aspects	
(1) Stream order	6
(2) Stream Number	2857, 526, 78, 13, 4 and 1 in increasing order of stream order
(3) Stream Length	Varies between 0.9 to 21.0 km.
(4) Avg. Bifurcation Ratio	5.08
(5) Avg. Length Ratio	0.58
B. Areal Aspects	
(1) Drainage Area	2036 sq. km.
(2) Shape Prameters	
(a) Elongation Ratio	0.20
(b) Form Factor	0.23
(c) Circularity Ratio	0.27
(3) Drainage Density	1.82 km/km^2
(4) Stream Frequency	1.71
(5) Infiltration Number	3.11
(6) Length of Overland Flow	0.27
(C) Relief Aspects	
(1). Channel Gradient	
(a) Source Region	106 m/km (Krishna River) 113 m/km (Koyna River)
(b) Middle Reaches	10 m/km (Krishna River) 7 m/km (Koyna River)
(c) Confluence Zone of the Koyna with the Krishna)	5 m/km (Krishna River) 3 m/km (Koyna River)
(2) Maximum Basin Relief	882m
(3) Relief Ratio	7.74
(4) Relative Relief	287.30
(5) Ruggedness Number	1.61

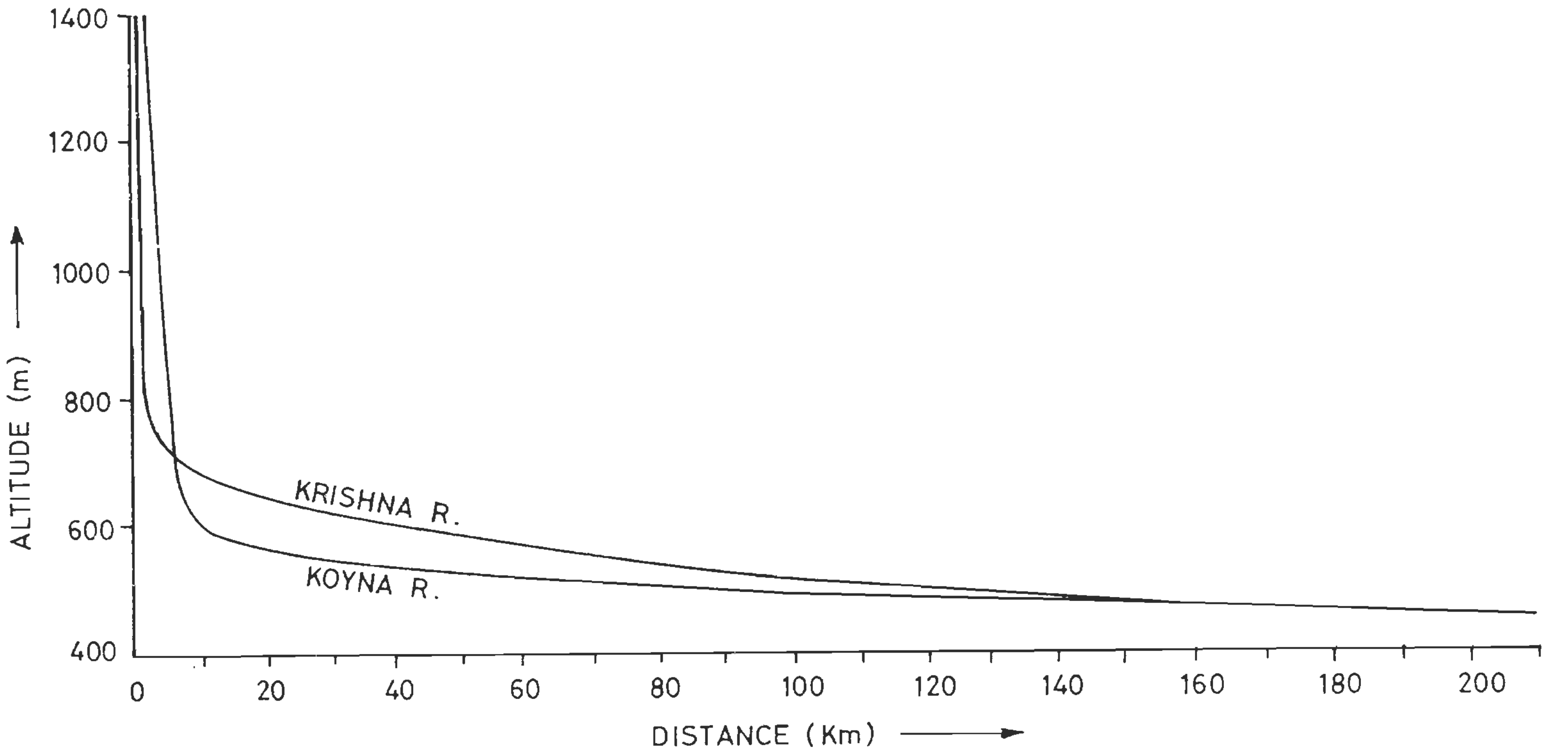


FIG. 1.10-LONGITUDINAL PROFILES OF THE KOYNA AND KRISHNA RIVERS

Two distinct river terraces occur on the banks of the Koyna river. The one formed of older alluvium occur 10 to 20m high above the modern bed level, while the other formed of younger alluvium occurs around 2 to 5m above the present river bed. The terraces are wider in the left-flank of the river and are of unpaired nature.

The morphometric analysis (Table 1.1) puts Koyna as a 6^{th} order stream. Strahler (1964) suggests structural control for a drainage basin which shows bifurcation ratio of greater than 5. The bifurcation ratio of 5.08 for the Koyna sub-basin is indicative of structural control over the drainage network. The sub-basin is well-drained and is characterised by greater surface run-off, steeper gradient and lower rate of infiltration. The longitudinal profile of the Koyna river indicates that the river has a gradient of 113 m/km in the source region, 7 m/km in the middle reaches and 3 m/km in the confluence zone (Fig. 1.10).

1.5 SURFACE HYDROLOGY

Although Koyna sub-basin receives very high amount of rainfall, most of the rainfall flows as surface run-off. The major factors causing excessive run-off and poor groundwater recharge are :

(i) steep slopes of the hill ranges,
(ii) presence of massive trap-units blocking the downward movement of water,
(iii) low premeability of the rock units,
(iv) poor vegetation on the hill slopes,
(v) major concentration of rainfall during a short period of rainy season and
(vi) discharge of groundwater in the form of springs at higher elevations.

1.5.1 Surface Water Structures

The Koyna sub-basin has one major surface water reservoir, one minor irrigation tank, 9 percolation tanks and a number of check-dams (Fig. 1.3).

The major surface water reservoir is known as Shivsagar Reservoir (Koyna Reservoir) constructed across the river Koyna at Koynanagar. The reservoir has a catchment area of 954.20 sq km with water spread area of 115.35 sq km. The gross and net storage capacities are 2797.4 MCM and 2677.6 MCM respectively. The Koyna dam has a height of 85.35m above river bed and 103.02m above foundation. It has got a total length of 807.72 m and top width of 10.70m to 14.80m. The reservoir started filling from 1961. After the worst earthquake of 1967 which caused considerable leakages in the dam structure water is released periodically (twice in a month) from the dam. The released water has given rise to a number of lift irrigation schemes in the central valley portion of the Koyna sub-basin. The lift irrigation societies number to 146 and consist of about 19500 members. At present out of 16590 ha of land in the Command area of such schemes only 7272 ha are irrigated in different seasons.

The minor irrigation and percolation tanks have total storage capacity of 6.26 MCM and have Command area of about 900 ha of land. Their performance is, however, not satisfactory in the area.

1.6 LAND USE

Lithology of different geological formations have played a diagonistic role in the land use pattern of the area. The following classes of land, based on their present use, have been recognised.

(i) Rock outcrops (without vegetation cover) : These are confined to the hill tops with resistant rocks and vertical cliffs.

(ii) Rock outcrops with very thin vegetation cover : These are covered mostly by shrubs, grass and scattered trees and are confined to the hill tops with or without lateritic cap rocks and steep slopes.

(iii) Forests on rock outcrops (with thin soil cover) : This class includes lateritic cover in many parts.

(iv) Forests on soil covered areas : This class is generally found in the western part. The forest types are (a)ever-green forests, (b) dry mixed deciduous forests and (c) wet mixed deciduous forests.

(v) Cultivated land with thin soil cover (<3m) : Hill terraces and gentle slopes are included in this class. Kharif crops such as sorghum, upland paddy, bajra, maize, pulses etc. are mostly cultivated.

(vi) Cultivated land with deep soils and regolith (>3m) : This class is found in the central valley portions. hybrid sorghum, rabi sorghum, wheat, sugarcane, pulses etc. are mostly cultivated.

(vii) Fallow/eroded land with variable soil cover.

(viii) Surface water bodies and rivers : Koyna reservoir having a water spread of 115.35 sq km is the main surface water body.

(ix) Habitations.

1.7 CROPPING PATTERN

The main kharif crops are hybrid-sorghum and upland paddy. The important rabi crops are rabi-sorghum, wheat, pulses etc. Sugarcane is a perennial crop and is confined to the central valley portions only.

1.8 PREVIOUS WORK

The area became the centre of attention for the geologists and seismologists for several years after the Koyna earthquake of 11th December, 1967. A strong belief that the Peninsular Shield is stable and aseismic was greatly shaken after the earthquake, which measured about magnitude 7 in Richter scale. Some of the pioneer workers in the area are the officers from Geological Survey of India (1968-1974), Gupte (1968), Gupta et al (1969), Lee and Rayleigh (1969), Kailasam and Murthy (1969), Kailasam et al (1969), Balsundaram and Srinivasan (1971), Guha et al (1970, 1971, 1974), Auden (1975), Chandra (1976), Langston (1976), Rastogi andTalwani (1980), Kaila et al. (1981), etc. Two schools of thoughts developed regarding the probable cause of the earthquake. One school believed in the reservoir induced seismicity while the other group believed in the tectonic disturbance and crustal readjustment as the causative factors.

Gupte (1968) found sharp rise in temperature (5^0C to 9^0C) in the west coast hot springs immediately after the earthquake. Balsundaram and Srinivasan (1971) located several shear planes trending N-S and NE-SW in the Koyna sub-basin. Kaila et al (1981) proved the presence of a N-S trending fault in the basement rock just below the Koyna dam. Power (1981) suggested the presence of a prominent lineament called ' the Koyna lineament ' along the Koyna reservoir.Guha (1982) considers Koyna reservoir as an example of reservoir induced seismicity since the seismic activity is correlatable to the parameters such as lake level and ground tilt. Arur (1982) indicated lateral shift and change in elevation around the epicentre through geodetic control schemes for pre and post seismic events of the Koyna earthquake. Recently Tondale and Ayyangar (1992) have suggested tectonic disturbance as the chief factor for the Koyna eathquake.

Mahabaleshwar sitting on the peak of the Western Ghats has attracted attention of many workers. Kulkarni (1962- 63) studied the laterites of the Mahabaleshwar area. Deshmukhet al. (1969-70) gave petrographic details of Poladpur ($17^0$59' - $73^0$28')-Mahabaleshwar road section. They found that the flows are of tholeiiticcomposition and are porphyritic to varying degrees. Sahasrabudhe et al (1969-70) noticed 42 basaltic flows in this Poladpur-Mahabaleshwar road section with thick laterite capping. Pal and Bhima-shankaran (1972) classifed the flows around the area, based on paleomagnetic studies, in three differnt groups. Kaneoka and Haramura (1973) determined the ages of some of the flows of Mahabaleshwar by K-Ar method. The calculated values are, however, not in conformity with the sequence of the flows. Nazafi et al (1981) divided the Poladpur-Mahabaleshwar sequence into three groups on the basis of petrogrphic and geochemical studies. A slight tendency of the rocks to become more Fe-rich relative to Mg with time was detected. Mahoney et al (1982) proposed two fold classification of the basaltic flows based on Sr isotope ratio. This change is noticed at 950 m level and is confirmed by K/Zr ratio. Ghodke and Pawar (1982-83) studied the lateritic profiles around Panchaghani and Mahabaleshwar and found the laterites to be rich in iron oxides and primary in nature. High concentration of chromium (1000 ppm) was found in top portion of laterite at Mahabaleshwar.

In other parts of the area, officers of Geological Survery of India have carried out detailed geological mapping. They include Kulkarni et al (1971-72), Raman et al (1972-73), Dubey and Venkatesh (1974-75), Dubey et al (1975-76), Sahasrabudhe and Sharma (1987) and Rao (1987). Khatavkar and Trivedi (1992) have studied the river water pollution of Upper Krishna basin and have found the river Koyna less polluted than the river Krishna.

Despite all above studies by various workers, no detailed hydrogeoloical investigation covering the Koyna sub-basin as a whole has so far been carried out. However, the sub-basin embodies about 1500 dugwells for drinking and irrigation and 305 borewells exclusively for drinking. While most of the dugwells have been dug by the local inhabitants indiscriminately, the borewells have been drilled by the local authority of the State Government for water supply considering only the local hydrogeological condetions for which records are poorely available. Chadha (1976-77) for the first timeconducted reconnaitary hydrogeological studies in a small portion in the lower reaches of the Koyna sub-basin. Later Naik (1988-89) carried out hydrogeological studies in parts of the middle reaches of the sub-basin. These studies are of very limited scope and a whole-some picture of the hydrogeology of the sub-basin cannot be obtained through such studies since they are carried out in parts toposheetwise in differnt years not covering the sub-basin as a whole.

1.9 SCOPE OF PRESENT STUDY

A review of the previous work reveals that hydrogeological studies of very limited and localised nature have so for been carried out in the Koyna sub-basin. The groundwater resources of the area have not yet been evaluated. The aquifer parameters of various water-bearing horizons have not yet been estimated. The springs existing at higher elevation have not yet been studied from the point of view of their origin, classification, yield, chemical - quality etc. Therefore, the present investigations are aimed at detailed hydrogeological studies of the sub-basin and evaluation of its groundwater potential.

The present study is based on both field and laboratory work. The field work includes detailed hydrogeological mapping of the area during premonsoon, postmonsoon and winter periods, performace of pumping tests at selected locations, collection of water samples from differnt sources, investigation of springs at higher elevations etc. The laboratory work includes the study of aerial photographs and setellite imageries, drainage basin analysis, interpretation of field data, chemical analysis of water samples etc.

The thesis has been divided into 8 chapters including the present introductory chapter. The topics dealt with in each of the seven chapters are briefly described as follows.

Chapter 2 describes the geological set-up, hydro-geomorphic features, structure and tectonics of the area. Various land forms and lineaments have been identified with the help of aerial photographs and satellite imageries. The structure and tectonics of the area have been analysed in brief.

Chapter 3 deals with the occurence of groundwater in different aquifers in the area. The water bearing properties of the formations, the occurrence of groundwater, depth to water level of the groundwater regime in differnt periods, seasonal fluctuations of water levels, long-term trends of water-levels in both Command and non-command areas have been described in detailed.

Chapter 4 incorporates the studies on the natural springs of the sub-basin. The distribution of springs, their origin, classification, discharge, sustainability, development etc. have been described in detail.

Chapter 5 evaluates the hydraulic parameters of the shallow aquifer system and yields of dugwells.

Chapter 6 deals with the qualitative aspects of the groundwater being used for drinking and irrigation. Analytical results of the major chemical constituents have been presented in tables and plotted in standard diagrams for classification.

Chapter 7 evaluates the quantity of groundwater available as a source. The regional specific yield has been determined. The minimum replenishable recharge due to rainfall and the static groundwater reserve have been estimated. For effective groundwater management and development, the safe-yield of the sub-basin has been estimated.

Chapter 8 summarises and concludes the findings of the present investigations.

Chapter 2

Geology Of The Area

2.1 GEOLOGY

Geologically, the Koyna sub-basin occupies a terrain characterised conspicuously by flat topped hills which are commonly known as 'Deccan Trap'. These traps are formed by the basaltic flows which erupted through fissures in late Cretaceous to lower Eocene (Pascoe, 1973). At times these traps are capped by laterite (Fig. 2.1). Alluvium of the Koyna river system is localised in the valley section. With a view to have clear perspective of the Koyna sub-basin, a brief description of these units is given herewith.

2.1.1 Basaltic Lava Flows

Black to grey coloured basalts overlie the rocks of granitic composition (Guha and Padale, 1981), with extremely irregular contact (Kaila et al, 1981). Deep seismic sounding data suggest a thickness of basaltic layer to be of the order of 1.6 km at Koynanagar and 0.6 km at Karad (Kaila et al, 1981). These basalts occur in the form of volcanic flows. 46 lava flows have been identified by Thorat and Ravi Kumar (1987). These flow vary in thickness from 10m to more than 60m (Rao, 1987).

Each basaltic flow consists of mainly two trap units, viz. (i) massive unit and (ii) vesicular unit, the former occupying the lower portion (Fig. 2.2). The massive one constituting the main trap unit, forms 60 to 85 percent of the individual flows. These are mostly fine-grained, dense and compact and greenish to dark-grey in colour (Fig. 2.3). They exhibit occasionally the columnar and spheroidal structure and very often show well developed joints in different directions (Figs. 2.4 and 2.5). Very often massive basalts are traversed by calcite veins. The vesicular trap unit forms the upper horizon of each flow and constitute 15 to 40 percent of the individual basaltic flows. These are generally soft, fine grained and greenish to brownish in colour. The vesicles are rounded to oval-shaped which are either open and interconnected or filled with secondary minerals like zeolite, quartz, calcite etc. Because of weathering the secondary minerals fall off and the rock imparts a pitted appearance (Fig. 2.6).

Generally, the consecutive lava flows are separated by a red layer varying in thickness from 0.20m to 1.30m. The terms such as red bed (Kanegaonkar, 1977), redbole (Gupte, 1979) or the tuffaceous material in the interflow zone (Kshirasagar, 1981) have been used to describe it. 'Redbole', however, is the commonly accepted term. Gupte (1979) ascribes their formation to the hydrothermal alteration of the black coloured trachylitic basalts, which then changes to vivid red. On exposure to the atmosphere the red trachylitic basalt disintegrates along closely spaced joints into a red friable material called 'redbole'. Kshirasagar (1981) assigns pyroclastic origin to these rocks based on petrographic and other evidences. However, most commonly they are considered to be an insitu product of baking and weathering of basalts representing a time gap between two successive flows (Kidwai et al., 1984). Thus, they indicate the local topographic highs during the time gap of the successive flows.

Apart from redbole beds, other criteria to demarcate the flow contacts are (i) fragmentary top, (ii) highly weathered top profile containing loose, gritty soil, (iii) lightly altered top and (iv) highly amygdaloidal top. At places springs are seen emerging from the contact zones.

Petrographically the basaltic flows are of the tholeiitic composition and are porphyritic to varying degree (Deshmukh et al, 1969-70). They are commonly composed of plagioclase, sub-calcite augite and olivine (Tandale and Ayyangar, 1992). Basalts containing olivine as chief constituent are rarely reported (Cox and Hawkesworth, 1985).

2.1.2 Laterites

Laterites occur as cap over the basalts and form plateau at an elevation range between 975m and 1400m above MSL (Fig. 2.7). These occur at an elevation of 975m above MSL South-West of the area around Valmiki while in the north around Mahabaleshwar, these occur 1280m above MSL. The lateritic profiles have a thickness of about 12 to 30m in the eastern and northern parts. However, in the southern parts, their thickness is of the order of 2 to 5m. Very often, the slopes at higher elevations are covered by laterite seree. Also, boulders and blocks of laterites fall off from the plateau due to erosion.

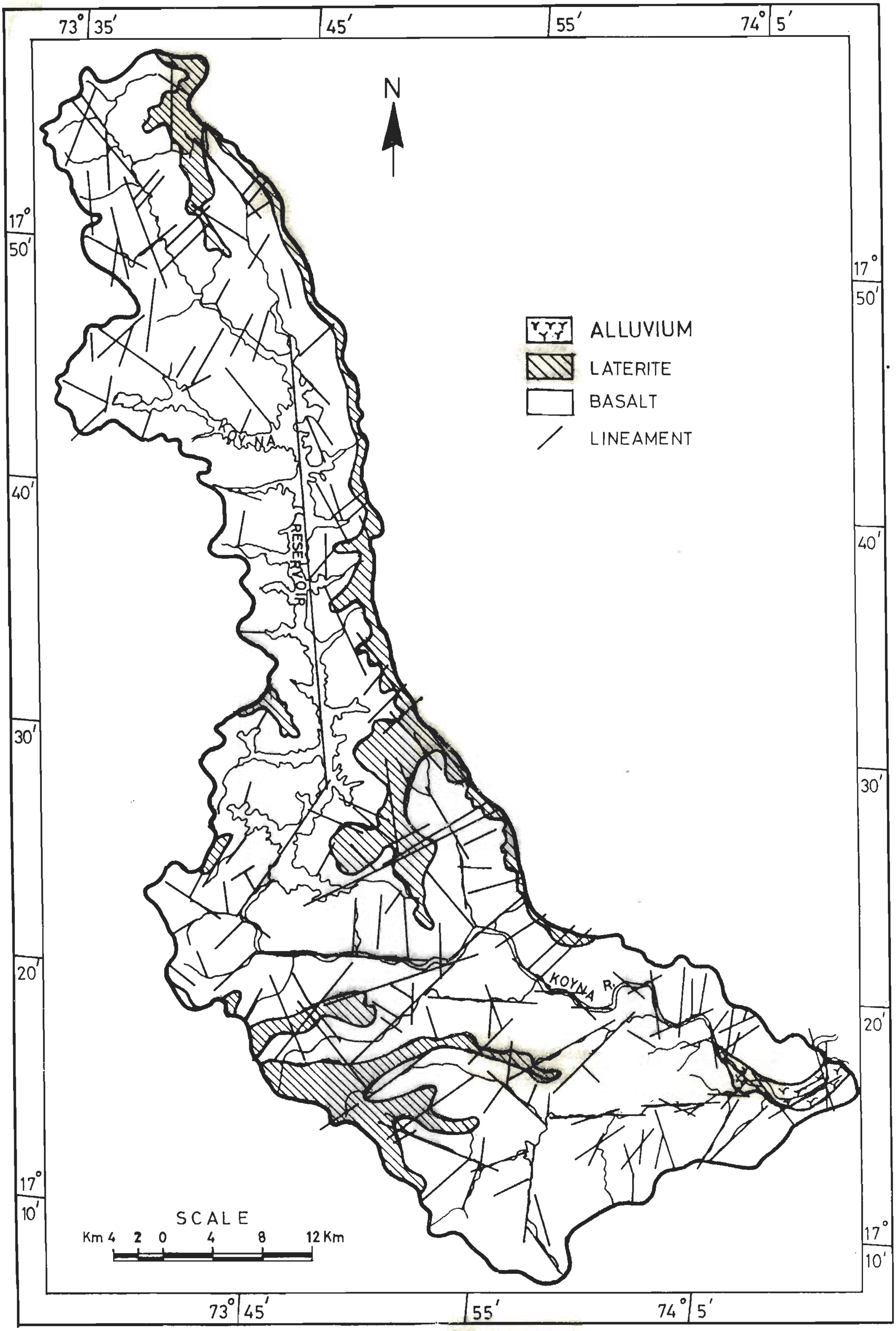


FIG. 2·1 GEOLOGICAL MAP OF OF THE KOYNA SUB BASIN

Fig.2.2 : A hill-section showing different units of a basaltic flow.

Fig.2.3 : The massive basalt.

Fig.2.4 : Joints in massive basalts.

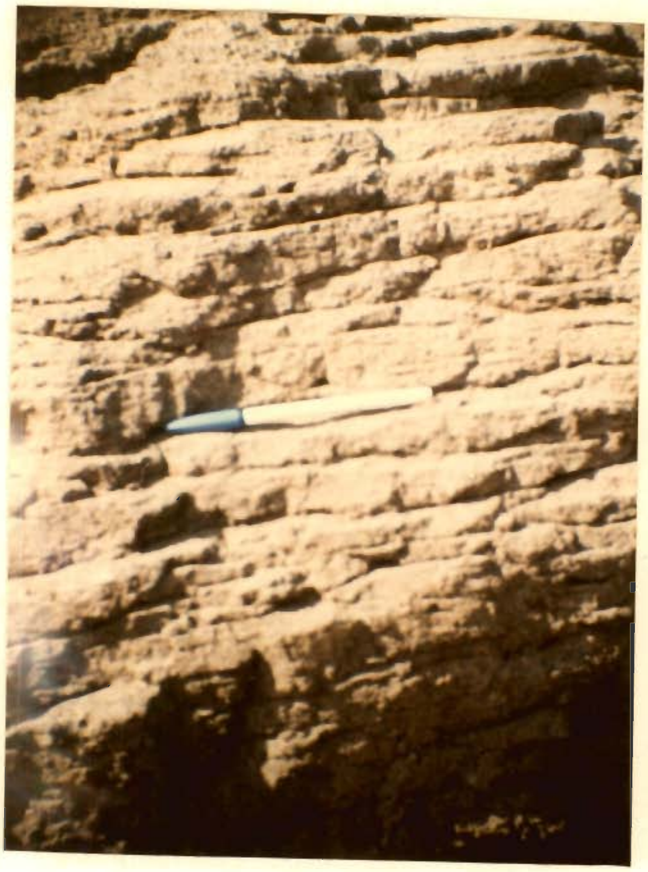


Fig.2.5 : Closely spaced horizontal joints in massive basalts.

Fig.2.6 : Pitted appearance in vesicular basalt.

Fig.2.7 : Laterites capping the basalts (elevation 1045m above MSL)

Laterites have a typical reddish brown colour. They are scoriaceous type with lots of cavities which are generally filled with yellowish to reddish white clayey material. Mostly they have duricrust at the top. The thickness of the crust is around 5 to 10m and is often porous. A zone of lithomargic clay marks the contact between traps and laterite. In many cases, the massive basalt in the hill terraces in the above range of elevations are in the process of lateritisation due to constant leaching as observed at Sadavaghapur. Tablelands formed by laterites are very common (Fig. 2.8). The laterites are highly ferruginous and contain irregular pockets and lenses of bauxite in Mahabaleshwar area (Thorat and Ravi Kumar, 1987).

2.1.3 Alluvium

A few isolated patches of recent alluvium varying in thickness from about 2m to 15m occur on the banks of the Koyna river and other major tributaries. The alluvium contains boulders, cobbles and pebbles of basalts along with sand, silt and clay. The sediments are generally poorly sorted. sedimentary breccia are also noticed at places. In a typical alluvial section in the middle reaches the basalt is overlain by gravel and sand for about 1 to 2m which are followed upward by silt of more than 7m thick indicating fining up sequence. These sediments at time show cross stratification interlayering of sand and fissured clay. In the lower reaches, the alluvial deposits are mostly sandy silts and clayey.

The alluvial deposits form terraces in the middle and lower reaches of the Koyna river. The clayey and silty nature of the alluvium has helped people in extensive brick- making in the middle and lower reaches (Fig. 2.9).

2.2 SOILS

The soils of the area belong mainly to two types, viz. (i) lateritic soil and (ii) black cotton soil.

2.2.1 Lateritic Soil

The lateritic soil is chiefly formed in the hilly upland region where the rainfall is about 2000m or more. While the insitu lateritic soil is found on the hill tops and adjacent slopes, breaking of large blocks downhill transport debris during scarp retreat and their reconsolidation at lower levels also produce thick pile of lateritic soil (Fig. 2.10) in the slopes and some times in the valleys. The heavy leaching during rainy season has rendered the soil rich in iron, aluminum and titanium and is classified as belonging to pedalfer type (Umarjikar, 1983). It is basically acidic, devoid of lime, poor in organic matter and is of brick red colour. The soil becomes coarser away from the valleys.

At many places 'red soil' is found to occur due to exposure of the redbole bed after complete peripheral erosion of the flow lying above it. These occur at places where transportation of lateritic soil is not possible (Fig. 2.11).

2.2.2 Black Cotton Soil

Black cotton soil is the product of tropical weathering of basalts. It is thick in river valleys and become thinner away from them. It generally occurs below a rainfall zone of 1500mm. The black cotton soil is fine, black and powdery when dry and forms a sticky mass when wet. It is rich in montmorillonite thus exhibit swelling property. As has been observed in the area, it has high capacity of moisture retention which has rendered it useful in the low rainfall areas for agriculture(Fig. 2.12). Excessive water supply by lift irrigation schemes has resulted in waterlogging of these soils in the central valley portions of the Koyna river.

The black cotton soil has a high content of calcium and magnesium carbonate and low content of nitrogen, potash and phosphate (Umarjikar, 1983). This soil is therefore classified as of pedocal type on account of its high calcium content. The black cotton soil is alkaline with pH around 7.2 to 8.00. The deep soils in the middle reaches at a rainfall around 1500 mm show

Fig.2.8 : Table lands formed by laterites at Sadavaghapur (elevation 1100m above MSL).

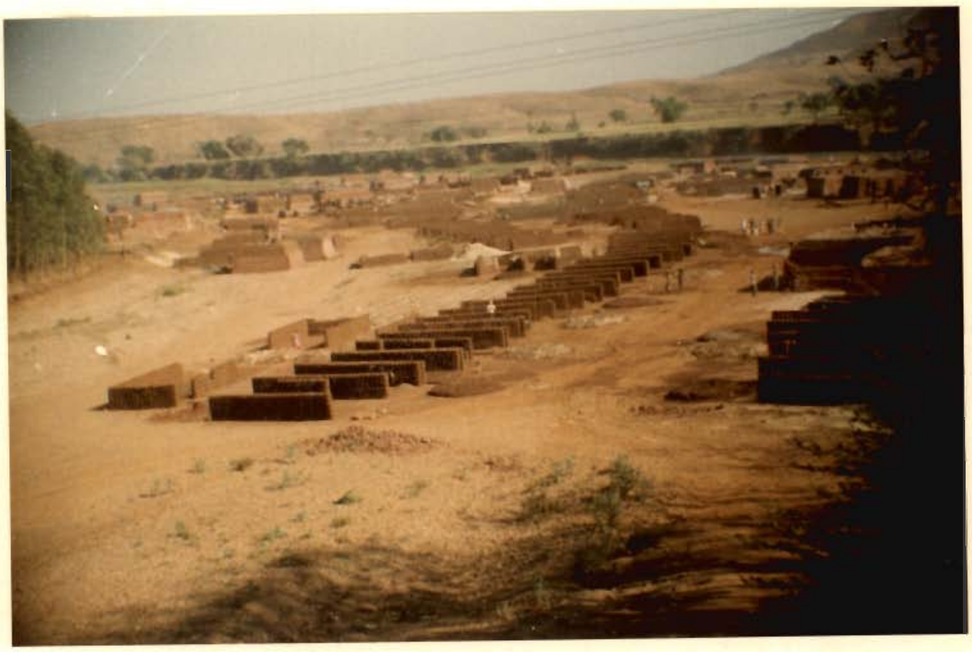


Fig.2.9 : Extensive brick-making along the Koyna river at Patan (middle reaches).

Fig.2.10 : Lateritic soil found at lower elevations.

Fig.2.11 : Red soil found due to red bole.

Fig.2.12 : Black-cotton soil in the lower reaches.

kaolinite. In low rainfall areas in the lower reaches they show montmorillonite. Owing to high montmorillonite content, the soil has plasticity (Rajguru, 1970) and is sticky when wet and develop polygonal cracks on drying.

2.3 GEOMORPHIC UNITS

The major geomorphic features have already been discussed in the section on physiography (chapter 1). The following sections deals only with the broad geomorphic units which are important from the point of view of occurrence of groundwater. The units, therefore, are termed as 'hydrogeomorphic units'. Four distinct units have been identified with the help of LANDSAT FCC 2, 3 and 4 (Fig. 2.13). They are (i) Plateau (flat), (ii) Dissected plateau, (iii) Pediment (shallow buried) and (iv) Pediment (deep buried). The salient features of each unit are described briefly as follows :

(i) Plateau (flat) : The flat plateaus are formed at the higher elevations. These cap the basaltic lava flows and consists mainly of laterites. They also form extensive table-lands (Fig. 2.8). These show fine texture and light tone in the imagery. Although the laterites forming flat topped plateaus are porous and permeable, they have poor potential to hold groundwater in storage. However, they give rise to a number of springs at the contact with the basaltic flow below.

(ii) Dissected Plateau : The dissected plateau show coarse texture and dark tone in the imagery. They form very rugged and undulating topography with steep slopes, at places. Most of the geomorphic features discussed earlier (chapter 1) are found in this unit mainly. Groundwater potential in shallow aquifers in this zone is poor. However, the borewells tapping deep aquifers often yield good quantity of groundwater.

iii) Pediment (shallow buried) : These are elongated belts of rock-cut surfaces forming the low relief areas and show light brownish tone and coarse texture. These occur as the transition zones between the hills and the neighbouring plains. The soil thickness is generally moderate (<3m). They have moderate to good potential for groundwater in the shallow aquifers.

(iv) Pediment (deep buried) : The deep buried pediments form low topographic area. Depth of weathering and soil thickness is more than 5m. This zone is distinguished from the shallow buried pediments on the basis of intense cultivation, dark red tone and fine texture. They have very good potential for groundwater.

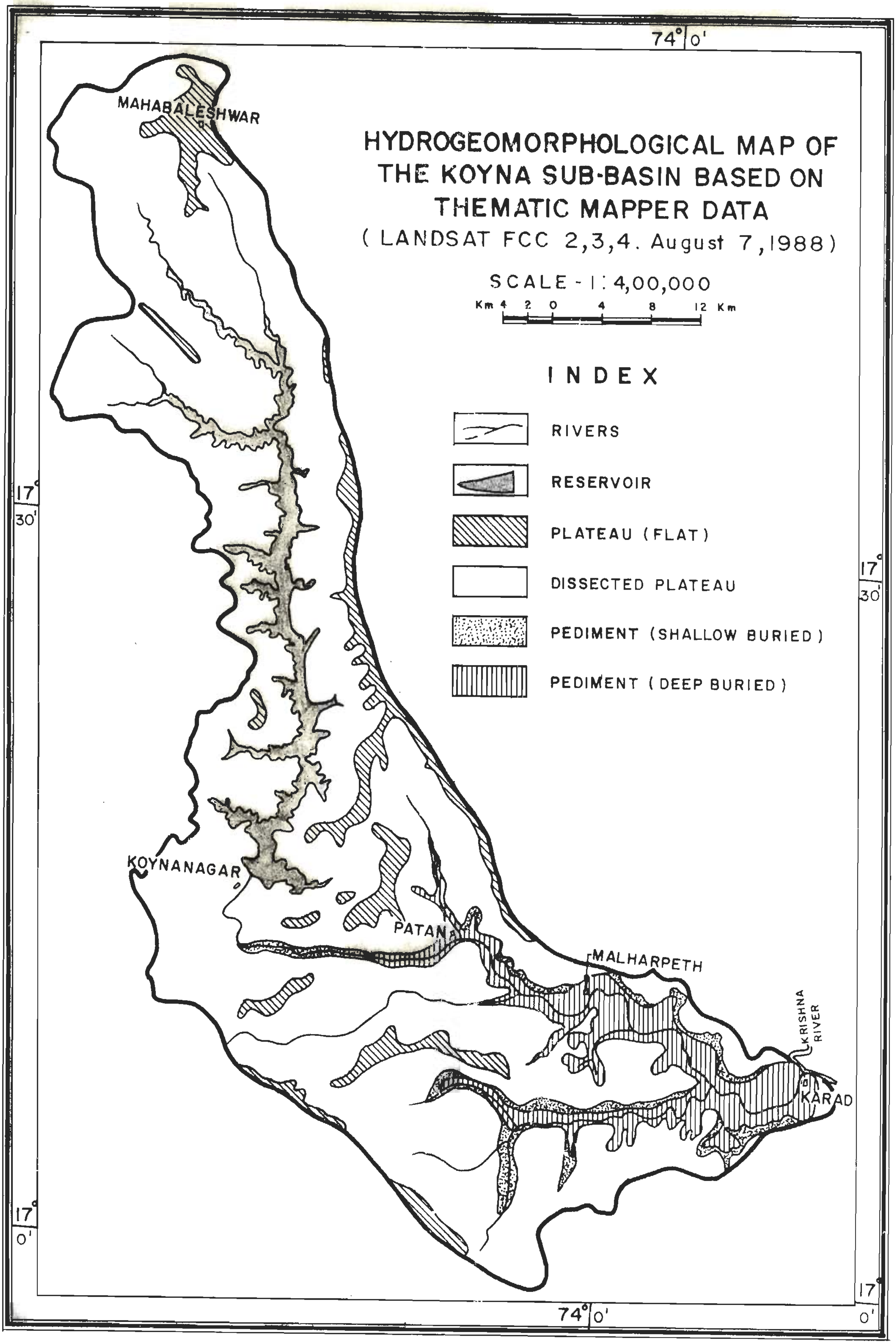
2.4 STRUCTURE

The major structural features found in the area are joints, lineaments and major faults.

In the upper reaches, major sets of joints trend NNW-SSE, N-S and NE-SW and less commonly E-W. All these joints are sub- vertical to vertical. In the middle and lower reaches, three sets of near vertical major joints are present. They trend between N20°E-S20°W to N20°W-S20°E, N40°E-S40°W, N60°W-S60°E to N80°W-S80°E. Horizontal to sub-horizontal joints or sheet joints at the interval of 0.2m to 2.0 m are also found at places towards top of individual flow layers. Very often the joints are closely spaced. Vertical joints are more prominent in the massive part of a flow and they do not extend into the vesicular/fragmentary top of the flow or the flow below. Columnar joints are well developed in the flows exposed along the scarp faces.

Based on aerial photographs and satellite imageries, the major lineaments were demarcated in the area (Fig. 2.1). The rose diagram, based on 162 measurements of the lineaments indicates prominent trends as NE-SW, N-S and NW-SE as (Fig. 2.14)

Balsundaram and Srinivasan (1971) observed the Koyna sub- basin to have been traversed by several other lineaments trending N-S and NE-SW. Powar (1981) suggested the presence of



P.K. NAIK

FIG.2.13-HYDROGEOMORPHOLOGICAL MAP OF THE KOYNA SUB BASIN

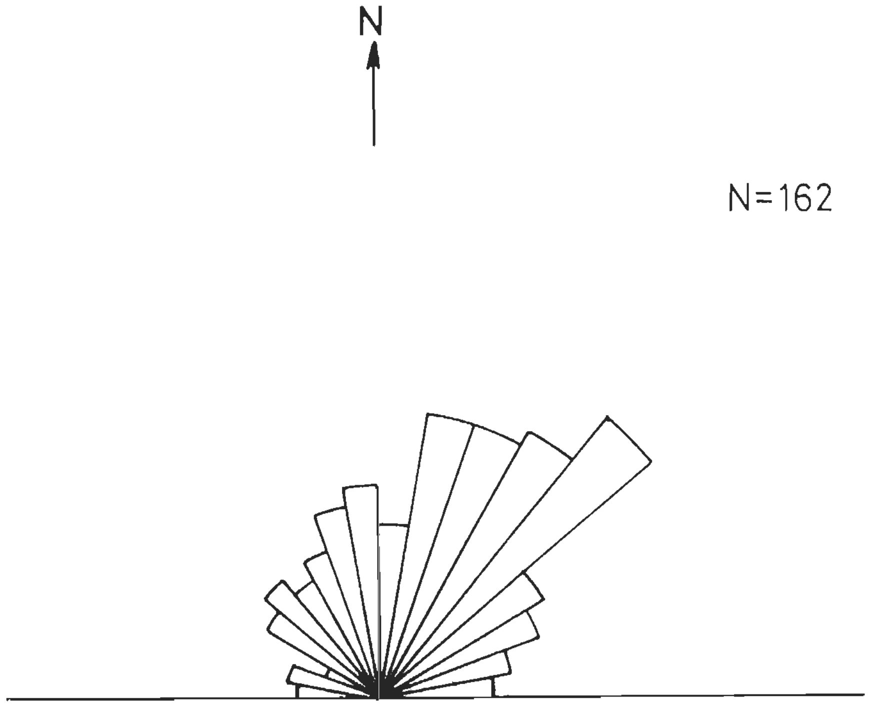


FIG. 2·14-ROSE DIAGRAM OF THE MAJOR LINEAMENTS a prominent lineament trending N0°-N9° in the area and named it as 'Koyna lineament', Kaila et al (1981) have proved the presence of a N-S trending fault in the basement rocks just below the Koyna dam.

Originating from Mahabaleshwar in the north, the river Koyna flows southerly along north-south lineaments for about 70 km upto Helwek, after which it takes an abrupt near right angle turn towards east. In its East-West trend, it flows along several lineaments as well. The channel gradient at the confluence zone for the river Koyna is nearly $1/40^{th}$ time less than that of the source region while in case of the river Krishna it is nearly half, i.e. $1/20^{th}$ time. The longitudinal profile (Fig. 1.10) also indicates that Koyna sub-basin after few kilometres downstream of its source, attains lower level than the main valley (Krishna) thus signifying a higher rate of downward erosion. This could have seen achieved either by higher discharges through the channels or due to the presence of a weaker zone over which the Koyna flows or both.

Umarjikar (1983) found asymmetrical transverse profile for the Koyna river. The asymmetry may be indicative of structural control (Thornbury, 1961). Also, the high bifurcation ratio of the order of 5.08 implies structural control of the drainage network (Strahler, 1964). The streams following the major lineaments in the area only testify the same.

2.5 TECTONICS

A strong belief of the earth scientists in the stability and a aseismic nature of the Peninsular shield was shaken after the occurrence of the Koyna earthquake on 11th December, 1967. It was felt over a radius of 700 kms with Koynanagar as its epicentre. It caused a great damage to life and property. Landslides, collapse of rubble masonry, opening of fissures (N11°E-S11°W) confined to surfacial zone, were some of the important effects noticed immediately after the earthquake. On the west of the Western Ghats along the base of the escarpment the steep hill slope forms, there is a line of hot springs in the Konkan parallel to the coast. Almost all the hot springs showed a sharp rise in temperature (5° to 9°C) immediately after the earthquake (Gupte, 1968). The west coast hot spring zone is a prominent feature and may be indicative of a deep seated fault. The Panvel Flexure along the western coast has its alignment along this probable fault.

Since impoundment of water in the Koyna reservoir, the seismic activities have been continuing for the past three decades in the area with varying degree of intensities. About 60 earthquakes of more than 4 magnitude have been recorded during this period along with more than one hundred accelerogrammes including that of the Koyna earthquake of December 11, 1967 with peak ground acceleration of 0.64g (Patil et al, 1992). Thus continuing seismic activity for the last three decades in the Koyna reservoir area since the year 1963 following impoundment is unique seismotectonic feature. Recent earthquakes of 9th september, 1993 and 1st February, 1994 of the order of magnitudes 4 and 5.5 respectively only support this inference.

More than 107 instances of reservoir induced seismicity have so far been reported (Guha and Patil, 1990) world over. Maximum magnitude of 7 at the Koyna reservoir is the highest so far recorded due to any reservoir in the world, the second being at Hsinfengchiang reservoir (M6.1) in China (Patil et al, 1992).

The plots of the epicenters in the Peninsular shield by Guha and Padale (1981) has indicated that the instability is localised in the marginal area and mostly to those areas within which rifts and faults are present. The existence of three major structural features in the form of Son-Narmada belt (West, 1962), Konkan offshore faulted belt (Krishnan, 1953) and Cambay Graben belt, have rendered instability to the Deccan plateau.

Bramham and Negi (1973) have found the axes of gravity low between Karad and Koyna and have expressed that the seismicity at Koyna is due to a rift concealed below the Deccan volcanics. In the Koyna foundation studies, 2 metres of wide shear zone was noted with prominent slickensides in crushed zone (GS1, 1974). Auden (1975) from the focal depths of aftershocks suggests that the seismic disturbance is virtually confined to the basement lithosphere.

The deep seismic sounding surveys in the area by National Geophysical Laboratory, Hyderabad have confirmed the presence of a fault in the basement rock reaching the Moho and located it slightly west of the Koyna dam and another fault below the town of Karad (Kaila et al, 1981). They have suggested that the region between Koynanagar and Karad is the upthrown block.

Inspite of the faults present in the basement rocks, it is noteworthy that there are very few shear zones actually located and that there is no surfacial evidence of displacement in lava flows. Guha and Padale (1981) suggest that the acceleration of the Indian Plate during the lower Eocene could have resulted into tensional stresses within the plate to give rise to rifts and faults in the area.

Tondale and Ayyangar (1992) opine that the isostatic readjustment along the pre-existing seismologically active fault zones in the basement and the movement of the Indian Sub-continent towards NE reactivate the tectonic activities in the region.

At the surface level as well, the tectonic activities are very much evidenced with the help of the geomorphic features. Gupte (1964) and Umarjikar (1983) have cited examples of river capture in the Koyna sub-basin. Due to resistance to weathering and denudation, hard rock areas generally exhibit uneven and undulating topography. Hence the water divides are well defined not only for the major river basins but also for the smaller sub-basins. Interbasinal transfer of surface water in such cases is very much uncommon except by the trunk streams at the outlet areas. But, a stream named Thomse Nala in the middle reaches of the Koyna sub-basin shows this aberration, by transferring surface water from the Mand sub-basin in the North to the Koyna river in the south cutting across the 860 m altitude of water divide (Fig. 2.15). The Thomse Nala was earlier a tributary of Mand river flowing in the course of the Phanshi Nala in the North of the surface divide, but due to the phenomenon of river capture, this stream has cut a deep gorge through the dividing ridge down the steep slope before it joins the Koyna near Nisre. While most of the streams in the areas joining the Koyna along the left bank are short and swiftly moving, the Thomse stream has a longer valley and flows through a 15 to 20 m deep gorge after its abrupt bend. There are large pot holes along the valley floor. A series of five nick points are represented by cascades, rapids and water falls with numerous pot holes. All these features suggest the increased competency of the stream. The deep incision of the gorge by Thomse stream might have been due to headward erosion. There are numerous examples of such geomorphic features in the Koyna sub-basin thus indicating slow rejuvenation taking place in the area.

River terraces are the topographic steps in the valleys and usually represent the former level of flood plains. The presence of alluvial terraces in the valley reflects the former cut and fill activity in the basin. The terraces in the Koyna sub-basin occur at two distinctly different levels. The one formed of older alluvium occur 10 m to 25 m high above the modern river bed level, while the other formed of younger alluvium occurs around 4 metres above the present river bed. These are unpaired terraces and indicate slower and more continuous rejuvenation (Howard et al, 1968), thus suggesting crustal movements of the epeirogenic type taking place in the area.

While summarising the observations made by several workers and the author in the area, it is evidenced that the Koyna sub-basin and for that matter the Deccan Plateau is no more a stable land and has indication of deep crustal movements and neo-tectonic activities taking place in the area.

2.6 SUMMARY

Geologically, the Koyna sub-basin occupies a terrain characterised conspicuously by flat topped hills which are commonly known as 'Deccan Trap'. These traps are formed by the basaltic flows. At times these traps are covered by laterites at higher elevations. In the lower reaches of the river valleys alluvium is found.

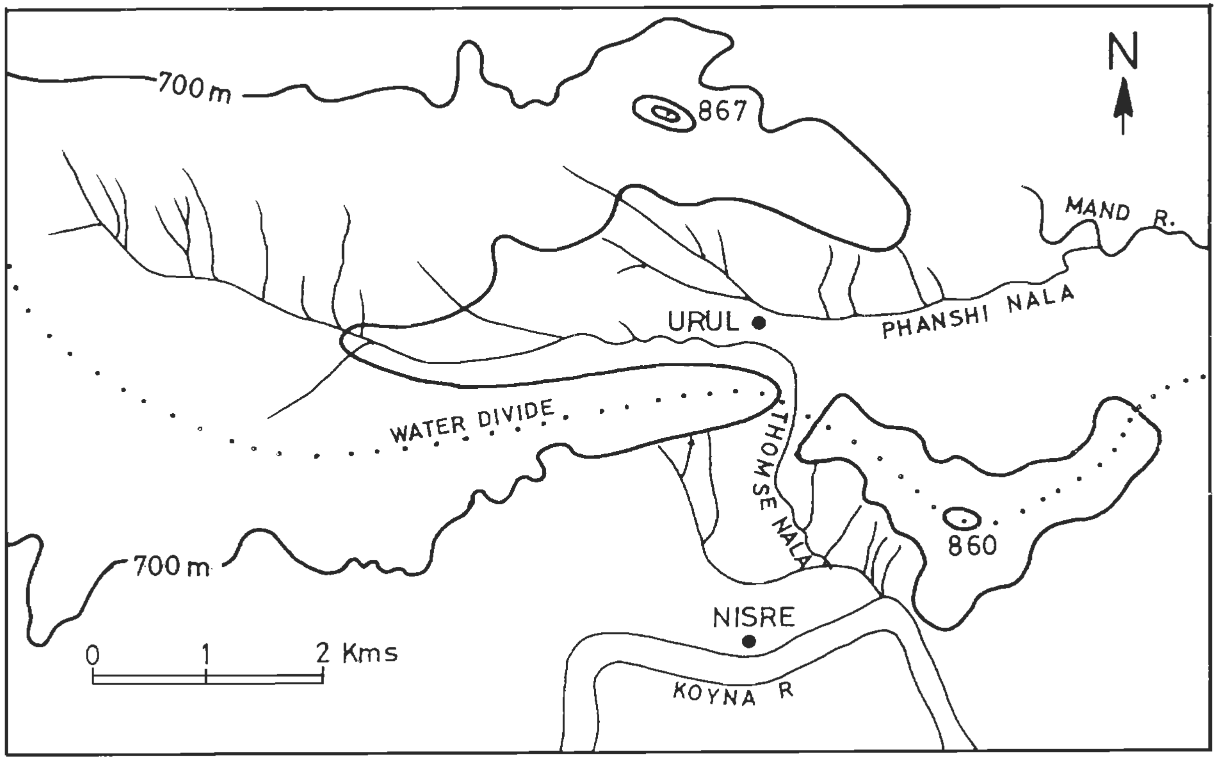


FIG.2·15–AN EXAMPLE OF RIVER CAPTURE IN KOYNA SUB BASIN NEAR NISRE IN MIDDLE REACHES

Each basaltic flow consists of mainly two trap units, viz. (i) massive unit and (ii) vesicular unit, the former occupying the lower portion and the later the upper part of the flows are commonly separated by redbole bed.

The soils of the area belong mainly to two types, viz. (i) lateritic soil and (ii) black cotton soil.

Four hydrogeomorphic units, viz. (i) plateau (flat), (ii) dissected plateau, (iii) shallow buried pediment and (iv) deep buried pediment have been identified on the basis of thematic mapper data. The deep buried pediment forms the most potential zone for groundwater occurrence in shallow aquifers.

The major structural features found in the area are joints, lineaments and major faults. Sub-vertical to vertical dipping joints are common. Horizontal to sub-horizontal joints commonly known as sheet joints, are also found at places towards the top of individual flows. The lineaments indicate prominent trends as NE-SW, N-S and NW-SE. The drainage network is mostly controlled by lineaments. The Koyna river flows along a north-south trending lineament in the upper reaches. It trends east-west along several lineaments in the middle and lower reaches. The bifurcation ratio of the order of 5.08 indicates structural control of the drainage network. The longitudinal profile and the assymmetrical transverse profile indicate structural control of the Koyna river.

Unpaired river terraces, river piracy with distinct knick points causing inter-basinal transfer of surface water etc. indicate slow but continuous rejuvenation in the Koyna sub-basin. An analysis of the structural and tectonic features indicates that the Koyna sub-basin and for that matter the Deccan Plateau is no more a stable land as conceived earlier by several workers but have evidences of deep crustal movements and neotectonic activities taking place in the region.

Chapter 3

Occurrence of Groundwater

3.1 INTRODUCTION

Field investigations together with the observations in 545 wells indicate the occurrence of groundwater in the basaltic rocks, laterites, alluvium, soils and talus deposits (Table 3.1). The shallow aquifers upto about 25 m depth are being exploited by dugwells and the deeper ones by borewells. On the basis of 240 dugwells and the data collected from 305 borewells, the occurrence of groundwater in various types of aquifers is described herewith.

3.2 OCCURRENCE OF GROUNDWATER IN VARIOUS TYPES OF AQUIFERS

3.2.1 Aquifers in Basalts

In the exposed section of the sub-basin, 46 basaltic flows have been identified (Fig. 3.1). Table 3.1 shows that thickness of the flows varies from 10 m to more than 60 m. As discussed in Chapter 2, the individual lava flows consists of two separate units, (i) the uppermost vesicular/ amygdaloidal basalt and (ii) the non-vesicular massive basalt. The water-bearing properties of these two units differ considerably. Their hydrogeologic significances are described briefly as follows :

3.2.1.1 Non-vesicular basalt

The non-vesicular basaltic unit is primarily hard and compact. It has negligible primary porosity and permeability. It generally acts as impermeable bed. However, the process of weathering, the jointing and fracturing at places, have made these massive basalts moderately permeable (Figs. 3.2 and 3.3). The depth of weathering and openness of these joints and fractures are more pronounced in the upper most flow at any given locality.

3.2.1.2 Vesicular/amygdaloidal basalt

The uppermost part of each unit of lava flow is characterised by vesicular nature. Unlike the lower non-vesicular massive part, the upper vesicular basalt possesses primary porosity and at places are permeable. It is weathered in most parts of the area. Even if the unit occurs at greater depth, the weathering character is conspicuous, as each lava flow was exposed to weathering and erosion for some time in geological past before the outpouring of the lava. The frequency of vesicles increases towards the top of the flow. Very often, these vesicles in it, especially in the upper part, are interconnected, making it highly permeable. However, many times, the vesicles found in a section of the unit immediately above the massive part are not interconnected and thus such parts are not permeable and behave like massive basalt. Hence, gradation from such compact and sparsely connected vesicular part to highly porous vesicular part above is quite conspicuous. Thus the permeability increases gradually from bottom to top in a particular flow. The vesicular basalts are generally capped by thin layer of poorly permeable redbole of thickness 0.2 to 1.3 m. The presence of redbole generally indicates the presence of possible water-bearing vesicular horizon underneath. Often, the vesicles are filled with secondary minerals such as quartz etc. and are closed. In such cases the vesicular basalt has poor permeability and does not yield appreciable amount of groundwater.

3.2.2 Aquifers in Laterites

Laterites are highly porous and permeable. Groundwater percolates down very rapidly through laterite and thus they have poor storage at shallower depth. However, whenever the downward movement of groundwater is blocked by underlying lithomargic clay, laterites form aquifers.

3.2.3 Aquifers in Alluvium

Isolated patches of clay rich alluvium, have developed along the banks of the Koyna river and other tributaries. Hardly few sandy or gravelly zones occur at the bottom of the alluvial

Table 3.1 Distribution of Aquifers in the Koyna Sub-basin

Sl. No.	Aquiferous Units	Elevationwise Distribution (m above MSL)	Thickness (m)	Occurrence
1.	Flow 1	Upto 570 Base not Exposed	10+	Lower reaches of the Koyna sub-basin
	Flow 2	570 - 580	10	Central valley portion; large exposure in the lower reaches
	Flow 3	580 - 640	60	Main valley and recharge zones; greater coverage
	Flow 4	640 - 700	60	Recharge zones in the foothills.
	Flow 5 to 46	700 - 1280	10 to more than 60	Hilly areas
2.	Laterites	Above 975 in southern and eastern part and above 1280 in northern part	Varies; 2-30(?) Thick in north and thin in south	Form cap rocks at different elevations
3.	Alluvium	-	0-20	On the banks of river courses (especially the Koyna river)
4.	Soil	-	0.50 - 8 (Black cotton) 0.50 - 20(?) (Lateritic)	Above basaltic flows and Laterites
5.	Talus	-	0 - 20	In higher elevation on hill terraces and slopes ; in lower elevation on flow 4 and rarely on flow 3.

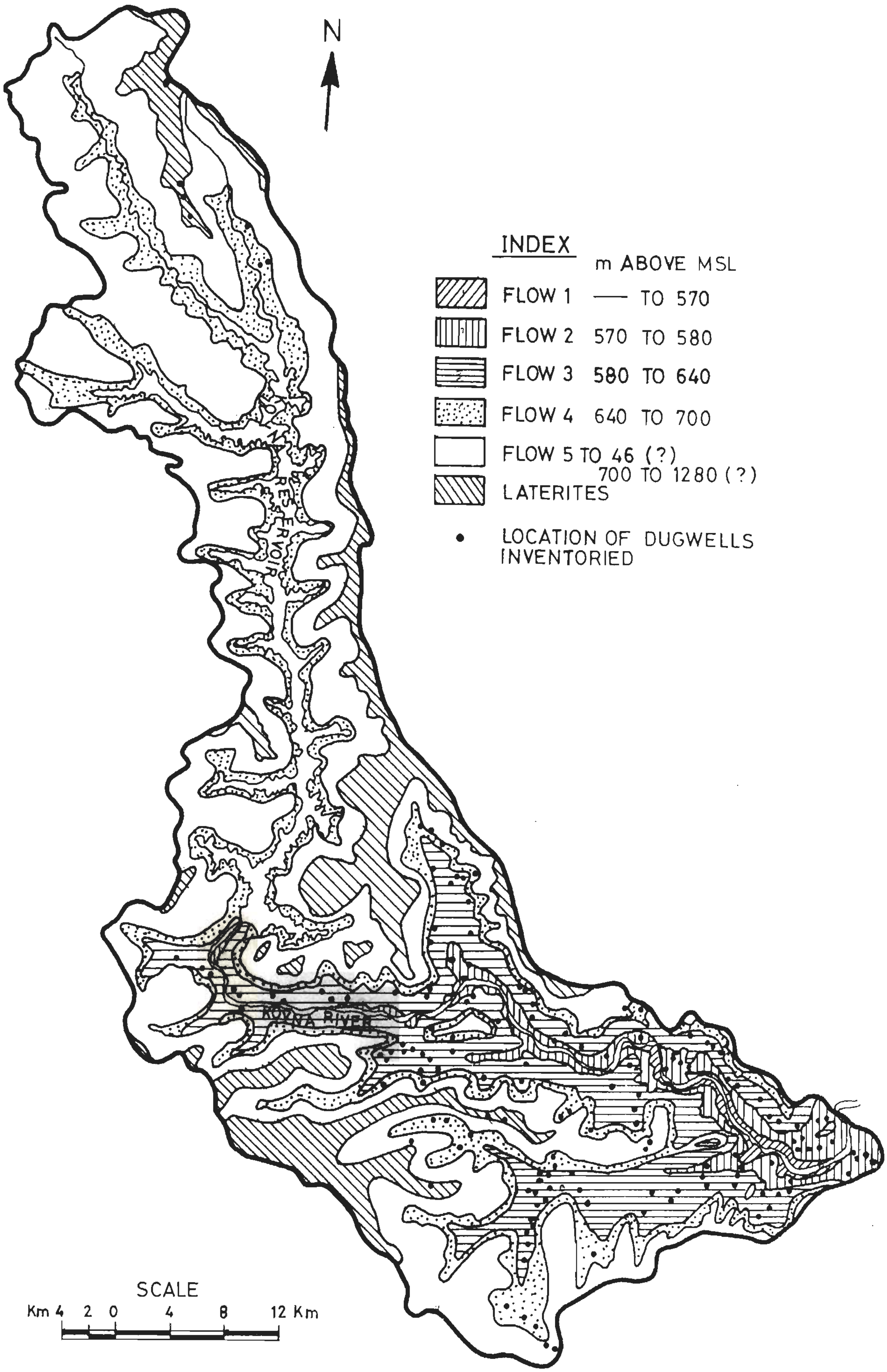


FIG. 3·1 – DISTRIBUTION OF DIFFERENT BASALTIC FLOWS IN KOYNA SUB-BASIN

Fig.3.2 : A dugwell tapping highly weathered and fractured non-vesicular massive trap at Yeravle in the lower reaches.

Fig.3.3 : Jointed non-vesicular basalt in a dugwell near Malharpeth in the middle reaches.

sections, which, because of their porous and permeable nature,form worthy locales of groundwater. However, the water-bearing properties of the alluvium are largely controlled by the sand/clay ratio of a particular area.

3.2.4 Aquifers in Soils

The black cotton soils are of very low permeability due to the presence of clay-content in them. On higher grounds, the weathered profile of basalt thins out and the clay is sometimes absent. The black cotton soils form aquifers mostly in the central valley portions. They have maximum thickness of about 8 m in the area.

3.2.5 Aquifers in Talus Deposits

Thick pile of talus or deposits occur on the hill terraces and gentler slopes (Fig. 3.4) irrespective of height. These cover the basaltic flow-4 in the foothill zones. They also cover discreetly the basaltic flow-3. The talus deposits have a thickness of about 15 to 20 m in the foothills and thin out gradually away from the hills. These consist of unconsolidated materials of boulders, pebbles, soils, clay etc. produced by the down slope movement of the weathered and eroded products of basalts and laterites. These are quite porous and permeable and form good recharge zones.

3.3 DEPTH OF OCCURRENCE OF GROUNDWATER

Based on 240 dugwells and 305 borewells, the groundwater is found to occur at shallow and deeper levels in this sub-basin. Accordingly, aquifers have been classified as shallow and deeper aquifers. The dugwells are generally not more than 12m deep (Fig. 3.5a & b). Most of them are 2-4m deep. Rarely they go beyond 25m depth. The borewells mostly of 150 mm diameter, are generally 30 to 80m deep (Fig. 3.6a & b) and rarely go beyond 90-100m depth.

Most of the borewells are 50-70m deep. The dugwells are thus tapping shallow aquifers and the borewells deeper aquifers. 88% of the dugwells tap shallow basaltic aquifers as against only 12% of wells in laterites, alluvium, soil, and talus deposits (Fig. 3.7). Thus, laterites, alluvium, soils and talus/colluvium deposits form shallow aquifers of secondary importance as compared to basaltic aquifers. Even in basalts, 57% of the dugwells are in the basaltic flow - 1 (Fig. 3.8) which is aerially more extensive as compared to any other flow.

3.3.1 Shallow Aquifers

The occurrence of groundwater in the shallow aquifers in basalts is controlled by the degree and extent of weathering, density of joints and fractures and its interconnecting vesicular features. The basaltic lavaflows in their present-day weathered zone consist of the following four water-bearing horizons.

(i) black cotton soil with yellow or reddish clay (0.5-8m)

(ii) highly weathered and highly jointed basalt (3-10m)

(iii) poorly weathered and highly jointed basalt (1-2m) and

(iv) poorly weathered and poorly jointed basalt which overlies the hard massive basalt (about 1-2m)

A typical dugwell section tapping all the horizons is shown in figure 3.9.

The second horizon, i.e. the highly weathered and highly jointed layer consists of both weathered vesicular and non-vesicular (massive)basalt , in which the joints in the upper portion are completely filled with clay. Gradually the clay content goes on decreasing downward and the joints become more open with decreasing effects of weathering. It is at this stage that the horizon has the highest permeability (horizon 3). Further downward the joints close up (horizon 4) and merges with the hard massive basalt.

Such horizons in basalts have also been observed by Buckley (1980) and Lawrence (1985) in Nion sub-basin, Madhya Pradesh, India. They have termed the bottom jointed layer as blocky

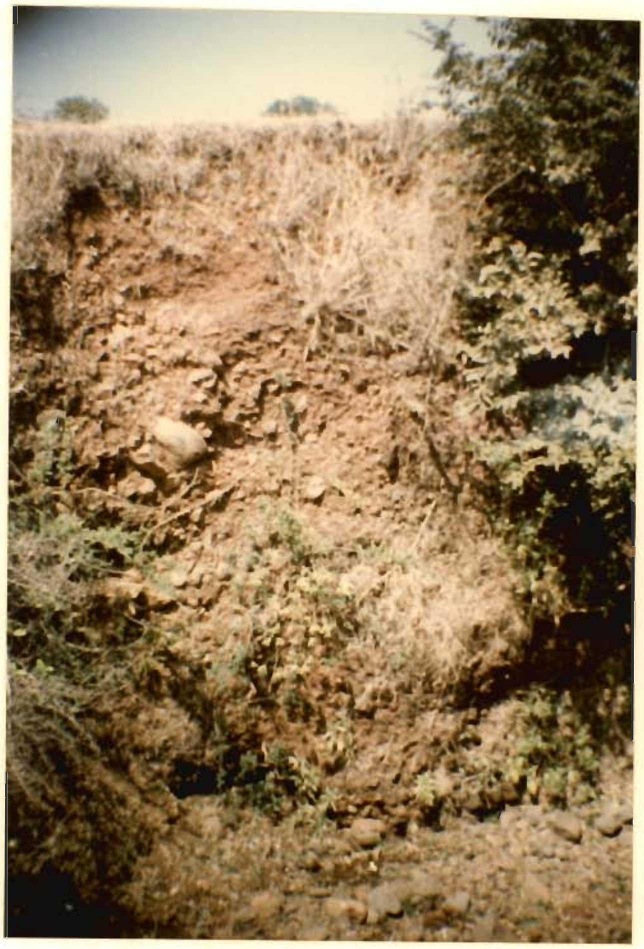


Fig.3.4 : A thick-pile of talus deposit (about 10m) near Mestivadi.

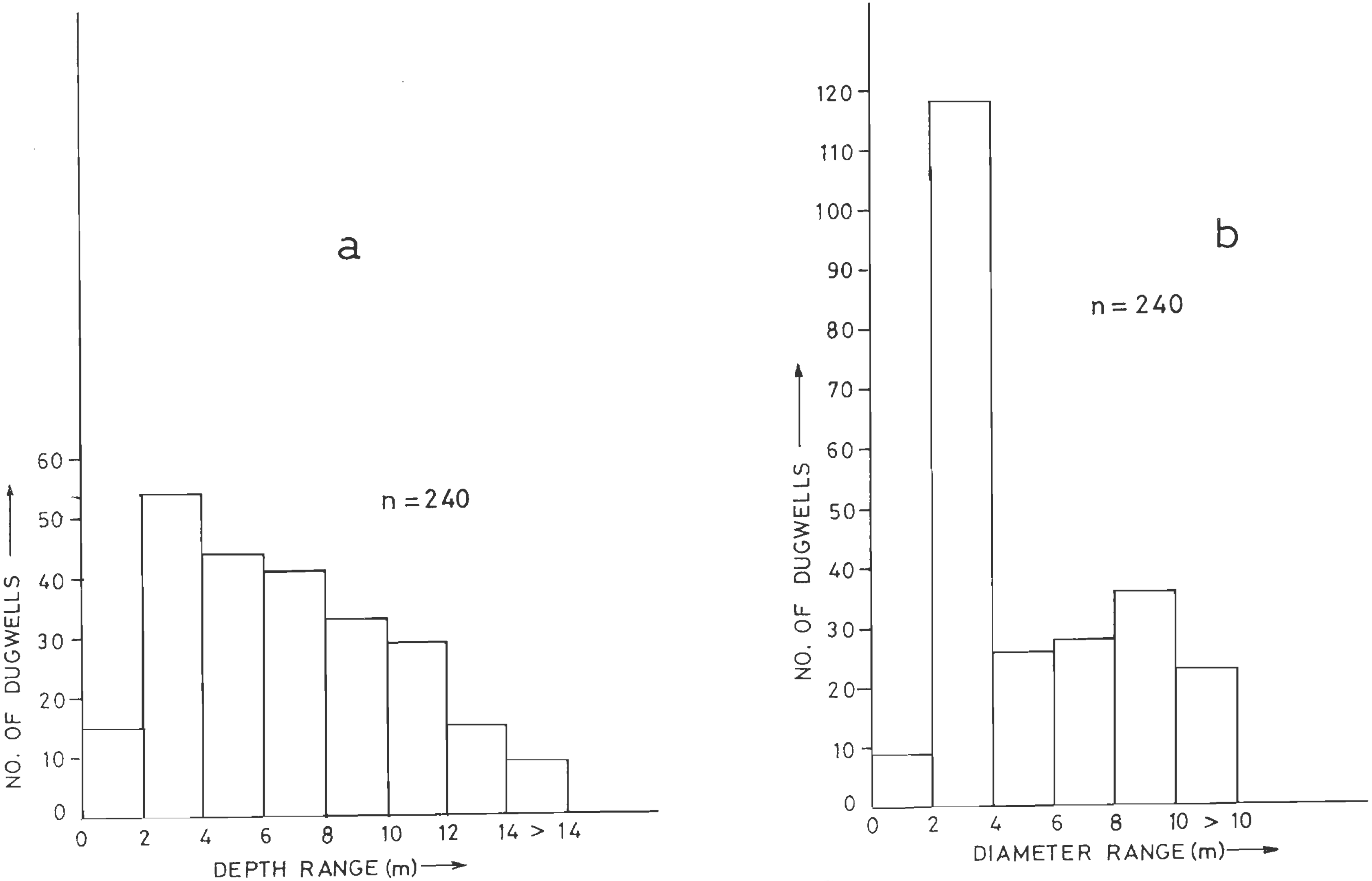


FIG. 3·5–NO. OF DUGWELLS SHOWING VARIOUS DEPTH AND DIAMETER RANGES

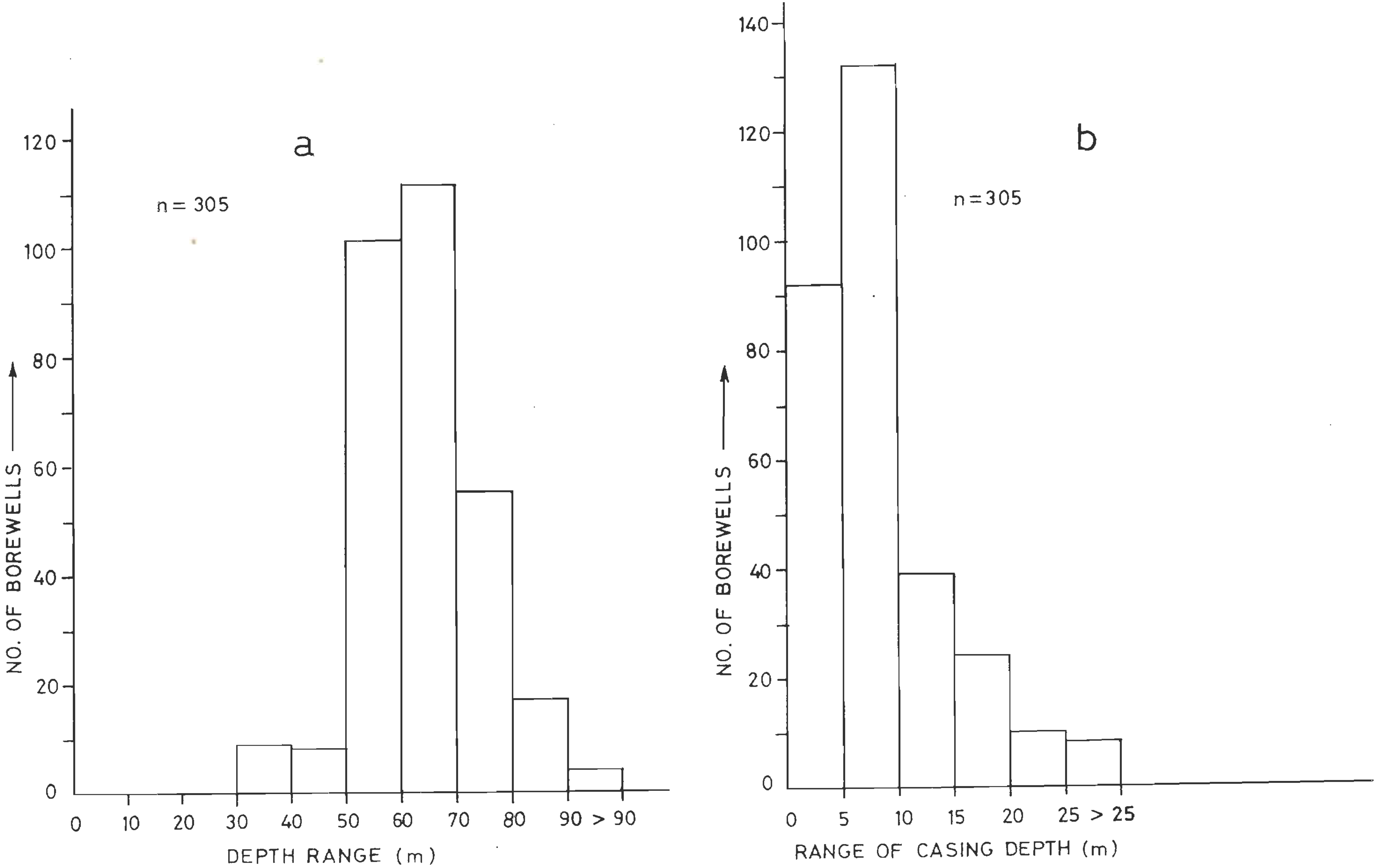
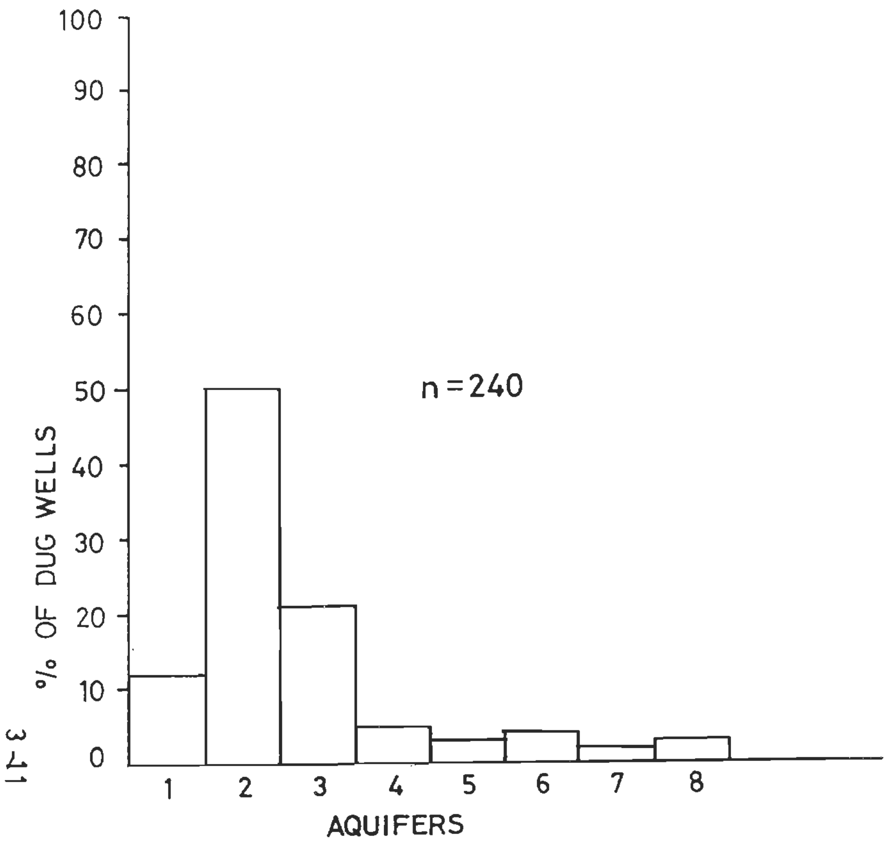


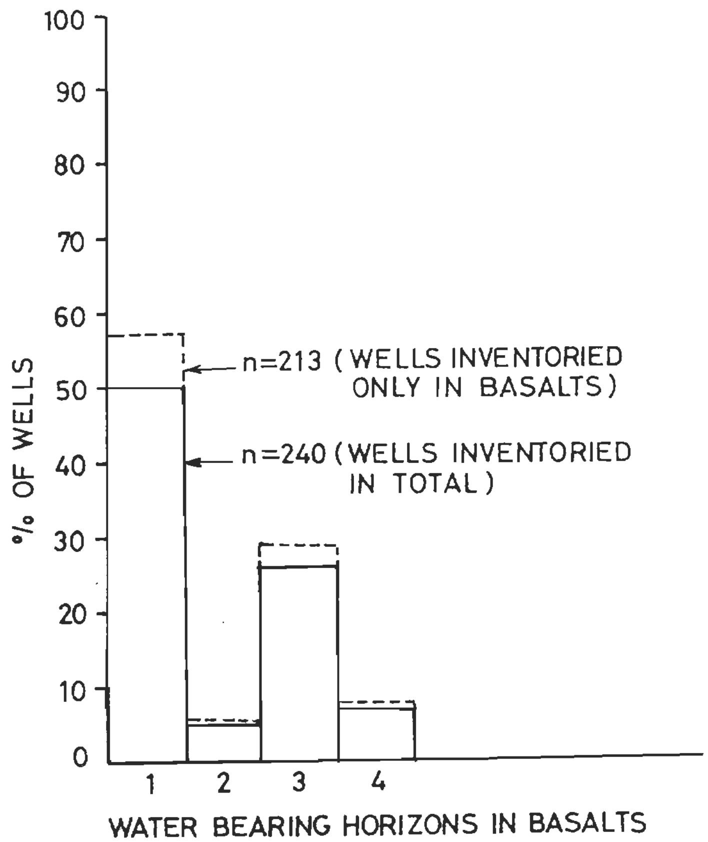
FIG. 3·6 – NO. OF BOREWELL SHOWING VARIOUS RANGES OF DEPTH AND CASING DEPTH



INDEX

1 FLOW 2
2 FLOW 3
3 FLOW 4
4 FLOW 5 TO 46
5 LATERITES
6 ALLUVIUM
7 SOILS
8 TALUS / COLLUVIUM

FIG.3·7-PERCENT OF DUGWELLS IN VARIOUS AQUIFERS



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1 POORLY WEATHERD POORLY JOINTED
2 POORLY WEATHERED HIGHLY JOINTED
3 HIGHLY WEATHERED HIGHLY JOINTED
4 WEATHERED VESICULAR

FIG.3·8-PERCENT OF DUGWELLS IN VARIOUS WATER BEARING HORIZONS IN BASALTS

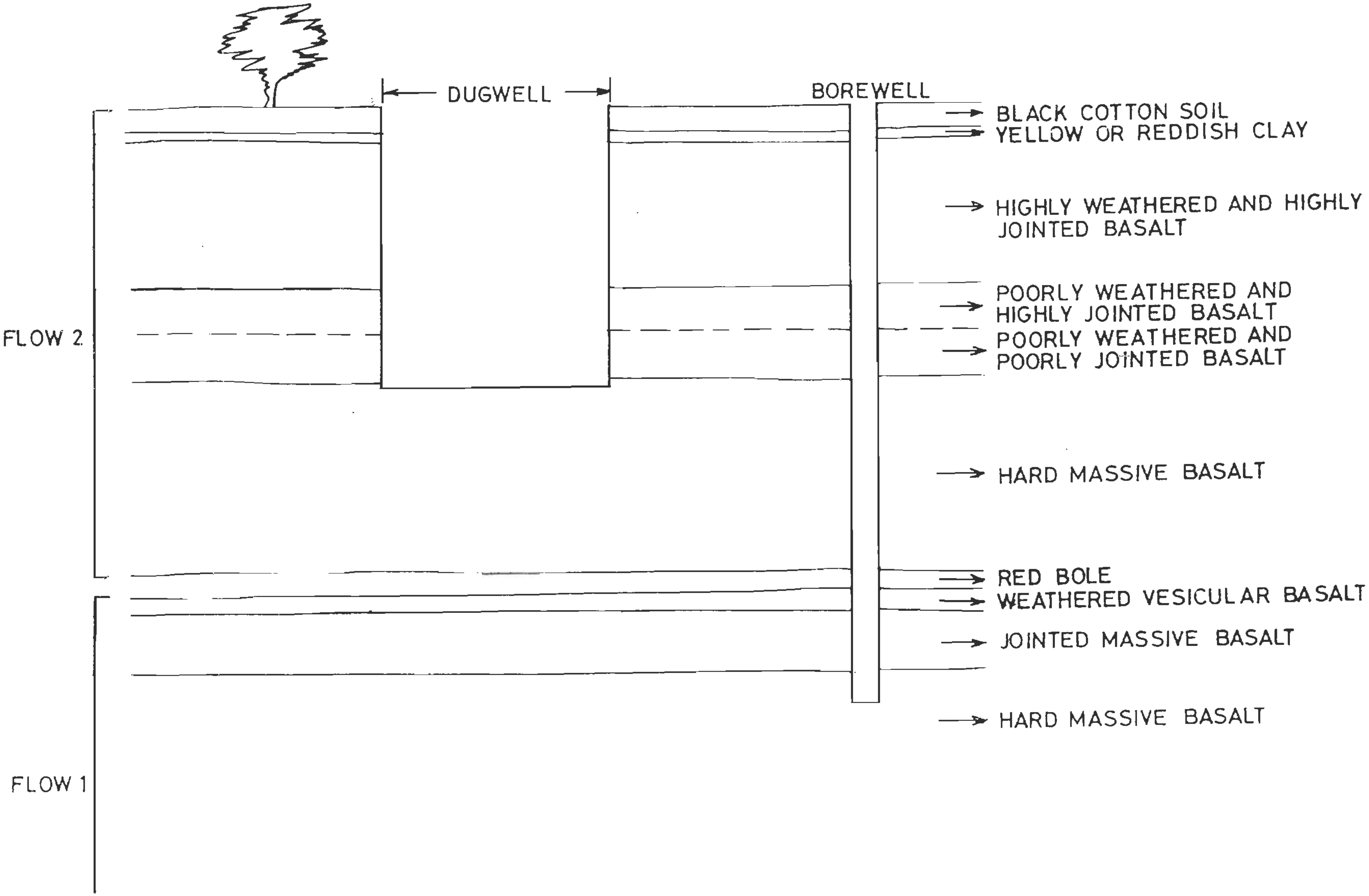


FIG. 3·9 — A SCHEMATIC SECTION OF A DUGWELL AND A BOREWELL basalt or broken basalt. But such blocky or broken nature of jointed basalts is not found in the study area.

Groundwater generally occurs under water-table condition in the shallow aquifers. However, in the central valley portion especially in the lower reaches of the Koyna sub-basin, where the thickness of black cotton soil is of the order of 5m or more, semi-confined condition occurs due to the presence of thick silty clay in the soils overlying the weathered and jointed horizons. As the water level declines through the black cotton soil and clayey horizon and through the other horizons the semi-confined condition changes to unconfined condition.

3.3.2 Deeper Aquifers

The deeper aquifers are associated only with basalts. Occurrence of groundwater in these deeper basaltic aquifers is found

(i) at the flow contact,

(ii) within the vesicular at the flow top and

(iii) within the fractured and jointed section.

Groundwater occurs under semiconfined condition when the productive horizon is located at a deeper level separated by fractured/jointed massive basalt above it. The fractured/jointed massive basalt unit acts as a semi-confining bed. Some potential aquifers encountered at greater depth and separated by compact and hard massive basalts are found to be in leaky confined to confined condition.

Borewell data indicate occurrence of groundwater in the massive traps due to fracturing although it does not show any surfacial indication. It is interesting to note that the more usual occurrence of the deeper groundwater within fractured and jointed basalt immediately underlying the flow top clayey layers, is the equivalent position of the most productive layers in the shallow aquifers. It is possible that traces of groundwater are present at most flow tops and continuity of the water-bearing layers must exist over a large area because the flow top material represents a continuous land surface. The variation in character of the flow top material when traced horizontally, however, has some variation in permeability.

3.4 THE RELATIONSHIP BETWEEN THE SHALLOW AQUIFERS AND THE DEEPER AQUIFERS

Since the shallow aquifer is a composite unit which cuts across several flows, the deeper aquifer layers under topographically high regions of a basin can become part of the shallow aquifer system at lower elevations. Transfer of groundwater thus takes place between two successive layers showing different degree of cross-cutting and depth of weathering. The fractures/lineaments act as conduit of groundwater from shallow aquifers to deeper levels.

3.5 OCCURRENCE OF GROUNDWATER IN RELATION TO STRUCTURAL AND GEOMORPHIC FEATURES

Borewells yielding 3000 litres per hour (lph) or more are considered high-yielding by Groundwater Survey and Development Agency (GDSA), Govt. of Maharashtra. These high-yielding borewells and the dugwells having unit area specific capacity of > 1.5 lpm/m/m^2 were plotted on a map showing lineaments and geomorphic features with a view to assess the effect of these features on the occurrence of water and yields of borewells and dugwells (Fig. 3.10). From the plot, the following observations could be made.

(i) Borewells along or near to the lineaments have high yields (Fig. 3.11, a and b), i.e. deeper aquifers have intrinsic relationship with the lineaments and in the shallow dugwells, the yields have little influence of the lineaments.

(ii) When two or three lineaments meet each other, borewell yield increases.

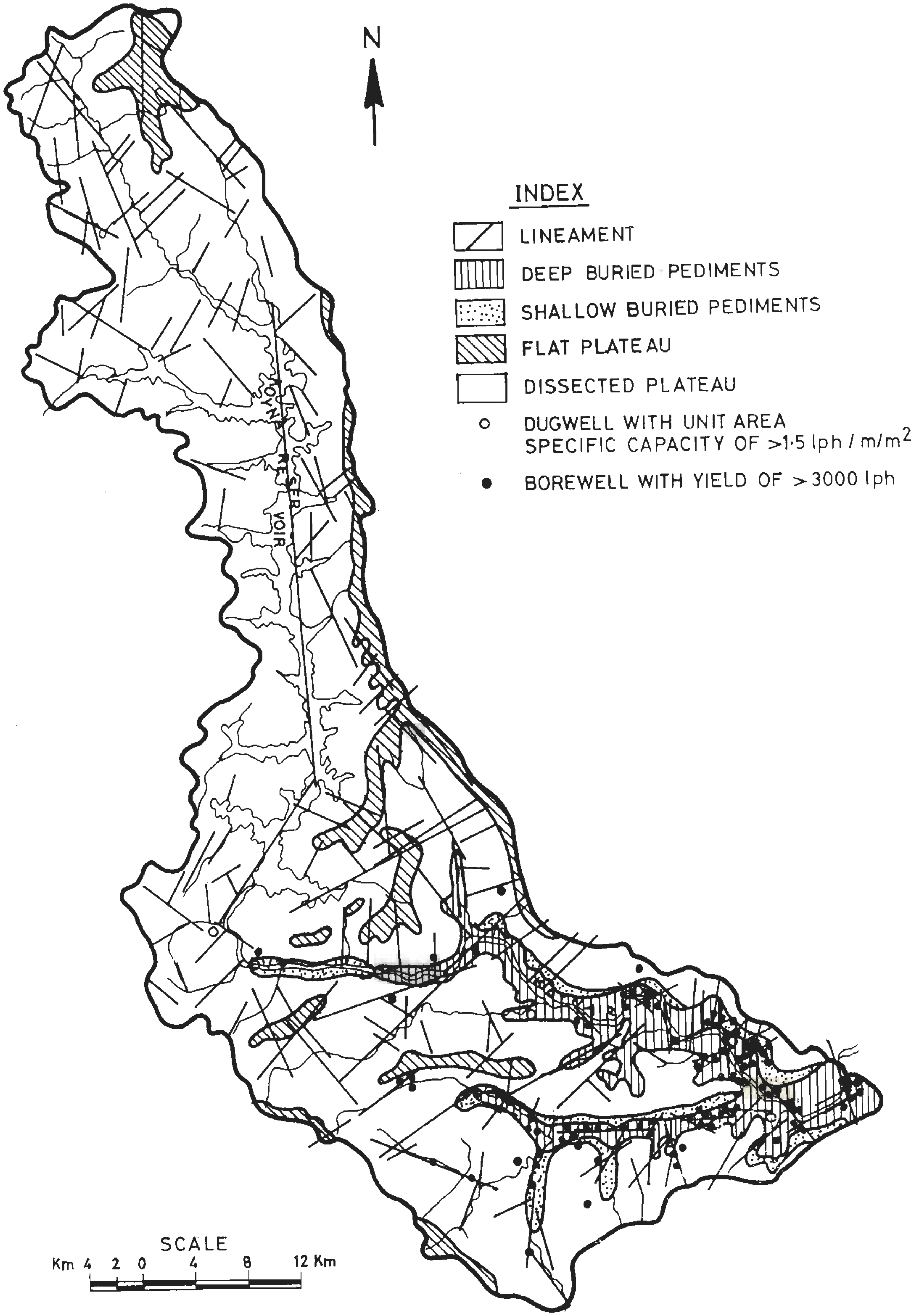
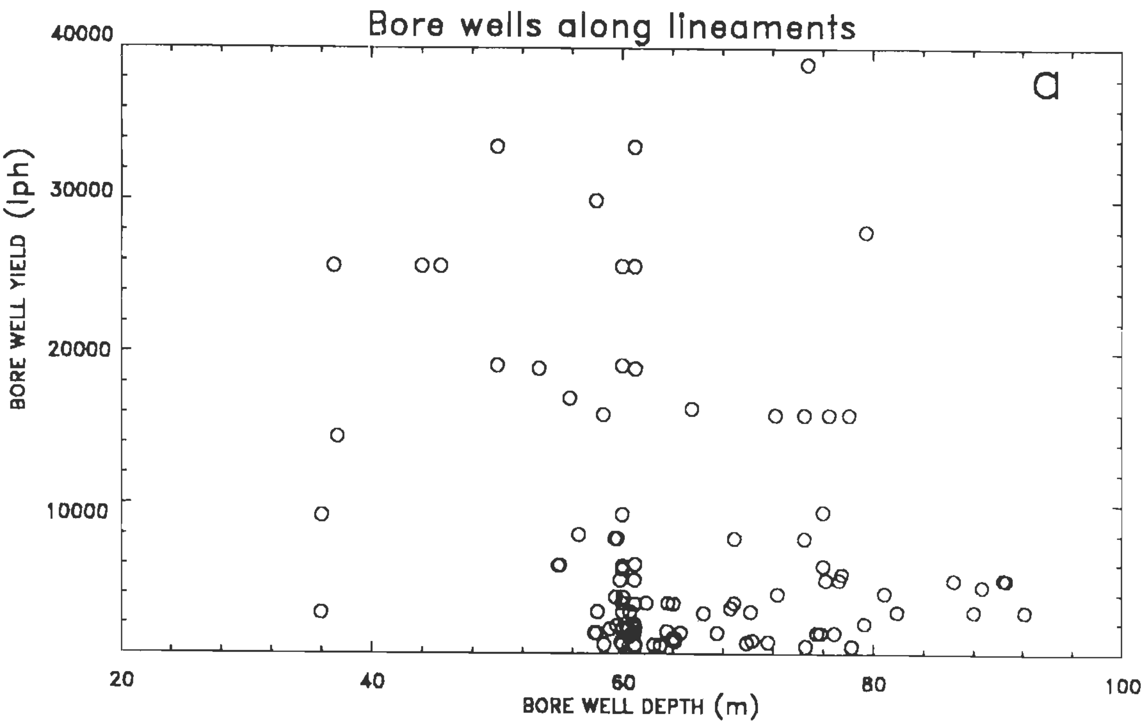


FIG. 3·10–LOCATIONS OF HIGH YIELDING WELLS IN RELATION TO LINEAMENTS AND GEOMORPHIC FEATURES



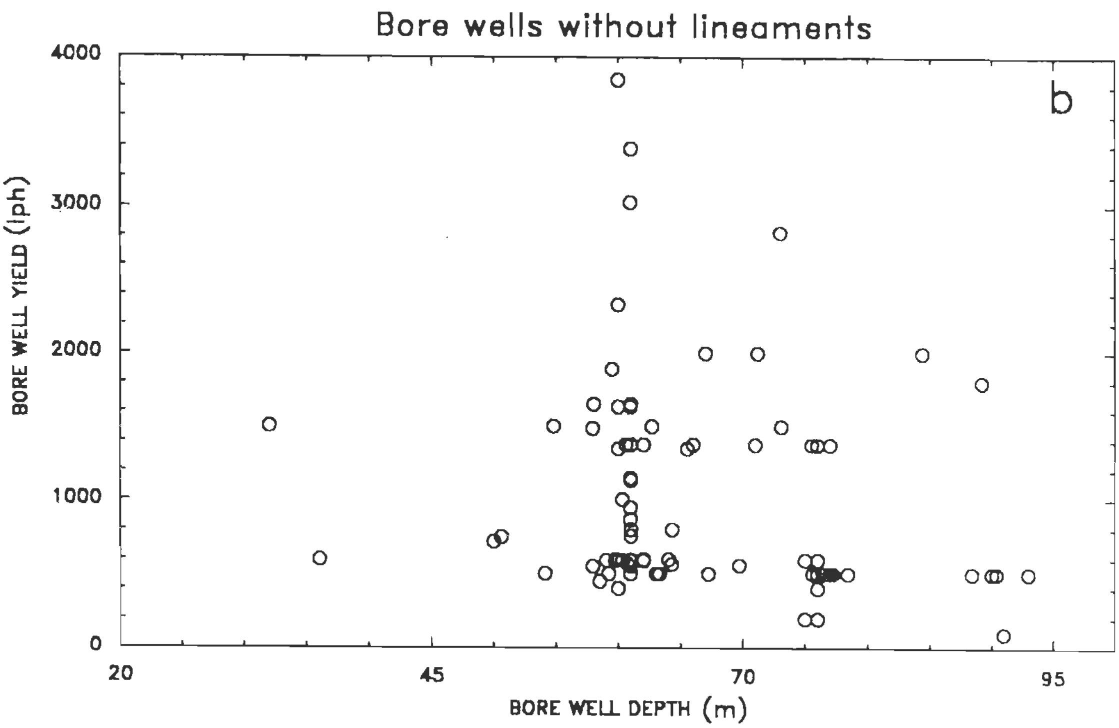


Fig 3 11 (a and b) . BOREWELL YIELDS IN RELATION TO LINEAMENTS

(iii) Borewell yields are more along the NE-SW trending lineaments.

(iv) NE-SW trending lineaments are high yielding in deep buried pediments than on the dissected plateau. The borewells in such areas have a yield as high as 39,000 lph.

(v) Borewells along the NW-SE trending lineaments are high-yielding if a stream is flowing along these lineaments and the borewells are very close to it. The borewells along the lineaments in this direction have a yield as high as 6000 lph.

(vi) Yields of dugwells are found to be related to the geomorphic features, i.e. shallow aquifers are related to the geomorphic features. The yield is high in deep buried pediments than in shallow buried pediments and dissected plateau.

On the basis of these observations it is concluded that deep buried pediments with NE-SW trending lineaments are the high potential areas for groundwater resources in the Koyna sub-basin.

3.6 ANALYSIS OF GROUNDWATER LEVELS IN SHALLOW AQUIFERS

Groundwater level data are important from the point of view of evaluation , development and management of groundwater resources. Such data are utilised for assessment of the changes in storage and its response to rainfall, evaporation, draft and surface irrigation. The levels also help to study the reaction of the groundwater regime to natural and artificial conditions of recharge and discharge in relation to geology, structure and hydrologic characteristics. The present study of groundwater levels in the area, therefore, has been carried out with the following basic aims :

(i) To know the depth to water levels in shallow aquifers.

(ii) To find out the seasonal fluctuations (premonsoon to postmonsoon) of water levels of dugwells.

(iii) To determine the long-term trends of groundwater levels vis-a-vis time and rainfall.

3.6.1 Depth to Water Levels

The depth to water levels (DTW) were recorded in 42 representative wells in 1988 and 47 representative wells in 1992 during premonsoon and postmonsoon periods (Table 3.2). Also premonsoon water levels in these wells were measured during 1989 and 1993. These wells are distributed throughout the area and were selected judiciously to represent the groundwater levels of the area as a whole. A perusal of Table 3.3 indicates that in the premonsoon period, the depth to water levels in majority of the representative wells (31% in 1988 and 32% in 1992) range from 2 to 4 m below ground level (bgl). The water levels generally do not exceed 8-10 m in more than 90% of the wells. In the postmonsoon period, the water levels rise and in most of the wells (60% in 1988 and 56% in 1992), the depth to water level is O to 2 mbgl. The depth to water levels in more than 95% of the wells do not exceed 4-6 mbgl in the postmonsoon period.

Some patches of shallow water table (0 - 2 mbgl) during premonsoon period are found west of Patan and Malharpeth in the middle reaches and west of Karad in the lower reaches of the Koyna valley (Figs. 3.12 and 3.13). These shallow zones are due to heavy recharge to groundwater through the extensive lift irrigation from the Koyna river. Sugarcane is the main crop in the central valley in the command area of the lift irrigation schemes (Fig. 3.14). Since it needs frequent irrigation throughout the year, these areas show very shallow water table even in summer. Although the patches west of Patan and Malharpeth have started showing water-logging conditions, the effect is felt only in the narrow strips and real deterioration of soils and crops has not yet started. But in the lower reaches west of Karad, where the land is more or less plain, the soils have started showing salt encrustation and productivity of crops such as sugarcane is gradually decreasing due to near water-logging conditions (Fig. 3.15 a and b).

During postmonsoon period although large parts of the sub-basin show water level of 0-2 mbgl in the sub-basin, in the western and southern parts the water levels are found to be 2-4 mbgl (Figs. 3.16 and 3.17). The shallow water levels in the postmonsoon period indicate good saturation of the aquifers during the monsoon period.

TABLE 3.2 : DEPTH TO WATER LEVELS (DTW) AND SEASONAL FLUCTUATIONS OF WATER LEVELS IN DUGWELLS

Well No.	Location	Depth of Dug-well (mbgl)	Dia-meter of well (m)	Water-bearing horizon	DEPTH TO WATER LEVELS (DTW) 1988 Premonsoon	1988 Post-monsoon	1989 Premon-soon	1992 Premon-soon	1992 Post-monsoon	1993 Premon-soon	Seasonal Fluctuations (Premonsoon to Postmonsoon) 1988	1992
1.	Mahabaleshwar	19.00	3.20	Laterite	15.65	14.03	14.90	18.70	14.00	18.75	1.62	4.70
2.	Dhangarwadi	11.70	5.00	-do-				11.60	9.56	11.60		2.04
3.	Kadamvadi	2.80	4.40	HWJMB	2.13	0.05	2.40	2.68	1.35	2.75	2.08	1.33
4.	Helwak	6.80	2.75	-do-	6.10	2.00	6.05	6.25	2.80	6.50	4.10	3.45
5.	Nivkane	6.74	3.45	Talus	3.04	1.30	3.80	4.60	2.21	4.95	1.74	2.39
6.	Mandure	5.93	2.47	HWJMB				3.05	1.85	3.50		1.20
7.	Mendoshi	3.11	2.51	Soil	2.49	0.90	2.55	2.80	1.25	3.05	1.58	1.55
8.	Sakhre	3.20	2.10	HWJMB				2.60	0.90	2.85		1.70
9.	Bibi	5.40	6.80	PWHJMB	5.32	1.38	5.25	5.25	1.50	5.30	3.95	3.75
10.	Ramamala	6.60	4.38	HWJMB	4.61	3.65	5.00	5.65	4.38	5.90	0.96	1.27
11.	Vajegaon	6.70	2.60	-do-	6.50	4.80	6.42	6.50	3.00	6.55	1.70	3.50
12.	Gojegaon	1.90	2.15	-do-				1.32	1.16	1.40		0.16
13.	Yerad	3.60	2.45	PWPJMB	1.88	0.92	1.80	1.95	1.13	2.25	0.96	0.82
14.	Tamkade	1.68	3.75	VB	1.00	0.72	0.95	1.52	0.95	1.50	0.28	0.57
15.	Patan*	8.60	8.00	HWJMB	1.48	0.00	1.60	0.74	1.05	0.80	1.48	-0.31
16.	Mhavshi*	10.06	2.67	-do-	2.30	0.70	2.60	2.90	1.70	2.70	1.60	1.00
17.	Yerphale*	8.80	8.40	Soil	3.20	2.80	3.10	2.75	2.90	2.70	0.40	-0.15
18.	Adul*	5.55	2.60	HWJMB	2.31	2.17	2.35	2.60	2.54	2.68	0.14	0.06
19.	Navsar*	8.05	8.45	HWJMB	0.38	0.54	1.35	1.42	1.50	1.40	0.14	-0.08
20.	Vadikotavdi	4.85	3.20	PWHJMB	3.08	2.22	3.85	4.10	1.60	4.35	0.86	2.50
21.	Gokul	3.10	2.50	PWPJMB	1.71	0.61	1.60	1.98	1.67	2.20	1.10	0.31
22.	Salve	9.14	3.50	PWPJMB	7.23	1.96	7.15	7.40	2.15	7.50	5.27	5.25
23.	Sanbur	6.57	5.00	PWHJMB	2.60	0.67	2.75	3.50	1.10	3.75	1.93	2.40
24.	Sonavde	9.60	9.20	PWHJMB	4.45	2.95	4.90	5.15	3.25	5.32	1.50	1.90
25.	Marli	8.10	7,00	HWJMB	3.40	1.10	3.05	4.00	1.10	4.20	2.30	2.90

Contd.Next

Well No.	Location	Depth of Dug-well (mbgl)	Diameter of Well (m)	Water-bearing horizon	DEPTH TO WATER LEVELS (DTW) (mbgl)						Seasonal Fluctuations (m) (Premonsoon to Postmonsoon)	
					1988 Premonsoon	1988 Postmonsoon	1989 Premonsoon	1992 Premonsoon	1992 Postsoon	1993 Premonsoon	1988	1992
26.	Divshi	4.25	3.90	HWJMB	2.70	1.70	2.95	3.50	2.00	3.80	1.00	1.50
27.	Savantiwadi	6.50	2.45	-do-	5.30	1.40	5.40	5.95	2.00	6.10	3.90	3.95
28.	Babuchivadi	9.07	2.45	PWPJMB	8.20	3.98	8.00	8.05	3.15	8.25	4.22	4.90
29.	Dhebehadi	12.00	5.60	HWJMB	8.10	3.70	12.30	11.60	4.00	12.35	4.40	7.60
30.	Gudhe	7.00	4.50	PWPJMB	6.87	1.40	6.70	6.95	1.65	6.95	5.47	5.30
31.	Dhamni	4.00	2.50	PWPJMB	1.95	1.40	2.15	2.30	1.75	2.45	0.55	0.55
32.	Kalgaon	6.20	5.95	PWPJMB	4.10	2.30	4.60	5.15	3.15	5.45	1.80	2.00
33.	Mutlavadi	7.70	2.50	PWPJMB	4.60	2.35	6.50	7.60	2.65	7.65	2.25	4.95
34.	Malharpeth*	15.30	3.25	HWJMB	1.30	0.75	0.85	1.05	1.18	1.30	0.55	-0.13
35.	Nisre*	9.50	7.20	HWJMB	6.50	1.65	6.25	6.30	1.27	6.40	4.85	5.03
36.	Sonachivadi	4.80	10.50	HWJMB	-	-	-	3.00	1.90	3.25	-	1.10
37.	Marul	9.80	9.65	HWJMB	9.00	4.10	9.15	9.35	4.25	9.60	4.90	4.50
38.	Beldare*	12.50	2.50	HWJMB	3.15	1.70	3.05	3.00	1.60	3.15	1.45	1.40
39.	Mhopre*	7.00	6.10	HWJMB	5.00	3.75	4.65	4.80	3.40	4.75	1.25	1.40
40.	Vasantgarh*	10.50	12.20	HWJMB	2.70	1.92	2.40	2.05	1.80	1.80	0.78	0.25
41.	Mundhe*	10.40	5.00	HWJMB	7.00	4.60	7.00	8.75	2.95	8.65	2.40	5.80
42.	Kese*	7.71	7.75	HWJMB	1.00	0.85	0.60	0.82	0.70	0.80	0.15	0.12
43.	Karad*	10.50	5.00	ALLUVIUM	1.75	0.65	1.60	1.90	0.90	1.75	1.10	1.00
44.	Kumbhargaon	6.12	2.40	PWPJMB	2.80	1.30	2.45	2.05	1.18	2.30	1.50	0.87
45.	Jmbhulvadi	9.60	11.10	HWJMB	-	-	-	8.50	3.10	8.90	-	5.40
46.	Khadakwadi	9.00	2.50	HWJMB	8.90	3.15	8.40	8.80	3.30	8.90	5.75	5.50
47.	Gharwadi	9.00	9.00	PWPJMB	7.20	3.30	6.85	6.90	3.00	7.25	3.90	3.90
48.	Ving	9.80	7.30	HWJMB	7.00	3.55	6.75	6.85	3.20	7.85	3.45	3.65

* Wells in Koyna Command area

PWPJMB : Poorly weathered and poorly jointed massive basalt.
PWHJMB : Poorly weathered and highly jointed massive basalt
HWJMB : Highly weathered and jointed massive basalt.
VB : Vesicular basalt.

Table 3.3 No. and Percentage of Representative Wells showing various Ranges of Depth to Water Levels during 1988 and 1992

DTW (mbgl)	1988				1992			
	Premonsoon		Postmonsoon		Premonsoon		Postmonsoon	
	No. of wells	%age	No. of wells	%age	No. of wells	%age	No. of wells	% age
0 - 2	09	21	25	60	08	17	26	56
2 - 4	13	31	13	31	15	32	17	36
4 - 6	07	17	03	07	08	17	02	04
6 - 8	08	19	0	0	08	17	0	0
8 - 10	04	10	0	0	05	11	01	02
7 - 10	01	02	01	02	03	06	01	02

DTW - Depth to Water Level

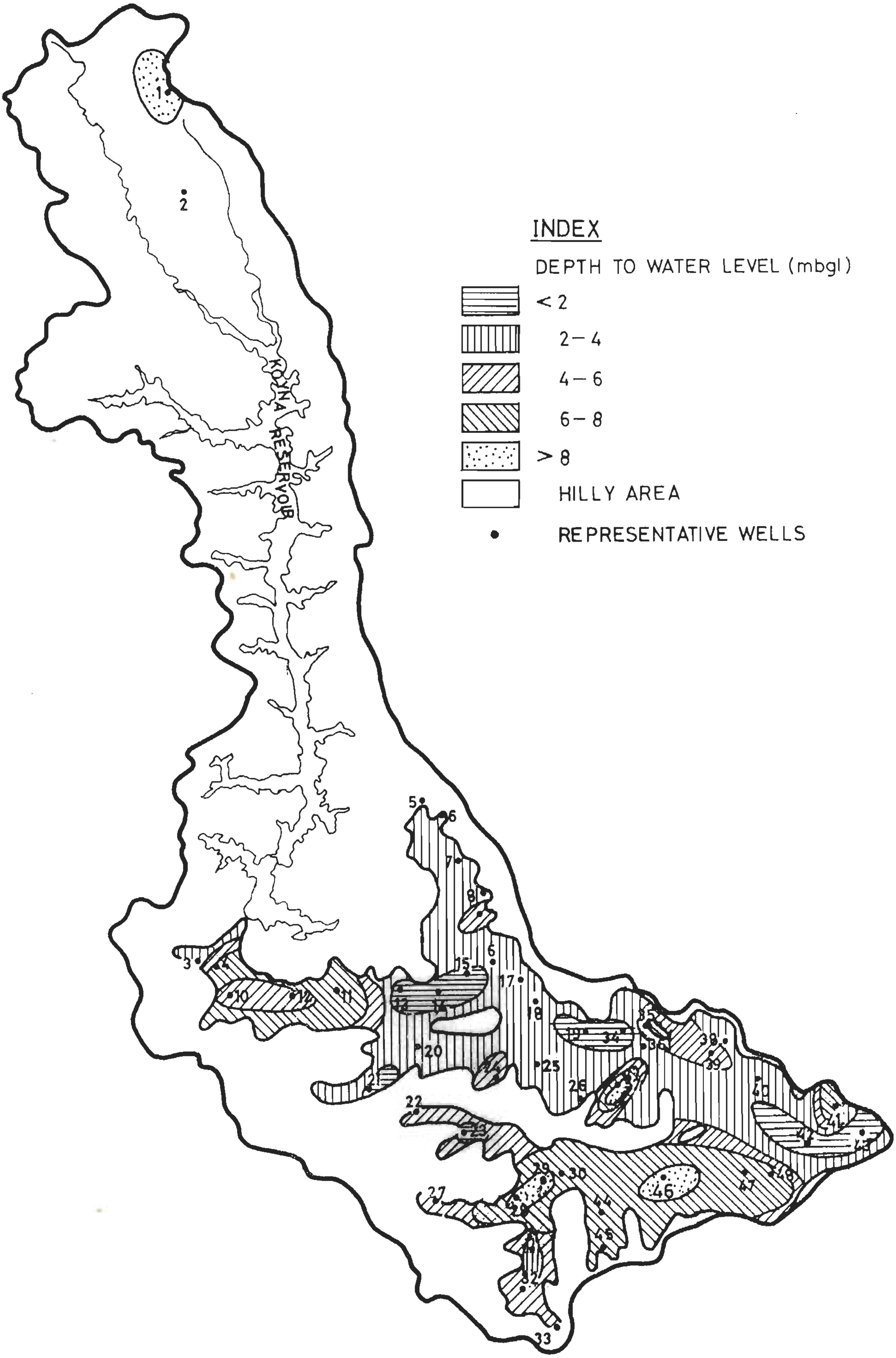


FIG. 3·12 – PREMONSOON DEPTH TO WATER LEVEL (1988)
(METRES BELOW GROUND LEVEL)

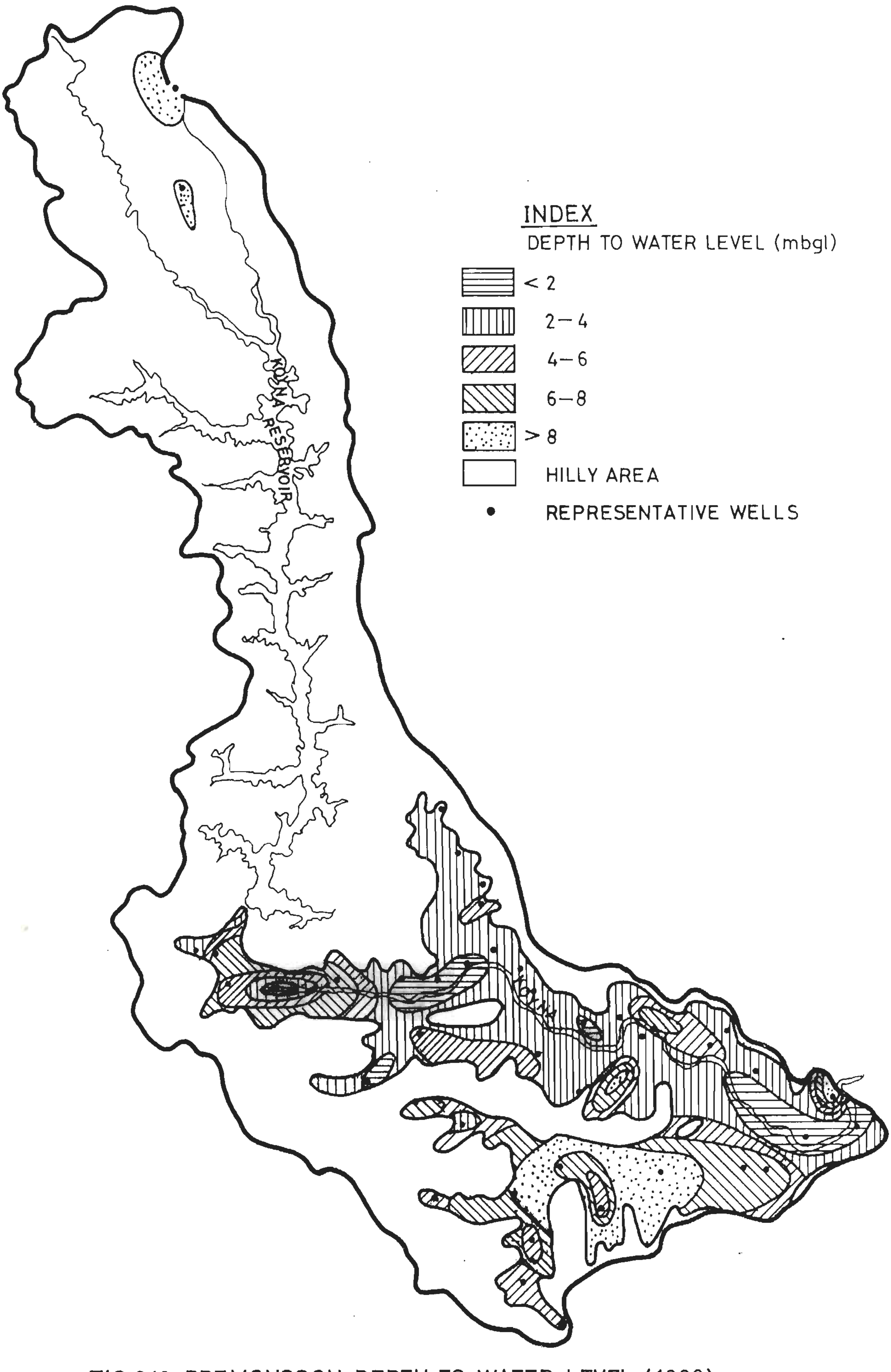


FIG. 3·13-PREMONSOON DEPTH TO WATER LEVEL (1992)
(METRES BELOW GROUND LEVEL)

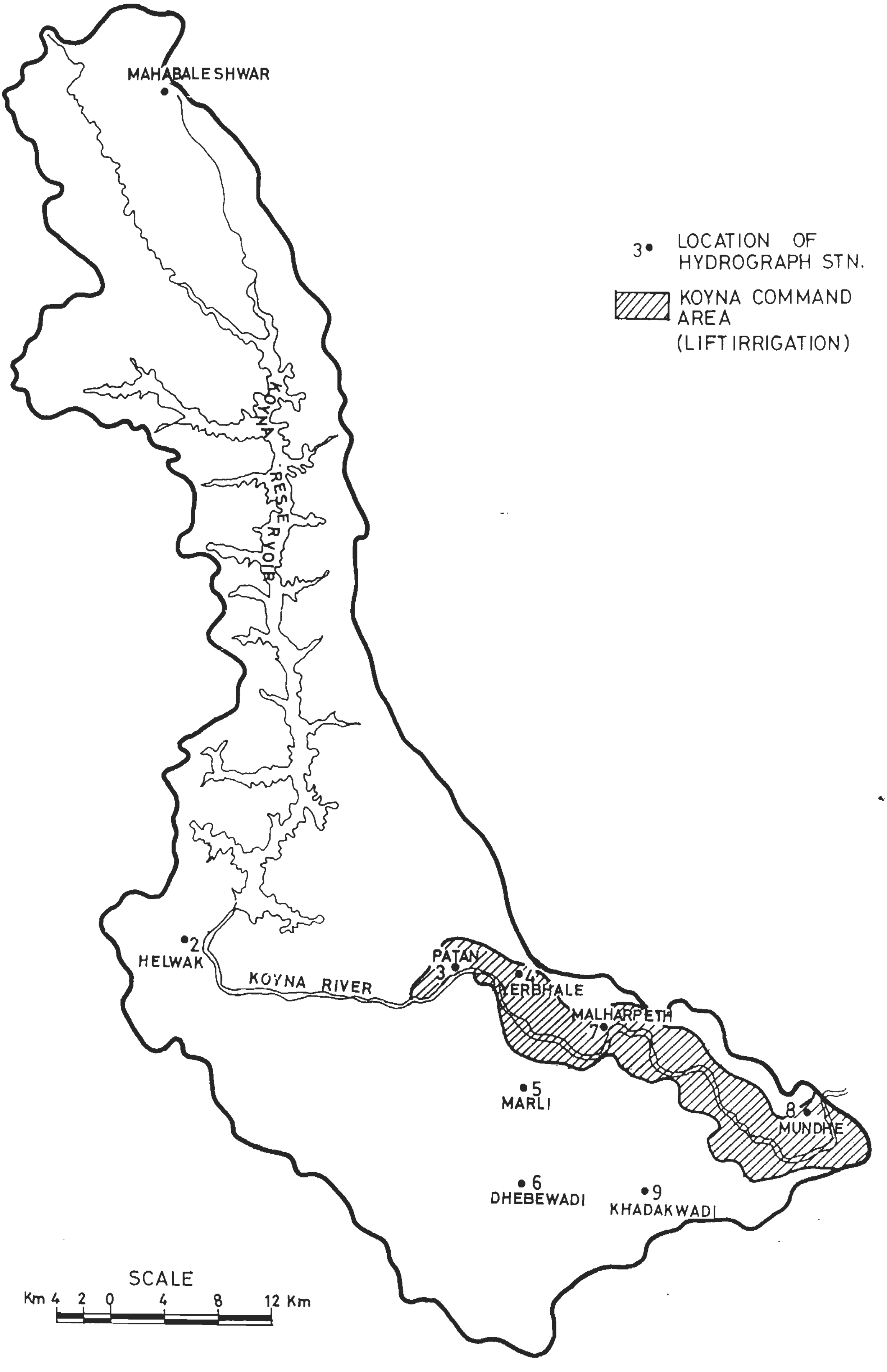


FIG. 3·14 — LOCATION OF HYDROGRAPH STATIONS AND KOYNA COMMAND AREA

Fig.3.15a : Water logging conditions in the lower reaches of the Koyna sub-basin.

Fig.3.15b : Water logging conditions in the lower reaches of the Koyna sub-basin.

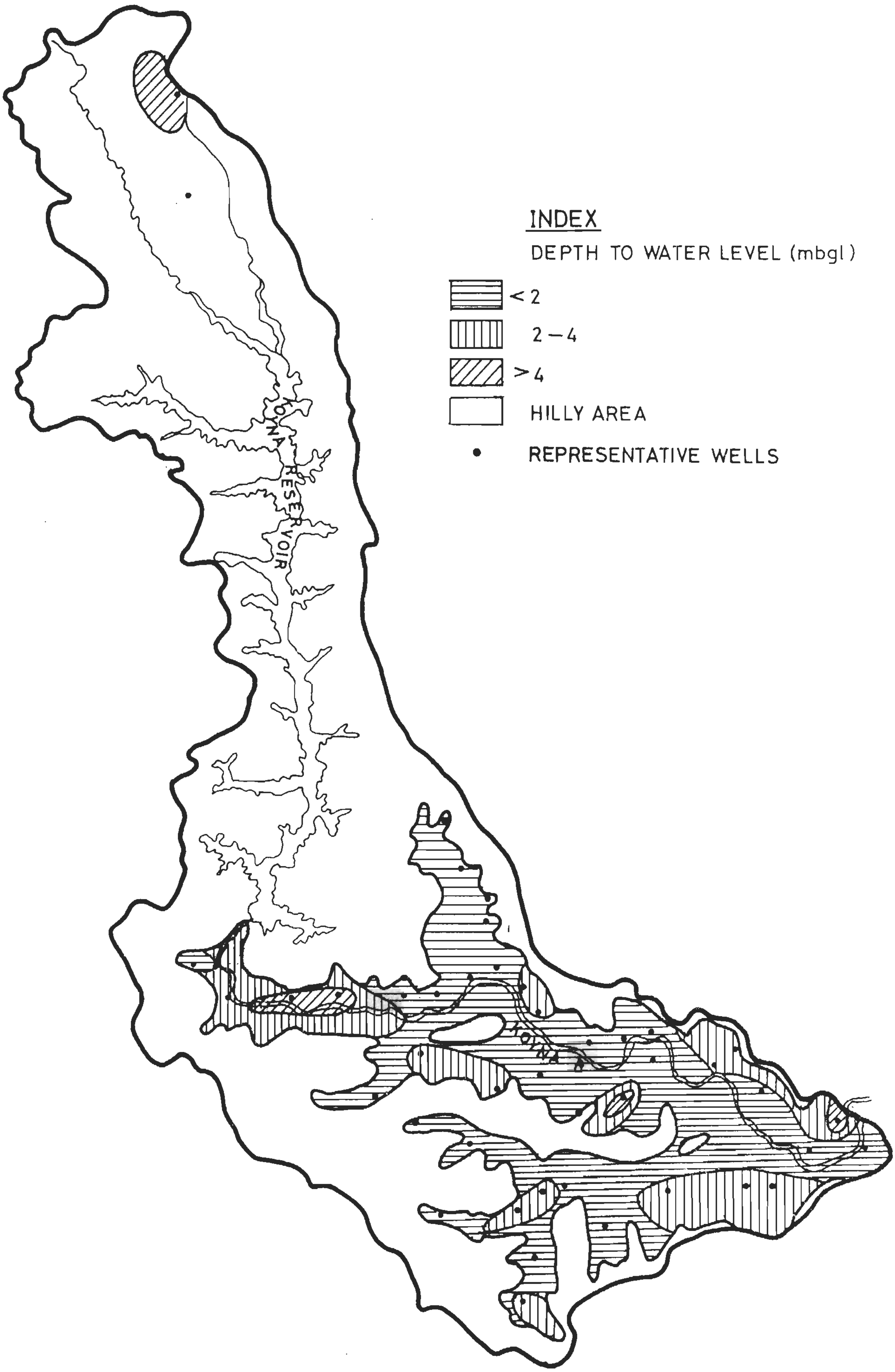


FIG.3-16 – POSTMONSOON DEPTH TO WATER LEVEL (1988)
(METRES BELOW GROUND LEVEL)

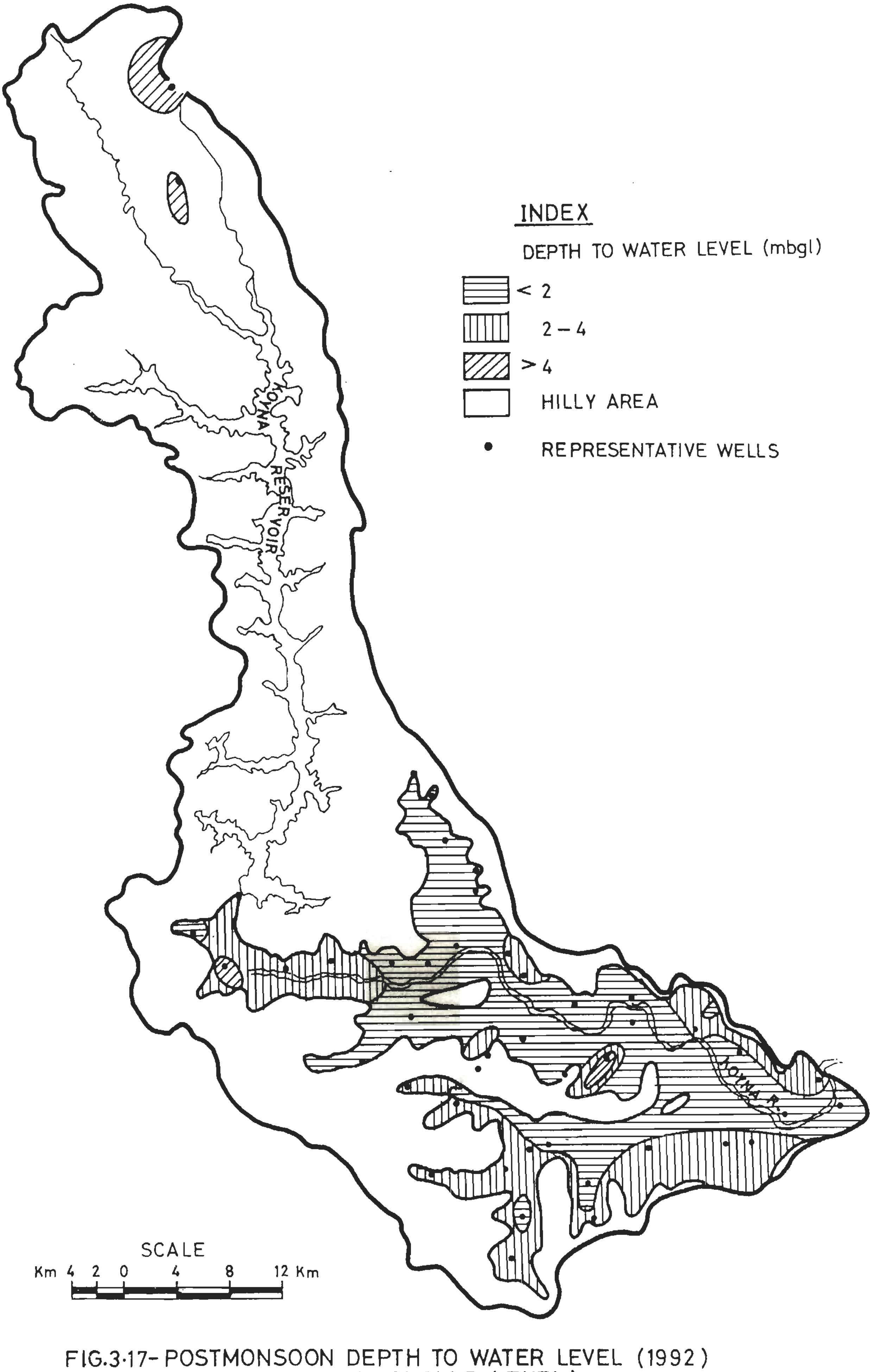


FIG.3·17- POSTMONSOON DEPTH TO WATER LEVEL (1992)
(METRES BELOW GROUND LEVEL)

Around Mahabaleshwar in the north, the groundwater levels in premonsoon and postmonsoon periods are relatively deep and are found to be of the order of 15.50 - 18.50 mbgl and 14 mbgl respectively. The wells in Mahabaleshwar tap laterites or lateritic soils and deep water levels in these aquifers are expected under natural condition. Around Dhebewadi in the south as well the groundwater levels are deeper during both premonsoon and postmonsoon periods compared to other parts in the central valley. The ground- water levels are found to be of the order of 9-11.50 mbgl and 4 mbgl respectively during these two seasons in this area.

3.6.2 Fluctuations of Water Levels

3.6.2.1 Seasonal Fluctuations

The seasonal fluctuations of water levels at the 48 key observation wells were obtained by taking the difference between the water-levels of premonsoon and postmonsoon periods at the individual stations for the years 1988 and 1992 (Table 3.2). During 1988, 62% of the key observation wells showed a fluctuation less than 2 m, while 19% of them showed a range of 2 to 4 m and an equal number showed a fluctuation greater than 4 m (Table 3.4, Fig. 3.18). Similarly, during 1992, 53% of the observation wells showed fluctuation range of less than 2 m while 24% and 21% of the wells showed fluctuations of 2 to 4 m and greater than 4 m respectively (Table 3.4, Figure 3.18). The percentage value of the dugwells indicating different ranges of water levels reveals that the year 1992 showed a decline (average 2.46 m) more than that of year 1988 (average 2.17 m). The diagrams (Figures 3.19 and 3.20) prepared to show the fluctuations in both the years reflect the higher fluctuations during the year 1992. For example, in the southern part, the extent of area showing a fluctuation range of 4 to 6 m is more in 1992 than that at the year 1988.

In the Command area of the Koyna lift irrigation schemes, the seasonal fluctuations of about 1 m or less are observed. In some cases, it is hardly appreciable (Adul, Vasantgarh and Kese). Even in many cases, the premonsoon level is shallower than that of the postmonsoon period, a case which is quite unusual (Patan, Yerphale and Navsar). All these are due to the intermittent but regular irrigation of lands through the lift irrigation schemes. This may happen either in two cases, i.e. the premonsoon water levels in these wells were recorded just before irrigation or the postmonsoon levels were recorded just after irrigation. Whatever may be the case the applied irrigation through lift schemes in the area does affect the groundwater regime and actual fluctuations that an aquifer should reveal are not reflected in the Command areas as in case of the non-command areas.

3.6.2.2 Long-term Trends

Variation in groundwater level reflects primarily the mass balance between recharge and discharge (Schlehuber et al., 1989). If the system is subjected to extraneous forces like withdrawal, contribution from surface water irrigation, seepage from canals etc., it is reflected directly on the water levels. Thus systematic analysis of long-term water-levels provides vital information to demarcate the areas having perceptible rise or fall of water levels. This information is a prerequisite for planned and scientific development.

Rainfall is the main source of recharge to the ground water system. Any appreciable change in the annual rainfall directly affects the groundwater levels (Viswanathan, 1984, Nair, 1981 and Angadi, 1986). The declining trend of premonsoon water levels indicates that there is development activity (groundwater) going on in the area while rising trend indicates that either the development activity has reduced or recharge due to sources other than the rainfall has increased. In case of postmonsoon water levels the declining trend suggests that a part of the aquifer is being desaturated every year due to developmental activities, deficient rainfall etc. (Kittu and Mehta, 1990). The rising trend in this case on the other hand, shows that additional water is being stored in the aquifer which may be due to increased rainfall, seepage through applied irrigation etc. The lack of significant variation suggests that there is little recharge or discharge during the recorded period (Schlehuber et al, 1989).

To study the long-term trends of water levels vis-a-vis time and rainfall, water level data of the existing 9 hydrograph stations established by Groundwater Survey and Development Agency, Govt. of Maharashtra (7 Nos.) and Central Ground Water Board (2 Nos.) have been

Table 3.4 **No. and Percentage of Representative wells showing various ranges of seasonal fluctuations.**

Fluctuation Range (m)	1988 No of wells	1988 % age of wells	1992 No. of wells	1992 % age of wells
< 2	26	62	25	53
2 - 4	8	19	11	24
4 - 6	8	19	10	21
>6	0	0	1	2

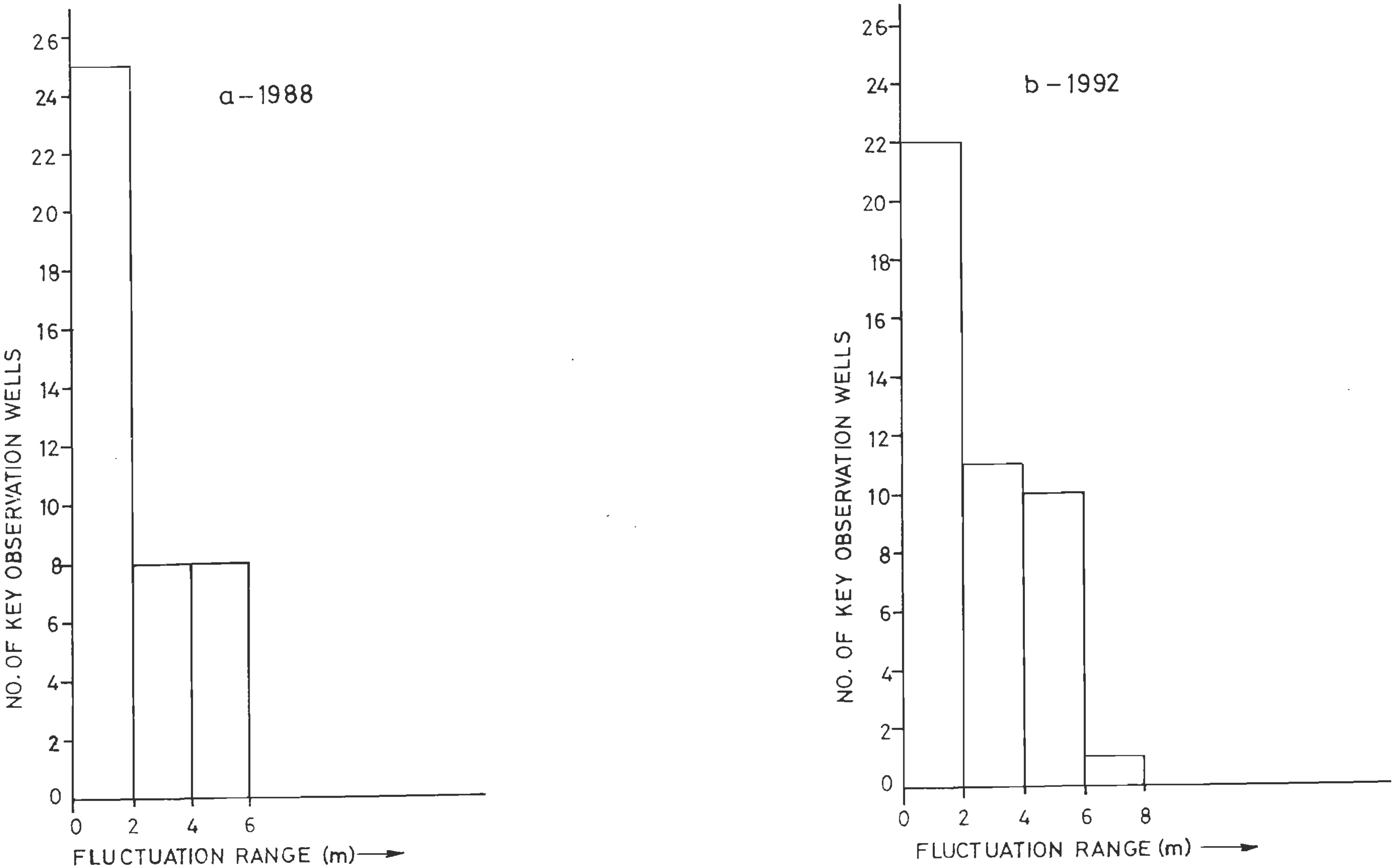


FIG 3·18-NO. OF OBSERVATION WELLS SHOWING VARIOUS RANGES OF SEASONAL FLUCTUATIONS

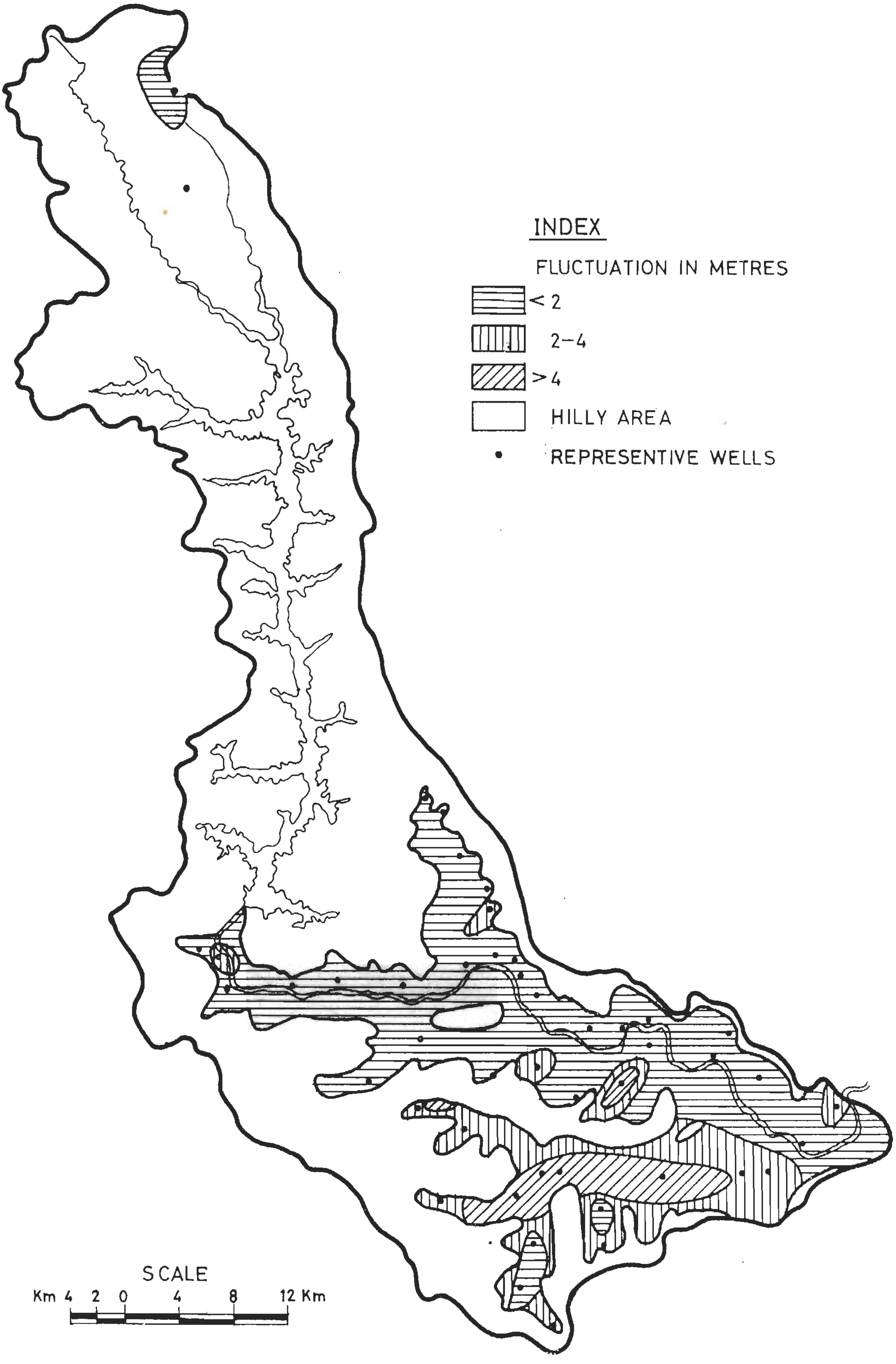


FIG.3·19-SEASONAL FLUCTUATION OF WATER LEVEL (PREMONSOON TO POSTMONSOON), 1988

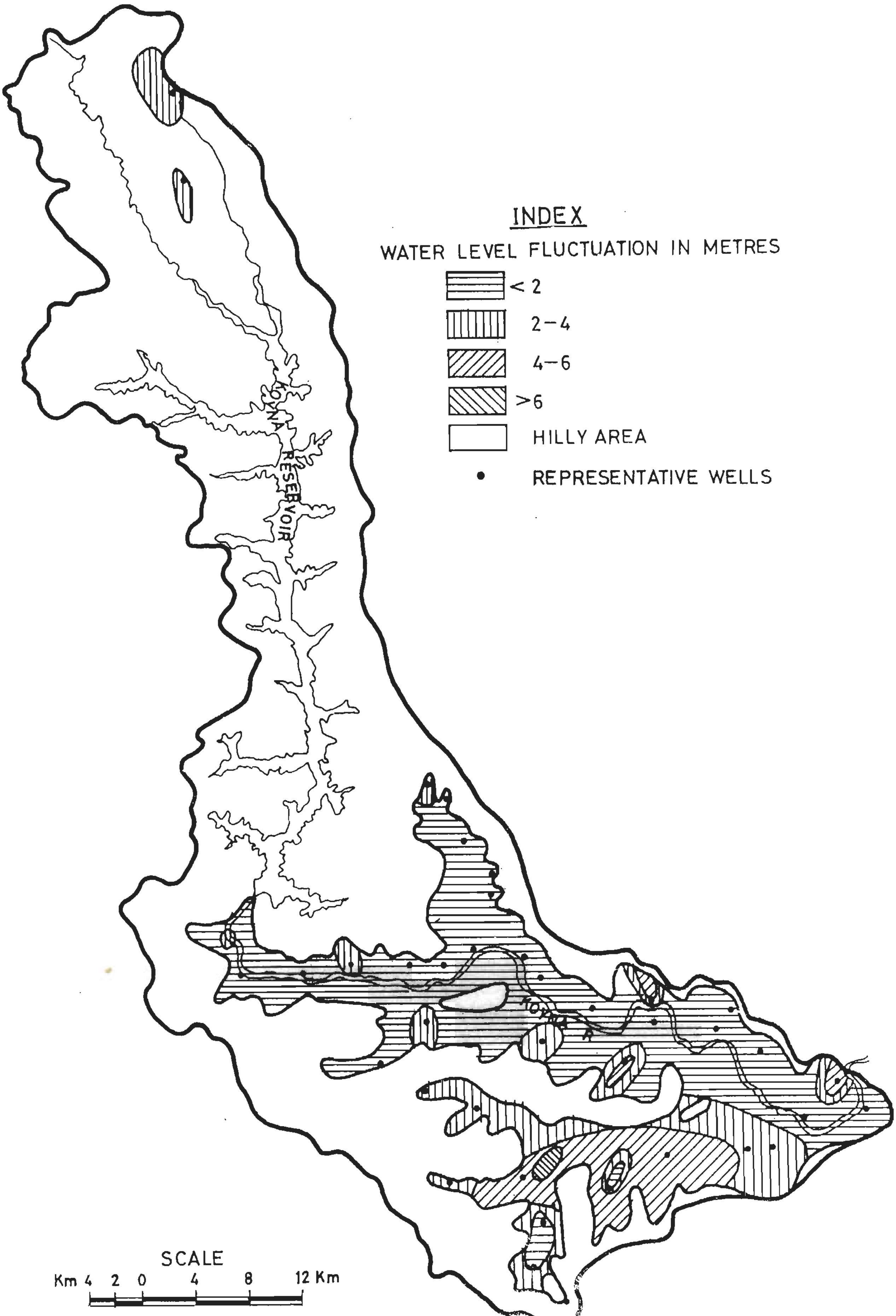


FIG.3·20 - SEASONAL FLUCTUATION OF WATER LEVEL (PREMONSOON TO POSTMONSOON) 1992 collected (Table 3.5). The location of the hydrograph stations are shown in figure 3.14. The trend analysis of premonsoon and postmonsoon water levels has been carried out using the time-series analysis. An attempt has been made to fit a trend line to the water levels using the least square method. The results of the analysis are given in Table 3.6.

Table 3.6 shows that the rainfall in the area as a whole for the period of record of water levels is in the rising trend except in the southern parts where it is declining. In the Command area of the Koyna lift irrigation schemes, the rate of rise of water levels in both premonsoon and postmonsoon periods is quite appreciable. The plots of water levels for the stations at Patan and Malharpeth show anomalous behavior (Figs. 3.21 & 3.22). Normally, the premonsoon trend should not cut across the postmonsoon trend, but it does not happen so in these two stations. This indicates interference of groundwater levels by some external source. In this case the external source is the continual recharge due to applied irrigation by the Koyna lift irrigation schemes. At Malharpeth, the premonsoon water level shows abrupt rise after 1979 while in case of Patan it is from 1987. The trends indicate steady rate of rise of premonsoon water level due to surface water irrigation. In the Command area of the Koyna lift irrigation schemes, in general, groundwater is rather poorly extracted due to easy availability of surface water. The continual recharge, therefore, has led to near water logging condition in the lower reaches of the Koyna sub-basin. In the peripheral zone (Yerphale - Stn. No. 4, and Mundhe - Stn. No. 8) of the command area, however, the rate of rise in water level is not appreciable (Fig. 3.23).

In the non-command areas, there is gradual decline in water level in both premonsoon and postmonsoon periods due to increased reliance on groundwater despite the fact that rainfall shows increasing trend except in the southern parts. The station at Mahabaleshwar, however, shows no appreciable decline and indicate a balanced recharge - discharge condition (Fig. 3.24). At Marli (Stn. No. 5), while the premonsoon trend shows a declining trend, the postmonsoon trend shows a rising trend (Fig. 3.26), thus signifying good saturation of the aquifers during monsoon rainfall, but gradual desaturation of these aquifers after the postmonsoon period due to overdraft. At Dhebevadi (Stn. No. 6), the rate of decline is pronounced in both premonsoon and postmonsoon periods (Fig. 3.25). The dugwells in the southern part tap poorly weathered and poorly jointed basalt. Rainfall in this area is declining steadily. In fact, drought occurs in this area once in every four years. Thus, in this area the aquifers are gradually desaturated not only because of the decrease in rainfall but also due to overdraft for irrigation. The premonsoon and post-monsoon water levels and their fluctuations for the years 1988 and 1992 have already identified this area as problematic. The long-term trends of water-levels and the rainfall only support the inference arrived out of the premonsoon and postmonsoon water levels. The southern part, therefore, calls for artificial recharge of the aquifers, which can be achieved with the help of percolation tanks, minor-irrigation tanks, check dams etc. The number of such structures are scanty (Fig. 1.3) and most of them are constructed at wrong sites. Moreover, these structures are very old and have been silted up. The role of these structures as an effective means for augmenting the groundwater regime in hard rock terrain has been studied by several workers, such as Shah and Khan (1989), Shah et al (1990), Murali and Shah (1990), Naik (1990) and Agarwal and Naik (1990).

3.7 SUMMARY

On the basis of 240 dugwells and the data collected from 305 borewells, the occurrence of groundwater in various types of aquifers was studied. The aquifers are found to be associated with basalts, laterites, alluvium and talus deposits. In the exposed section of the sub- basin, 27 basaltic flows have been identified. The thickness of the basaltic flows vary in thickness form 10 m to more than 60 m. The upper vesicular unit of the basaltic flows, unlike the lower massive part, exhibits primary porosity and permeability and is weathered in most parts even at depth. However, at many places, the non-vesicular (massive) unit has developed secondary porosity due to fracturing, jointing and weathering. The laterites and talus/colluvium deposits are highly porous and permeable, but have very low specific retention of groundwater. The water-bearing properties of the clay-rich alluvium are largely controlled by sand/clay ratio. The lateritic soils have better potential than that of the black cotton soils.

Based on the analysis of 545 wells, the shallow aquifers are found upto a maximum depth of 25 m. The laterites, alluvium, soil, talus/colluvium deposits and the weathered uppermost

TABLE 3.5 LONGTERM WATER LEVEL DATA OF THE PERMANENT HYDROGRAPH STATIONS (mbgl)

Abbreviations : a- premonsoon water level; b-postmonson water level

No.1	Location	1974		1975		1976		1977		1978		1979	
		a	b	a	b	a	b	a	b	a	b	a	b
1	Mahabaleshwar	17.75	13.80	16 50	13.00	16.30	13.50	15.20	3.10	15.70	13.30	19.10	13.60
2.	Helwak	4.30	1.95	6.20	2.00	5.90	2.90	5.90	2.65	5.75	2.70	5.10	3.20
3.	Patan												
4	Yerphale	3.45	2.25	3.50	2.60	3.05	2.60	3.25	2.70	3.00	2.50	2.90	2.65
5.	Marli			2.30	1.00	2.20	1.15	2.10	2.70	1.95	1.00	2.70	1 10
6	Dhebewadi					8.50	2.05	8.10	1.60	7.90	2.90	8.40	2.05
7.	Malharpeth	11.40	2.40	11.00	3.00	10.65	4.50	12.80	1.80	6.30	3.60	1.80	1.00
8.	Mundhe	7.80	-	7.90	3.60	8.20	4.50	9.40	2.50	6.40	4.45	8.0	3.10
9.	khadakwadi	5.48	2.60	5.90	2.70	8.70	2.95	4.40	2.60	4.90	2.70	8.80	2.90

	1980		1981		1982		1983		1984		1985	
	a	b	a	b	a	b	a	b	a	b	a	b
1.	14.60	14.00	14.65	14.00	14.50	8.85	16.80	14.30	18.82	12.90	16.65	14.00
2.	5.90	4.30	6.00	2.20	6.10	2.30	5.95	2.25	6.04	4.00	5.90	3.90
3.			6.32	4.12	6.40	2.74	6.50	2.93	6.11	3.54	4.72	1.85
4.	3.00	2.70	3.00	2.65	3.20	2.80	3.00	2.70	2.96	2.55	3.10	2.45
5.	2.60	1.05	2.35	1.20	2.40	1.10	2.45	1.00	2.90	1.05	2.80	0.90
6.	9.45	2.15	8.80	4.60	8.60	3.50	12.20	3.40	9.07	4.15	6.80	4.80
7.	1.10	1.25	1.30	1.10	1.50	1.00	1.30	0.90	1.42	0.90	1.35	1.10
8.	8.80	3.50	10.10	5.20	9.00	2.30	9.30	4.35	7.75	3.75	7.50	5.50
9	8.90	2.95	8.30	3.20	8.50	3.10	5.70	3.00	8.80	3.30	8.85	3.30

	1986		1987		1988		1989		1990		1991		1992	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1.	17.08	14.50	17.00	13.70	15.65	14.03	14.90	13.05	15.00	13.00	18.00	14.20	18.70	14.00
2.	5.95	3.60	5.80	4.20	6.10	2.00	6.05	3.10	6.15	3.90	6.20	2.50	6.25	2.80
3.	5.30	2.55	3.43	0.89	1.48	0.0	1.60	1.20	1.22	0.55	0.85	1.29	0.74	1.05
4.	2.95	3.20	3.20	2 70	3.20	2.80	3.10	5.10	3.00	3.05	2.80	2.80	2.75	2.90
5.	3.20	0.86	3.00	1.10	3.40	1.10	3.05	1.25	3.50	1.15	3.00	1.25	4.00	1.10
6.	11.05	4.00	9.30	4.40	8.10	3.70	12.30	4.90	11.00	3.00	9.90	4.10	11.60	4.00
7.	1.25	0.50	1.20	0.80	1.30	0.75	Well	Closed						
8.	6.85	3.05	6.00	3.60	7.00	4.60	7.00	3.90	9.00	3.20	8.90	3.00	8.75	2.95
9	8.50	8.30	8.50	4.70	8.90	3.15	8.40	3.70	8.45	2.60	8.00	3.20	8.80	3.30

Table 3.6 **Long-term Trends of Water Levels vis-a-vis time and rainfall**

Station No.	Location in Command/ Non-command area of Koyna L.I.S.	Period of Record	Rainfall Trend (Rising/ Declining)	Water-level Trends Premonsoon Rising/Declining	Water-level Trends Postmonsoon Rising/Declining
1. Mahaba-leshwar	Non-command	1974-1992	Rising	Declining gently	Declining gently
2. Helwak	- do -	- do -	- do -	Declining	Declining
3. Patan	Command	1981-1993	- do -	Rising	Rising
4. Yerphale	- do -	1974-1992	- do -	Rising	Declining
5. Marli	Non-command	1975-1992	- do -	Declining	Rising gently
6. Dhebevadi	- do-	1976-1992	Declining	Declining	Declining
7. Malhar-peth	Command	1974-1988	Rising	Rising	Rising
8. Mundhe	- do -	1974-1991	- do -	Rising gently	Rising gently
9. Khadak-wadi	Non-command	1974-1992	Declining	Declining	Declining

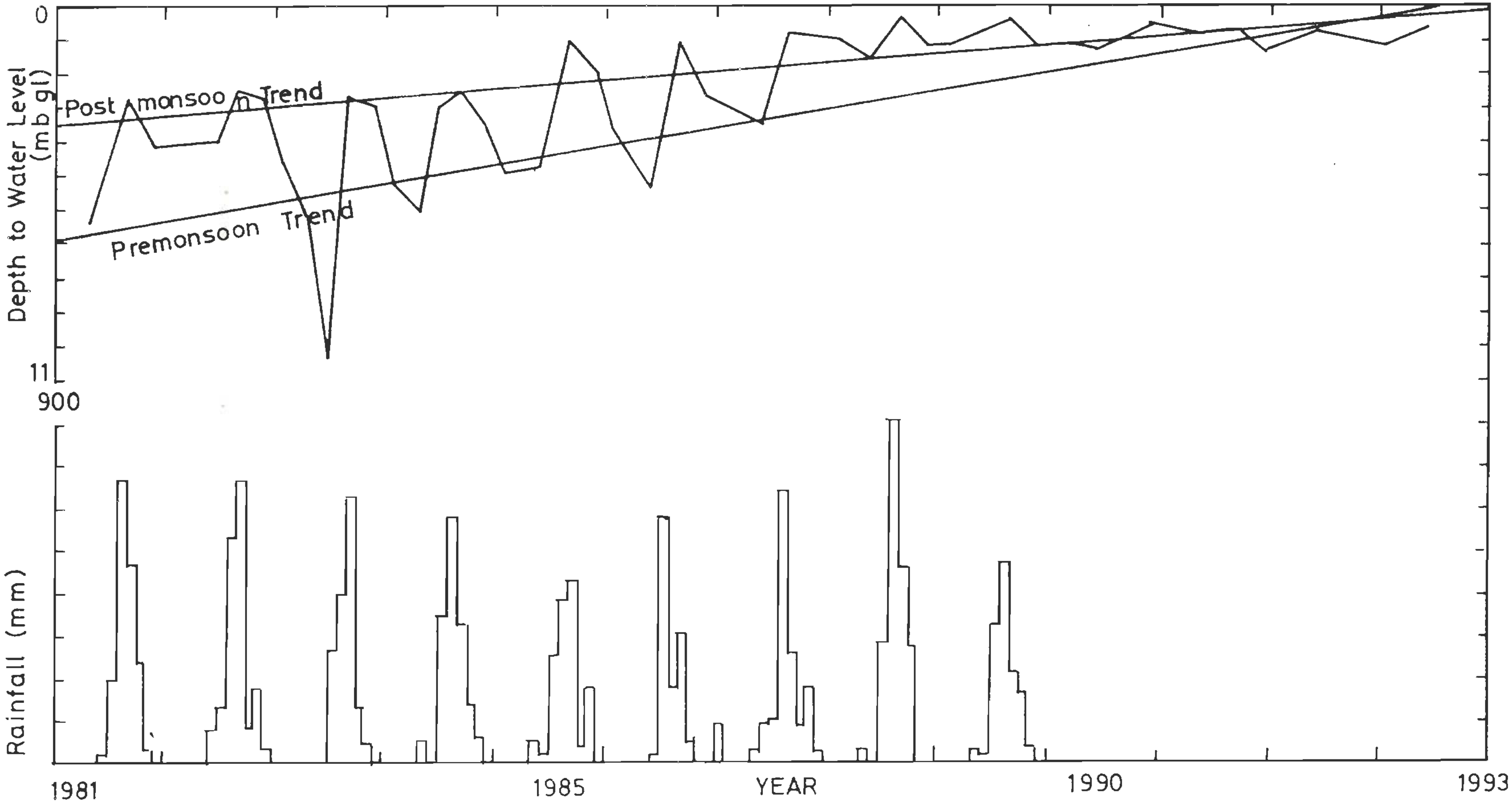


FIG.3·21–HYDROGRAPH OF PATAN (Stn. NO. 3)

Scale on Y axis

Rainfall 1 unit = 100 mm

DTW 1 unit = 1·0 m

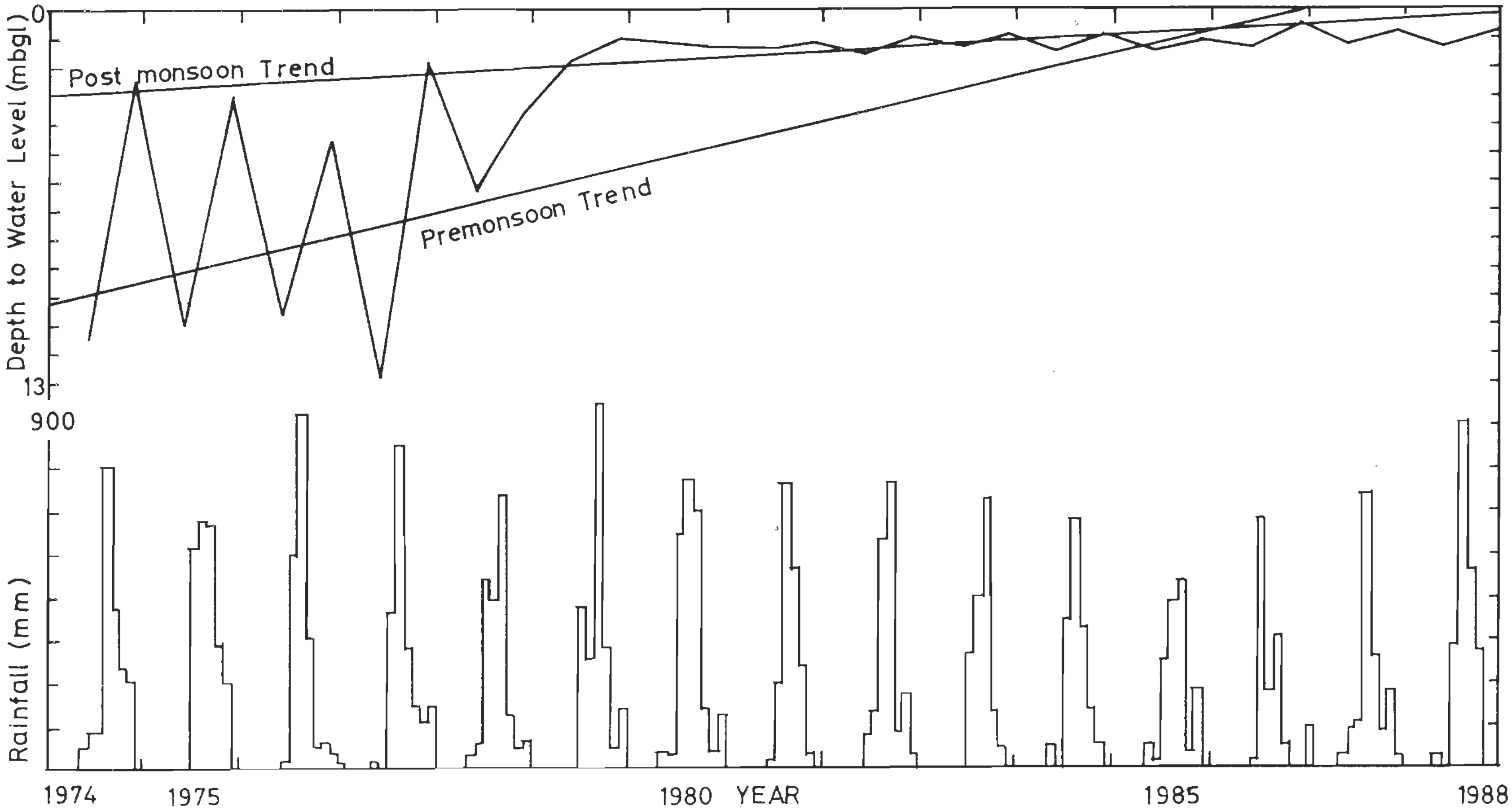
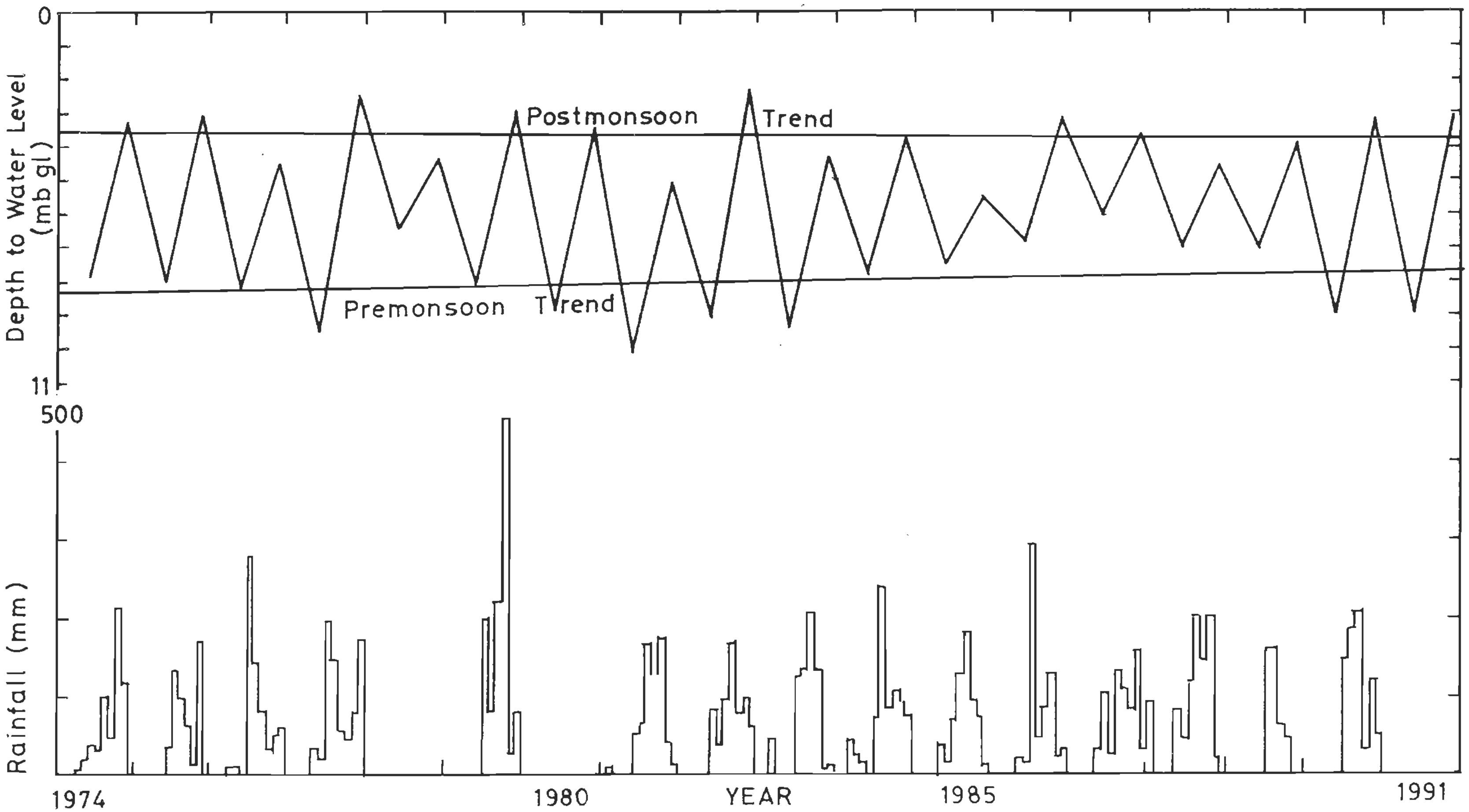


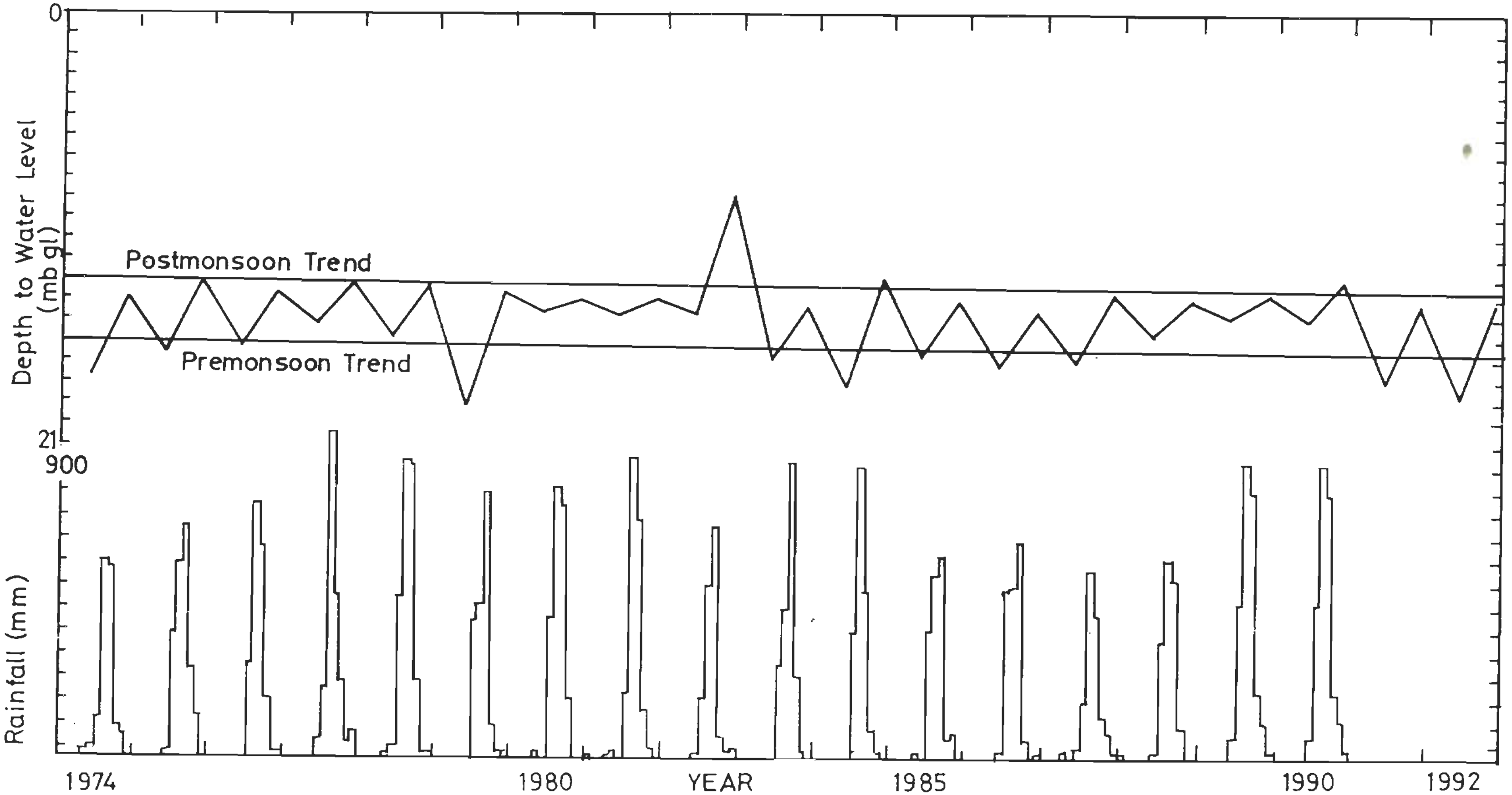
FIG.3·22-HYDROGRAPH OF MALHARPETH (Stn. NO. 7)

Scale on Y axis :
Rainfall 1 unit = 100 mm
DTW 1 unit = 1·0 m



Scale on Y-axis :
Rainfall 1 unit = 100 mm
DTW 1 unit = 1·0 m

FIG.3·23-HYDROGRAPH OF MUNDHE (Stn. NO. 8)



Scale on Y-axis :
Rainfall 1 unit= 200 mm
DTW 1 unit= 1·0 m

FIG.3·24-HYDROGRAPH OF MAHABALESHWAR (Stn. NO. 1)

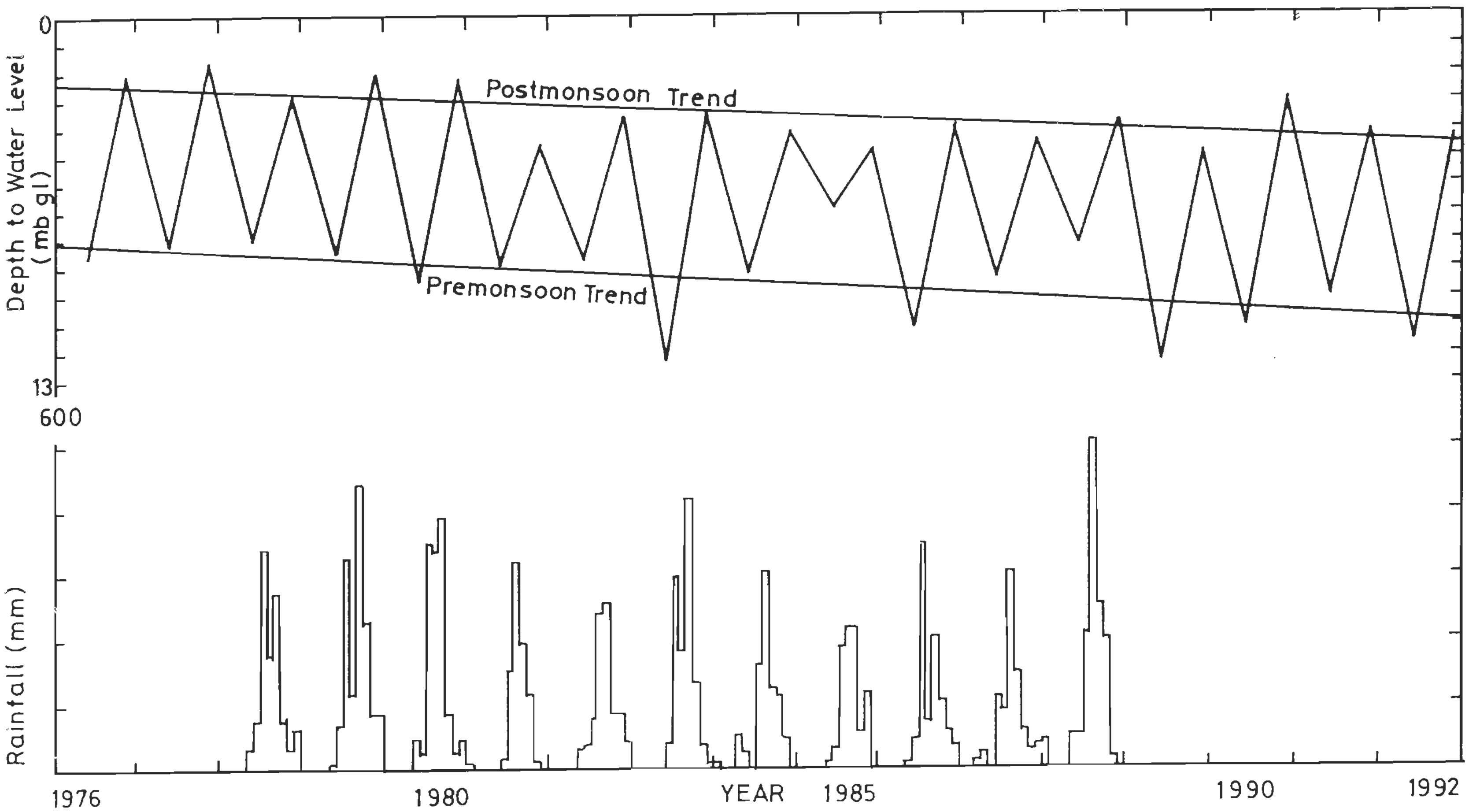
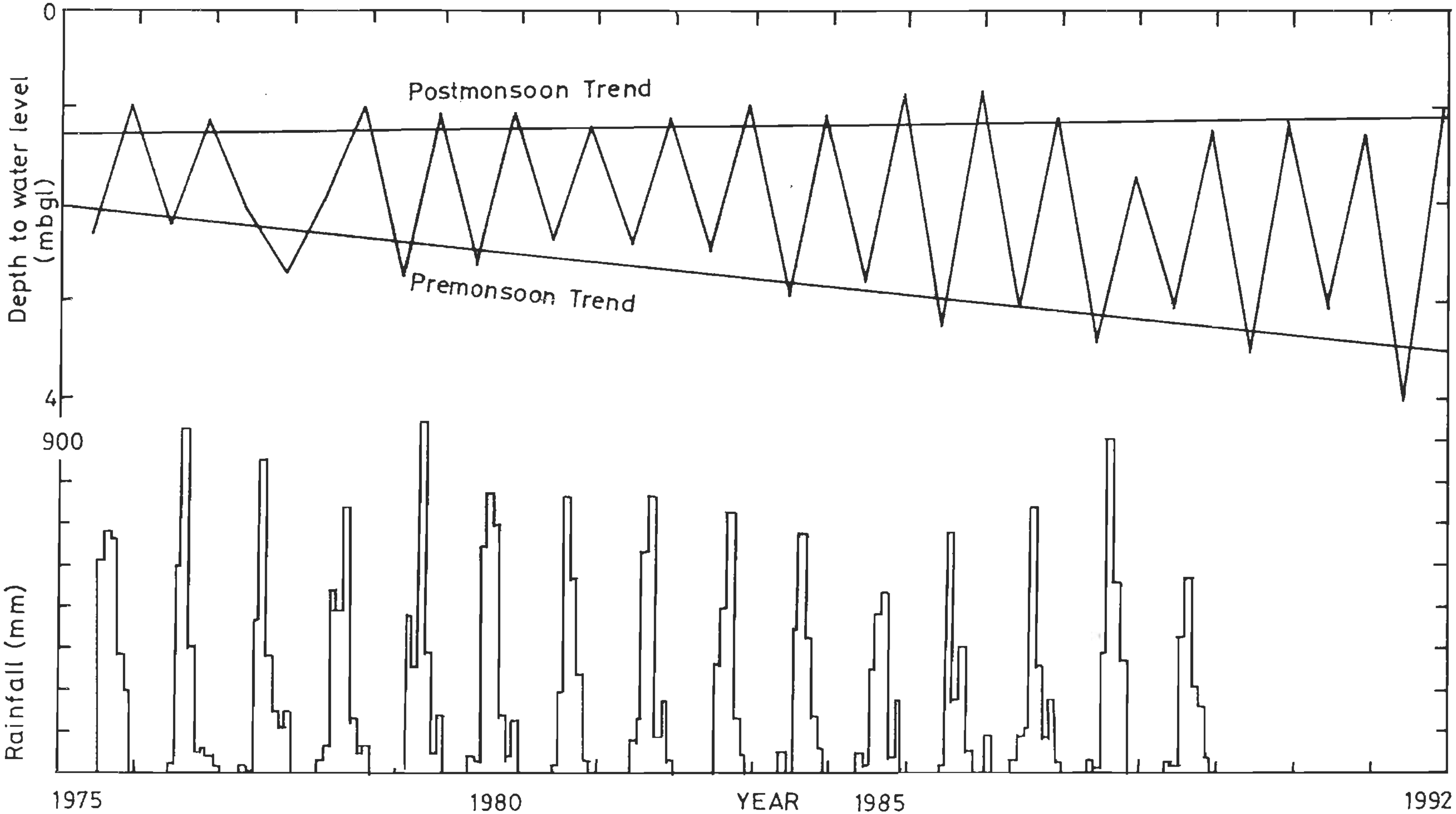


FIG.3·25–HYDROGRAPH OF DHEBEVADI (Stn. NO. 6)

Scale on Y axis :
Rainfall 1 unit = 100 mm
DTW 1 unit = 1·0 m



Scale on Y axis :
Rainfall 1 unit = 100 mm
DTW 1 unit = 400 mm

FIG.3-26 – HYDROGRAPH OF MARLI (Stn. NO. 5) basalts form shallow aquifers in the area. The deeper aquifers are found below the zone of weathering in basalt, due mainly to fracturing and are tapped only by borewells. 88% of the dugwells in the area tap shallow basaltic aquifers as against 12% of the wells in laterites, alluvium, soil and talus/colluvium deposits. Thus, laterites, alluvium, soils and talus/colluvium deposits form shallow aquifers of secondary importance as compared to basaltic aquifers. The basaltic lava flows in their present-day weathered zone consists of 4 typical water- bearing horizons, such as (i) black cotton soil with yellow or reddish clay (0.50-8m), (ii) highly weathered and highly jointed basalt (3-10m), (iii) poorly weathered and highly jointed basalt (1-2m) and (iv) poorly weathered and poorly jointed basalt, which overlies the hard massive basalt (1-2m). Depending on location all or part of these four horizons are tapped by the dugwells. The poorly weathered and highly jointed horizon forms the most potential aquifer in the area.

Groundwater generally occurs under water-table condition in the shallow aquifers. However, in the deep pediments, especially in the lower reaches of the Koyna sub- basin, where thickness of black cotton soil is of the order of 5m,semi-confined conditions occur due to the presence of thick silty clay in soils overlying the weathered and jointed horizons. The groundwater in deeper aquifers occurs at the contact between the basaltic flows, within the vesicular and amygdaloidal section at the lava flow top or within the fractured and jointed section. It occurs under semi-confined condition when the productive horizon is separated by fractured and/or jointed basalt. Confined aquifer conditions are found when the water-bearing horizon lies at the contact of two lava flows - the upper one occurring as massive basalt and the lower one as vesicular or fractured basalt. There does take place transfer of groundwater from the shallow aquifer to the deeper aquifers.

Well yields of groundwater are found to be related with the lineaments and the geomorphic features. While the lineaments have a better control over the yields of the borewells tapping deeper aquifers, the geomorphic features have greater control over the shallow aquifer system. NE-SW trending lineaments are the high potential areas for groundwater resources in the Koyna sub-basin.

The depth to water levels (DTW) in the shallow aquifers were recorded in 42 representative wells in 1988 and 47 representative wells in 1992 during premonsoon and postmonsoon periods. The DTW in the premonsoon period in most of the wells (31% in 1988 and 32% in 1992) range from 2 to 4 mbgl. The water levels generally do not exceed 8-10 m in more than 90% of the wells. In the postmonsoon period, the DTW is O to 2 mbgl in most of the wells (60% in 1988 and 56% in 1992). The DTW is more than 95% of the wells do not exceed 4-6 mgbl in the postmonsoon period.

The seasonal fluctuations of water levels at the 48 representative wells were obtained by taking the difference between the water-levels of premonsoon and postmonsoon periods in the individual stations for the years 1988 and 1992. During 1988, 62% of the wells show a fluctuation less than 2 m, while 19% of them show a range of 2 to 4 m and an equal number show a fluctuation greater than 4 m. Similarly, during 1992, 53% of the observation wells show a fluctuation range of less than 2 m while 24% and 21% of the wells show fluctuation of 2 to 4 m and greater than 4 m respectively. In the Command area of the Koyna lift irrigation schemes, the seasonal fluctuation of about 1 m or less are observed. In some cases it is hardly appreciable.

In the Command area of the lift irrigation schemes, groundwater is poorly extracted due to easy availability of surface-water for irrigation. Because of continual recharge due to irrigation, the water table in this area is rising steadily. Thus, this is leading to near water-logging condition in the lower reaches of the sub-basin. The non- command area, on the other hand, indicates a gradual decline of water table due to overdraft for irrigation. The decline in water table is more pronounced in the southern parts away from the Command area, due not only to overdraft but also to the general declining trends of rainfall since 1974. In fact, drought occurs in this area once in every four years. This part of the sub-basin,therefore, calls for artificial recharge of the aquifers to augment the existing groundwater regime.

Chapter 4

Springs As Source Of Water

4.1 INTRODUCTION

Springs are natural outlets through which the ground water emerges at the ground surface as concentrated discharge from an aquifer and are most conspicuous forms of natural return of groundwater to the surface. These are part of groundwater system and could occur in various sizes, i.e. from a small trickle to a large stream.

Seepages are distinguished from springs because of the slow movement of groundwater from the seepage zone unlike the springs. In the seepage areas, the water may be accumulated in the form of a small pond and it may evaporate or flow according to magnitude of the seepage, climate and topography. Dugwells and borewells from which groundwater is drawn, come into the category of artificial discharge centres whereas a spring is the natural groundwater outlet.

Springs are found in the Himalayas, in the Western Ghats and in many other places in India where it is logistically difficult to create storage for water. As such, study of springs has great relevance to the water supply to rural areas, especially in the hilly region. Springs emerging from basalts are among largest known ones and compare in importance with those emerging from carbonate rocks. Meinzer (1927) has reported large springs in the basaltic terrain of California, Oregen etc. of U.S.A. In India, although the basalts cover a very large areal extent of about 500,000 sq km in the Peninsula, very little efforts have been made to investigate and effectively harness them as important source of water, especially in the Western Ghats where they are found to occur in plenty. Pitale et al (1987) have studied the hot springs of the West Coast belt of Maharashtra.

Cold water springs have received little attention of geoscientists. In the present investigation of a part of Western Ghats (hills) where people living at higher elevation depend solely on spring-water both for drinking and irrigation purposes, an attempt has been made to study them with reference to their origin, distribution, classification, discharges and their possible use as a source of water in the Koyna Sub-basin.

A total of 121 springs as shown in figure 4.1 were examined. The details regarding the location and discharge of these springs are given in Appendix.

4.2 ORIGIN OF SPRINGS

The conditions necessary to produce springs are many and are related to different combinations of geologic, hydrologic, hydraulic, pedologic, climatic and even biologic controls (Maxey, 1964). In the Western Ghats the geologic control in addition to the physiographic or geomorphic set up plays the most important role for the origin of springs.

As has been stated earlier, most of the hills in the Western Ghats are flat-topped. Hills with narrow ridge at the top are also frequently seen. The top of such ridges is, however, flat although of small areal extent and gives indication of a broad flat plateau, which existed earlier. Characteristically, at elevations lower than flat tops of hills, on both sides of the hills, there exist flat plateaus or hill terraces (Fig. 1.6), giving a step like appearance in an aerial view. This feature is a characteristic of the Deccan Plateau. Such hill terraces generally underlie relatively resistant rocks (massive basalts), but due to constant leaching, they are generally weathered and sometimes are in the process of lateritisation or are completely lateritised. Mostly hill tops in the area above a height of 975 m above MSL are lateritised. The cross sectional view of the hill tops with narrow ridge and broad flat plateaus or caprock are shown in figure 4.2.

During rains the rainwater percolates down through joints, fractures, weathered basalts, in the hill terraces. The amount of rainfall infiltration is directly proportional to the area of exposure of the basaltic flows and their water-bearing properties such as permeability or transmissivity. A thin soil cover is naturally formed on the top of such hill terraces and below this soil cover, there exist highly weathered and porous basaltic rocks. The degree of weathering is more in vesicular basalt than in massive basalt. Rainwater percolates downward easily under such conditions. Similar percolation process is also observed in the terrains with flat lateritic tops and poorly lateritised basaltic units. The rate of weathering and development of secondary

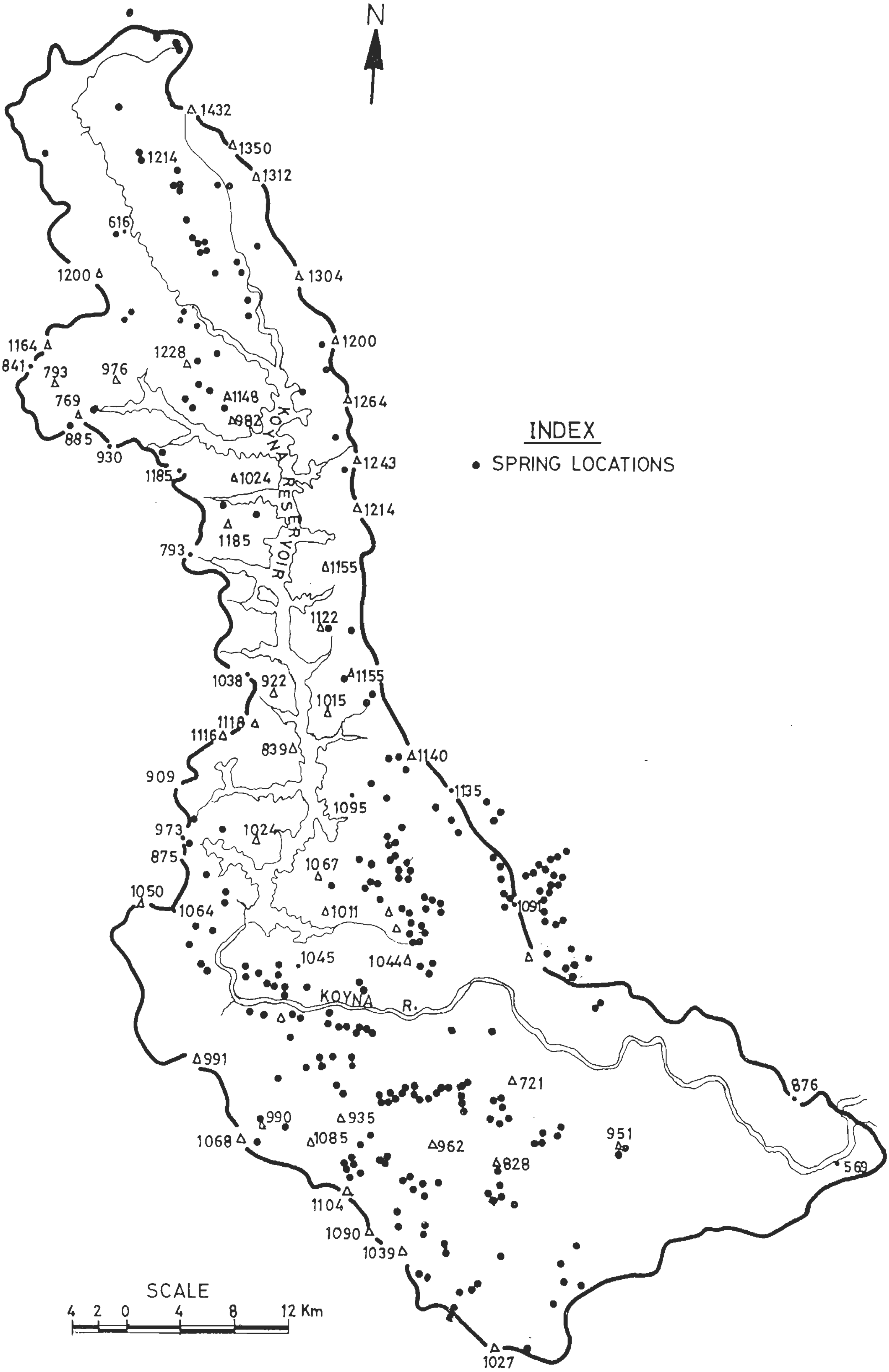
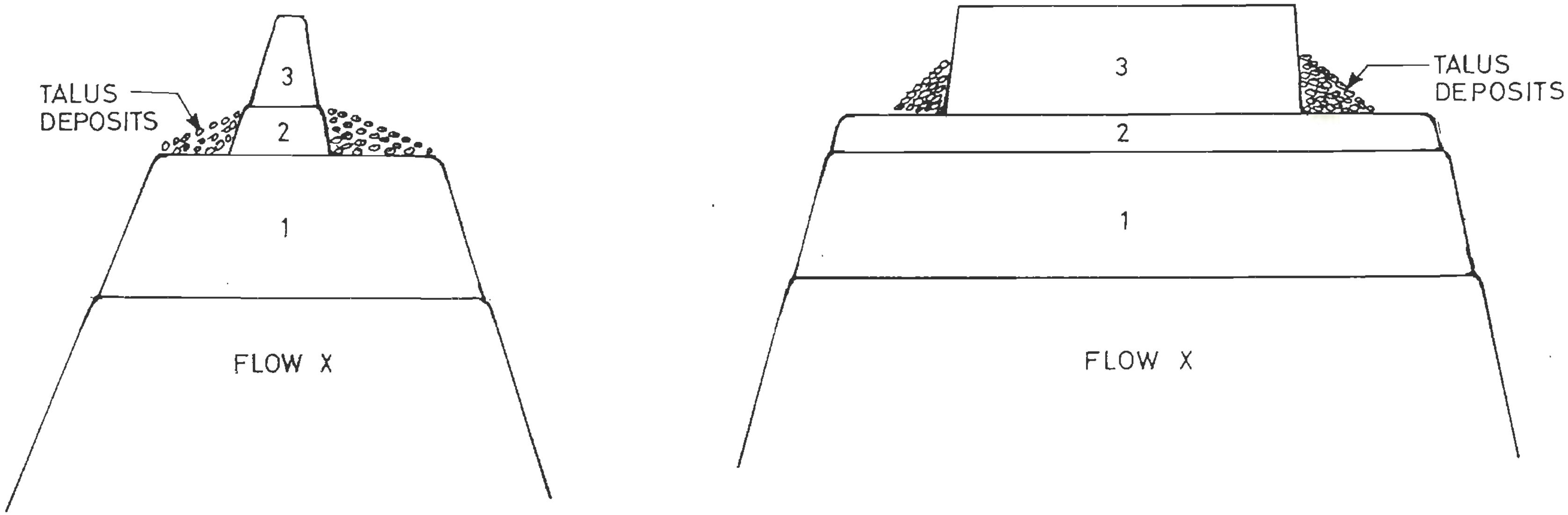


FIG. 4·1-LOCATION OF SPRINGS IN THE KOYNA SUB-BASIN



a) HILL TOP WITH NARROW RIDGE

b) HILL TOP WITH FLAT PLATEAU

FIG.4·2-IDEALISED CROSS-SECTIONAL VIEW OF THE HILL-TOPS porosity go on decreasing with depth in successive older flows. Thus the downward percolation of rainwater (now groundwater) gets obstructed by relatively non-porous massive basaltic unit existing at relatively lower levels. The water then starts accumulating and then wherever possible, tricks more laterally through the permeable unit above the impermeable massive basaltic unit. This laterally moving water oozes out at the hill face, in the form of spring..

The preferred flow path of the groundwater to emerge as a single spring in an area is determined by the intercommunicating pore spaces existing in the rock units, generally at the flow contacts and at the contact between the vesicular unit and massive unit or highly weathered massive unit and relatively poorly weathered (or unweathered) flow unit. Sometimes, the flow path is carved by the pore space formed due to fissures or joints or fractures. The numerous streams in the hilly tracts in the Western Ghats generally start with such spring which carves a narrow gully on the hillface. Such narrow gulleys gradually grow in size and expose the source aquifer, the water of which oozes out from a number of points above the impermeable stratum. A group of springs, thus, contributes significantly to the stream flow. When a stream travels for a long distance in a sprawling hill the stream flow is further strengthened by the contribution from several such points all along its flow path. Such a contribution of groundwater is nothing but baseflow which is found even at higher elevation. Such a stream never gets dry in summer as reported by the inhabitants living in the area.

4.2.1 Geological Controls of Springs

The discussion above shows that rainwater is the only source of recharge to the aquifers which serve as source- rock for the springs. The following geologic conditions control the occurrence of springs.

(1) If the source-rock or source-aquifer happens to be laterite, the rainwater in it percolates down very rapidly due to high permeability of the rock. However, the downward movement of water is blocked by a lithomargic clay existing below it and the groundwater emerges as a spring just above the lithomargic clay (Fig. 4.3). Sometimes the lithomargic clay is not found to exist

at the bottom and spring emerges out at the contact between laterite and poorly lateritised basaltic flow. 9% of the springs investigated at the source have this type of origin.

(2) If the source aquifer happens to be vesicular basalt above, the springs ooze out at the contact between the vesicular basalt above and the non-vesicular massive basalt below. 20% of the springs investigated have this type of occurrence, viz. they emerge at the contact between the vesicular basalt and weathered massive basalt or relatively hard massive basalt.

(3) Generally in the hill terraces or below it, the entire thickness of a massive basalt is weathered, but the degree of weathering gradually decreases with depth. Thus the highly weathered basalt grades into the poorly weathered basalt of the same flow unit and two separate layers are formed accordingly. Rainwater percolating downward gets blocked in the poorly weathered massive basalt and oozes out as springs (Fig.4.4). 20% of the springs examined are found at the contact between the weathered massive basalt and moderately weathered massive basalt or hard massive basalt.

(4) When the entire thickness of a flow in a hill terrace is weathered considerably, the rain water percolates down very easily throughout the thickness of the basaltic flow unit, but may not permeate through impermeable redbole bed existing below it. Under such conditions spring emerges at the contact between the overlying weathered basalt and the underlying redbole bed (Fig. 4.5). 17% of springs were found to belong to this category.

(5) If the redbole is too thin to inhibit the downward movement of water or is absent, a case rarely found at higher elevations in younger flows, the groundwater percolates still downward till it is blocked by a relatively impermeable stratum to emerge as springs.

(6) Talus deposits are very common at higher elevations and a thick pile of broken pieces of rocks and weathered materials are found on hill slopes. Since the hill ranges are of sprawling nature, the talus deposits are found everywhere. The narrow ridges on hill tops are product of erosion and the eroded materials are found in piles in their bottoms on the hill terraces. The talus deposits are quite permeable since these contain unconsolidated materials. Water very easily

Fig.4.3 : Spring oozing art at the contact between laterite above and lithomargic clay below near Sadavagapur (Spring No.53) (elevation 1080 m above MSL).

Fig.4.4 : A spring emerging at the contact between the weathered massive basalt and hard massive basalt at Chikhli (Spring No.12) (elevation 1200 m above MSL).

seep in the talus deposits and emerge as springs when the downward movement of water is blocked by a impermeable rock (Fig. 4.6). 23% of the springs were found at the contact between the talus deposits and the impermeable strata.

(7) The face of a hill is not steep at lower elevations but consists of a number of step-like features or makes an acute angle with the hill top, due to differential weathering of the basaltic flows. Thus along the hill slopes, many permeable strata are suitably exposed. Rainwater while flowing downhill seep in such rock exposure and give rise to springs at lower elevations when the percolated water is blocked by an impermeable stratum. Springs of such types are rare and hardly flow throughout the year due to their limited recharge.

(8) Springs oozing out of the fractures are also found in the Western Ghats. In many cases, water issues in vertical direction giving indication that the fractures are vertically oriented (Fig. 4.7). Springs issuing from horizontal joints are also observed. But mostly the horizontal joints form seepage zones in a stream course instead of forming distinct springs. Springs issuing from the horizontal joints are reported to be dry in summer while the springs emerging from the vertical fractures are reported to be giving poor discharge during the season (summer). It may be due to the fact that the piezometric pressure which causes the upward movement of groundwater through such fractures are low in summer due to limited recharge.

A 'hot spring' at Aravalli (17°18'37" : 73° 31'05") on the western side of the Western Ghats was observed. The spring existed at an elevation of 10 m above MSL on the flood plain alluvium of Gad river and has a water temperature of about 43°C. It lies in the line of the hot-spring belt of the West Coast. Pitale et al. (1987) opine that the water discharges through a N20°E-S20°E steeply dipping fracture in the trap flow underlying the alluvium of the Gad river.

Officers of Geological Survey of India, namely Rao (1987), Thorat and Kumar (1987), Sahasrabudhey and Sharma (1987), etc. report existence of springs at the flow contacts.

The basaltic flows have horizontal disposition and despite the fact that they have lateral variations in characters, the characters are more or less similar within a few kilometre. A number of springs emerge from a particular flow at several points and generally they are aligned in a line in a horizontal section at least within few kilometres (Fig. 4.8). Again, the springs emerge on both the sides of a water-divide due to the exposure of the rock formation on either sides of the divide. However, spring issuing from a point at one side may not exist exactly at the same level on the opposite side. Thus, local variation in lithological and other related characters has a role in the emergence of springs.

The above discussion follows that the springs generally issue at the contact between

(i) laterite and lithomargic clay or poorly lateritised basaltic flow

(ii) vesicular basalt and non-vesicular massive basalt,

(iii) highly weathered massive basalt and moderately or poorly weathered massive basalt or redbole

(iv) talus deposits and hard massive basalt or laterite or lateritised basaltic flow

Also springs emerge in fractures, both horizontal and vertical.

4.3 DISTRIBUTION OF SPRINGS

4.3.1 Elevation wise Distribution

The springs are distributed at the elevation range of 600 to 1350 m above MSL (Fig. 4.1). The elevation-wise distribution is shown in Table 4.1. While groundwater development through dugwells and borewells in the area is concentrated at the elevation range of 550 to 700 m above MSL, the springs in the hilly slopes start emerging from the elevation of about 650 m above MSL and form additional source of water for the inhabitants in the foothill zone where

Fig.4.5 : A spring oozing out below a basaltic flow layer above red bole at Chikhli (Spring No.9) (elevation 1140m above MSL).

Fig.4.6 : Springs at the contact between Talus deposits and hard massive basalt at Pimploshi (Spring No.62) (elevation 660m above MSL).

Fig.4.7 : Springs issuing through fractures at Kavadevadi (Spring No. 64) (elevation 630m above MSL).

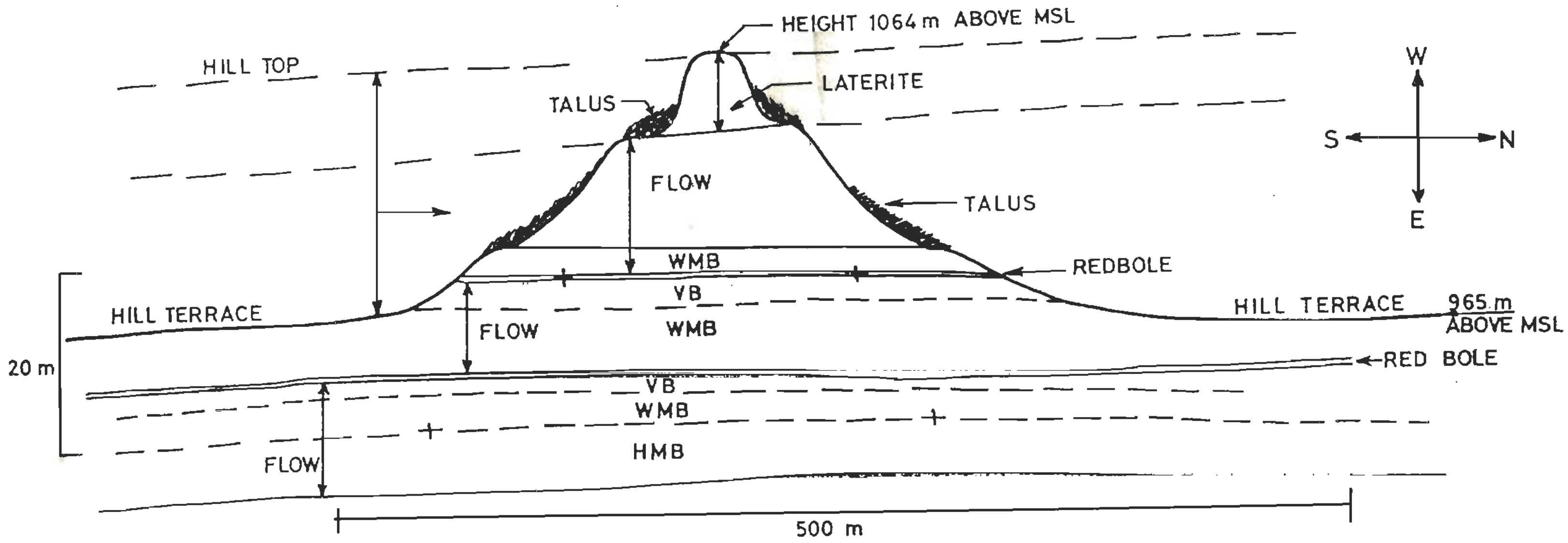


FIG.4·8-BORGEVADI-MALEVADI HILL SECTION (DISTANCE 3 Kms) SHOWING EMERGENCE OF SPRINGS AT SEVERAL POINTS

INDEX

VB - Vesicular Basalt
WMB - Weathered Massive Basalt
HMB - Hard Massive Basalt

Table 4.1 Elevationwise Distribution of Springs

Elevation Range (m above MSL)	No. of Springs	% of Springs
600- 700	13	11
700- 800	12	10
800- 900	12	10
900-1000	57	47
1000-1100	16	13
1100-1200	4	3
1200-1300	2	2
1300-1400	5	4
Total	121	100

the success rate of dugwells and borewells is meager. 13 (11%) of the 121 springs examined occur at an elevation range of 600 to 700 m above MSL.

In the southern part gentler slopes are found at the elevation range of the 800 to 900 m above MSL. A distinct break in slope is found at 900 m contour. Hill slopes start becoming steeper below this contour. Above this the area as a whole is generally of sprawling nature. Hill terraces occur extensively. Rocks show lateritisation above 975 m above MSL. Talus deposits are of considerable thickness. The same is the case with the central part as well, but here the hill terraces are above 950 m altitude. Thus maximum number of springs (47%) exist at the elevation range of 900 to 1000 m.

In the northern part of the sub-basin, the western side has sprawling hill range and the slope/gradient is not steep thus giving rise to a number of springs at different elevations. The hill tops have an average height of 1000 m above MSL in this area.

In the eastern side around Sadavaghapur the contour interval of 900 to 1000 m still forms steep slope and a distinct rock cliff of laterite is found at about 1060 to 1080 m above MSL which also extends to the central part. The cliff is of 20 m thick and ends with 1080 to 1100 m contour line. Above this elevation table lands are found (Fig.2.8) which serve as recharge areas for the springs existing below the cliff. 15% of the springs investigated occur at the elevation range of 1000 to 1100 m above MSL.

Around Mahabaleshwar in the north and Taldev, about 15km SE of it, three distinct terraces exist at the elevation range of 1000 to 1100 m, 1100 to 1200 m and 1200 to 1300 m above MSL. These terraces form good recharge zones and give rise to about 9% of the total number of springs examined. Above 1300 m above MSL the occurrences of springs are rare. The highest springs location was found at an altitude of 1340 m above MSL at Old

Mahabaleshwar. The area occupied by the Koyna sub-basin above the elevation of 1100 m is very small and as such very small percentage (7%) of springs could be accounted above this altitude.

4.3.2 Recharge Areas for Springs

While springs occur at elevation range of 600 to 1350m above MSL, their concentrations are more in the sprawling hill tops and flat areas. The steep slopes though contain springs their numbers is very few. In fact these slopes hardly allow rainwater to percolate down to form potential springs and hence do not form recharge areas. Therefore, such areas have been demarcated and their area have been calculated with the help of planimeter. Similarly, the areas which form potential zones for spring formation have been demarcated (Fig. 4.9). The following is the calculation of coverage of different physiographic setup.

(1)	Spring recharge areas	722.30 km^2 (sprawling hill tops and flat areas)
(2)	Dissected plateau including steep slopes	622.65 km^2
(3)	Water spread area of Koyna reservoir	115.35 km^2
(4)	Relatively plain areas where groundwater development is through dugwells and borewells	575.70 km^2
	Total	2306 km^2

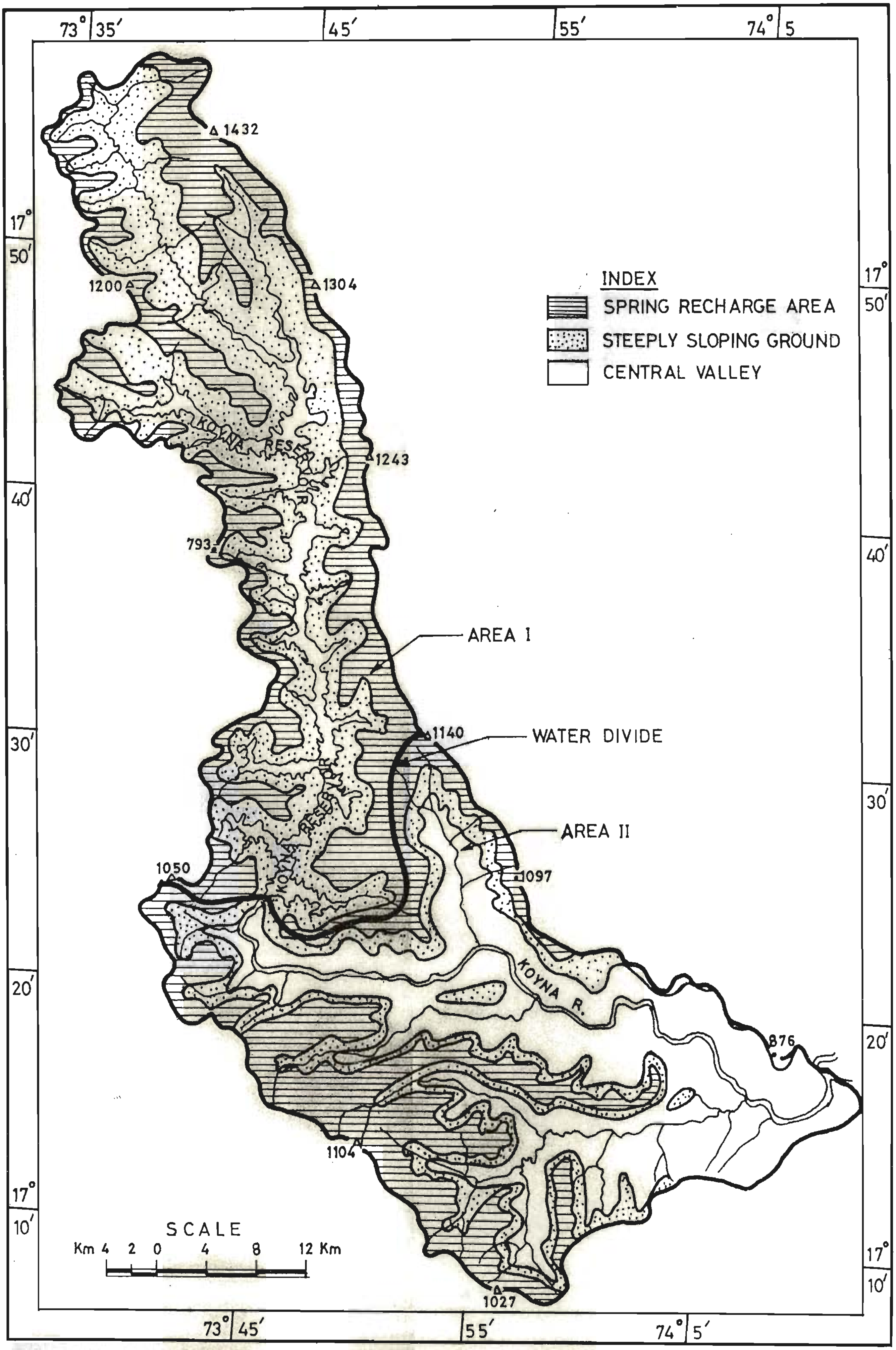


FIG.4·9 MAP SHOWING SPRING RECHARGE AND STEEPLY SLOPING GROUND

It is thus found that 35 percent of the total area of the Koyna sub-basin forms spring recharge area which are mostly responsible for the origin of potential springs. A survey in the central part revealed that for an area of 80 sq km in the spring recharge areas, there exist 70-80 potential springs, thus giving the average distribution springs to be one per square kilometer. Thus in an area of 722 sq km, considered to be the recharge areas for springs, about 725 springs are expected to occur.

4.4 SPRING DISCHARGES

4.4.1 Quantum of Spring Discharges

Rainfall is the source of recharge to the source aquifers. The recharge to the aquifers naturally reaches the peak in the monsoon period, i.e. in the months of June to September and thus the resulting spring discharges reach its peak during this period.Most of the springs are, however, perennial.

The discharge of the individual or a group of springs, wherever possible was measured and is given in Appendix. The discharge varies between 0.024 lps (or 2.06 m^3 /day or 86 lph) to 5 lps (or 18000lph or 443 m^3/day) in winter.The mean winter discharges of the individual springs is estimated to be 46 m^3/day. The summer discharges vary between 0.011 lps (or 39 lph or 0.94 m^3/day) to 2.5 lps (or 9000 lph or 216 m^3/day) and the mean discharge of the individual springs is estimated to be 28m^3/day. The summer discharges, though few,indicates the level to which discharge go down.During rainy season, the discharges are generally double of that of the winter season. Thus, the combined discharge of springs seasonwise is found to be 8 MCM during rainy season, 4 MCM during winter season and 2 MCM during the summer season bringing to a total of 14 MCM annually.

Meinzer (1923) has classified the springs based on their magnitude of discharge (table 4.2). Table 4.3 summarises the discharge ranges of springs based on Meinzer's classification. It is found that in the Western Ghats springs of the magnitude of 5th and 6th are generally common.

4.4.2 Relationship of Spring Discharges with Elevation

A distribution of spring discharges with elevation is given in Table 4.4. It is found that most of the high yielding springs (> 72 m^3/day) are found at the elevation range of 1300 to 1400 m above MSL. These springs emerge from the thick talus deposits found in the area. Although the elevation range of 900-1000 m above MSL accounts for the highest number of high-yielding springs their percentage value is less, i.e. 18% (6 out of 33). This elevation range contains a number of other low to medium yielding springs. The source aquifers at this elevation is generally laterites, talus, vesicular basalt, weathered massive basalt etc. and the spring discharges generally depend on the source aquifers, thus giving different ranges of spring discharges. Maximum number of springs (47%) are found at this elevation range due to its favourable physiographic condition as discussed in the section on distribution on springs.

4.5 CLASSIFICATION OF SPRINGS

There are various types of springs flow domain depending on aquifer geometry and other physical factors. As stated earlier, the conditions necessary to produce springs are numerous and are related to many and various combinations of geologic, hydrologic, hydraulic, pedologic, climatic and even biologic controls (Maxey, 1964). Therefore, numerous specific descriptive terms for springs have developed, but no single basis of classification satisfies the needs of a general usage. Maxey (1964) summarised the following bases of classification that have been used so far by various workers :

Table 4.2 Classification of Springs According to Magnitude of Discharge (After Meinzer, 1923).

Magnitude	Dischages cu ft/sec. and gpm	m^3/day
First	100 cfs or more	238000 or more
Second	10 to 100 cfs	23800 to 238000
Third	.1 to 10 cfs	2380 to 23800
Fourth	100 gpm to 1 cfs	530 to 2380
Fifth	10 to 100 gpm	53 to 530
Sixth	1 to 10 gpm	5.3 to 53
Seventh	1 pt to 1 gpm	1.3 to 5.3
Eighth	Less than 1 pt/min	Less than 1.3

(1 cfs = 448.8 gpm; 1 gallon = 4..546 ltrs; 1 gal/min = 5.300 m /day).

Table 4.3 Discharge Ranges of Springs Examined

Discharge Range (m^3/day)	Meinzer's Magnitude	No. of Springs	% of Springs
2-12	Seventh/Sixth	17	23
12-24	Sixth	24	32
24-36	Sixth	8	11
36-48	Sixth	8	11
48-60	Sixth/Fifth	4	5
60-72	Fifth	0	0
>72	Fifth	13	18
Total		74	100

Table 4.4 Relationship between Spring Discharges and Elevation

Elevation Range (m above MSL)	No. of Springs With Discharge Ranges (m³/day) 2-12	12-24	24-36	36-48	48-60	60-72	>72	Total No.	%
600- 700	0	3	1	0	0	0	1	5	7
700- 800	3	2	1	2	0	0	1	9	12
800- 900	0	3	1	1	0	0	1	6	8
900-1000	9	11	2	3	2	0	6	33	45
1000-1100	2	2	3	2	2	0	2	13	17
1100-1200	1	1	0	0	0	0	0	2	3
1200-1300	1	1	0	0	0	0	0	2	3
1300-1400	1	1	0	0	0	0	2	4	5
Total No.	17	24	8	8	4	0	13	74	100
Per cent of springs	23	32	11	11	5	0	18		100

i. Character of opening from which water issues.
ii. Character of the water bearing formations.
iii. The rock structure and resulting force that brings the water to the surface.
iv. Quantity of water discharged.
v. Uniformity and periodicity of the rate of discharge.
vi. Chemical quality of the water discharged.
vii. Temperature of the water.
viii. Deposits and other features produced by the springs.
ix. Sources of the water, whether shallow or deep seated.
x. Direction of movement of water.

Although a number of classification of springs, based on one or many of the above criteria have been given by various workers such as Meinzer (1923), Keilhack (1935) and Tolman (1937), none of these classifications cover all aspects of the origin, occurrence, nature of emergence, source aquifers etc. of the springs. Therefore, a simple classification of springs based on nature of emergence and source aquifers is suggested here for the basaltic terrain of the Koyna sub-basin.

4.5.1 Proposed Classification

The springs of the Western Ghats are essentially gravity springs, emerging either from the contact between two lithounits or from fracture surfaces. But since the emergence of the groundwater as springs is largely controlled by the water-bearing properties of the aquifers in the study areas, these springs can also be classified on the basis of their source aquifers as given below.

A. Contact Springs

i. If a spring issues at the contact between the laterite above and lithomarge or poorly lateritised flow or massive basalt below i.e. if the source aquifer is laterite, the spring may be termed as 'laterite spring'.

ii. When a spring issues at the contact between the talus deposits above and poorly lateritised or weathered hard massive basalt below, the talus deposits form the source aquifer and the spring may be termed as 'talus spring'.

iii. Likewise, when the source aquifer is vesicular basalt, i.e. when a spring emerges at the contact between the vesicular basalt above and weathered or hard massive basalt below, the spring may be called a 'vesicular basalt spring'.

iv. Similarly, when a spring issues at the contact between the weathered massive basalt (source aquifer) above and moderately weathered or hard massive basalt or redbole below, the spring may be called a 'weathered non-vesicular basalt spring'.

B. Fracture Springs

When a spring issues through a fracture vertical or horizontal, it may be called a 'fracture spring'. The fractures may not be deep seated. Here, no specific source-aquifer is involved although the fractures giving rise to springs are generally found in the massive basalt.

Thus, out of the five subclasses the first four are contact springs, categorised into four different types depending on their source-aquifers. Therefore, when one speaks of contact springs, it not only gives the idea about the nature of emergence of spring but also the source aquifer. Thus when one speaks of laterite or talus or vesicular basalt spring, one may easily imagine the source-aquifer and the nature of the spring emergence as well.

The frequency distribution of occurrence of the various types of springs as proposed, is given in Table 4.5.

4.6 SPRINGS AS WATER RESOURCES

4.6.1 Present Status of development

The springs act as the main discharging factor of the groundwater in the hilly tracts. The rain water concentrated only through a particular period of rainy season and having limited recharge area cannot sustain the springs to flow constantly throughout the year. Hence, rain and spring act as two opposite poles one recharging and the other discharging the groundwater. However, this discharging nature of springs act as a boon to inhabitants in the hilly tracts.

The springs are used both for drinking and irrigation by the inhabitants at higher elevations and foothill zones. Even, their water is considered holy at some places, e.g. the Panchaganga Temple at Old Mahabaleshwar, which is the highest spring location in the area (Fig.4.10). In many villages, springs irrigate more than 100 acres of land. Generally villagers combine the water of two or more springs and bring it to one channel to irrigate wheat, vegetables, sugarcane etc. While spring water flows in such open channels (Fig.4.11) down the slope, a major part of water carried is lost due to seepages on the way. Generally springs are tapped and water is supplied to small hamlets by the State Government under 'gravity water supply scheme'. Sometimes water of two springs are combined to cater to the need of the large population.

Generally, a small tank is made at the origin of a spring and water is allowed to flow through a pipe-line. Water thus tapped is stored in storage tank at the foothill at relatively higher elevation than that of the village supplied with spring water (Fig. 4.12). Water thus collected is released periodically or continually by pipelines to the village depending on the quantity of water stored.

Many of the springs are converted into dugwells, i.e. a dugwell is constructed at the emerging point of a spring so as to store the spring water, if the village supplied with the water is very near the spring (Fig. 4.13). However, water still keeps on flowing from such dugwells since the springs flow continuously.

Out of 30 water supply schemes investigated, (77%) of the schemes were found to be ineffective or yielding very poor result. The following are the common causes for the poor performance of the gravity water supply schemes.

i. **Tapping of only one small spring for a comparatively** large population : Sometimes although two or more springs are available closely for harnessing,only one spring is tapped for the gravity water supply. Thus, the stored water falls short of the total demand of the covered population.

ii. **Lack of thorough investigation of the springs including the summer discharge** : All the springs are not perennial. Or, although they are perennial they yield poor discharge during the summer compared to the winter. Thus, the spring becomes virtually ineffective during the season.

iii. **Breaking apart of the pipe-lines connecting the spring and the storage tank** : It is a very common feature in the gravity water-supply schemes. The pipe-lines get disconnected due to rolling down of rock boulders from the hills along the slope and interference of the wild animals (Fig. 4.14).

Table 4.5 Frequency of Occurrence of various types of springs

Type of spring	No. of springs	Percentage of springs
A. Contact springs		
i. Laterite springs	7	9
ii. Talus springs	17	23
iii. Vesicular basalt springs	15	20
iv. Weathered non-vesicular basalt springs	28	37
B. Fracture springs	8	11
Total no. of springs	75	

Fig.4.10 : Spring water coming out from the mouth of a statue-cow at Panchaganga temple at Old Mahabaleshwar. The water is considered holy by the local inhabitants (Spring No.1) (elevation 1340m above MSL).

Fig.4.11 : Spring water being taken in an open channel for irrigation near Sadavaghapur (47G/152B) (Spring No.53) (elevation 1080m above MSL).

Fig.4.12 : Storage-tank and delivery pipe for storage and supply of spring water.

Fig.4.13 : A spring converted into a dug-well at Bhandri (depth of dugwell about 2m) (elevation 700m above MSL).

iv. **Leakage of storage tank and silting up of the small tank at the origin** : Sometimes the small tank constructed at the origin of the spring to tap the flowing water gets silted up or develop fractures (Fig..4.15). Even the main storage tanks at times develop leakages in it. Thus, the water supply scheme becomes ineffective due to lack of proper storage of water, compelling people to repair them either at their own cost or find some other source of drinking water.

So far there is no law barring people to capture one full spring for their private use. In the entire investigation of spring there was only one instance of a farmer tapping one full spring at his own cost to cultivate about 10 acres of land (Fig. 4.16). Some rich people in Mahabaleshwar area tap many springs for gardening and drinking.

In many instances, the spring water from the tapped ones is wasted, which otherwise should be used for horticulture or irrigation (Fig. 4.17). In some villages near Mahabaleshwar, the Government has tried to store the flowing water after its use for drinking or irrigation purposes and such storage of water has proved to be very useful.

Not in all the villages, water is supplied through pipe-lines from the main storage tanks. In these villages, the storage tanks are fitted with water taps. But in many cases, these water taps are lacking or missing thus causing unnecessary wastage of the tapped water.

4.6.2 Suggestions for Future Development of Springs

The following are some of the suggestions for effective development of the existing springs :

i. The springs should be tapped after a thorough measurement of their discharges in different seasons including the summer. The water requirement of the village to be supplied with the water must be satisfied with the spring water.

ii. Whenever necessary two or more springs should be tapped together to cater to the demand of the relatively large population.

iii. After installation of the water supply schemes, they should be monitored periodically.

iv. In case of excessive water after its use, the surplus water may be stored in a tank to practice horticulture and to irrigate some acres of land.

v. Rainwater harvesting structures should be constructed at suitable locations on the hill tops for enhancement of the life of springs and their discharges.

vi. It is suggested that the pipe-lines connecting the spring origin and the storage tank be aligned underground in about 2-3 ft depth so as to protect it from detachments due to rolling down of rock boulders interference of wild-animals..

vii. Generally spring-water is supplied only through gravity to the village on the hill slope or foothills. In such a case the villages sitting right on the flat plateau (table land) on hill tops (e.g. Sadavaghapur) will be deprived of water supply although the villagers derive water by hand from the springs existing near their villages on hill face. In such locations, water could be stored in a relatively large-tank depending on the population of the village and water could be supplied through lift by means of electric motors. One such example of spring water supply through lift is found at Mahabaleshwar (Fig. 4.18). This system was constructed by Britishers in pre- independence period (i.e. before 1947) for supplying water to a few bungalows on the hill tops about 1 km away.

4.7 SUMMARY

The northern and western hilly region of the Koyna sub- basin is dotted by many cold-water springs. The high rate of precipitation and the terrace-like topographic features found in the hills facilitate recharge of the aquifers through weathered/ fractured/ jointed rocks. These aquifers, whenever are dissected by fractures, joints and hill face, are drained in the form of

Fig.4.14 : Breaking-apart of the pipe-lines tapping spring water in the hilly tracts (Dhangarvadi-Spring No.33) (elevation 975m above MSL).

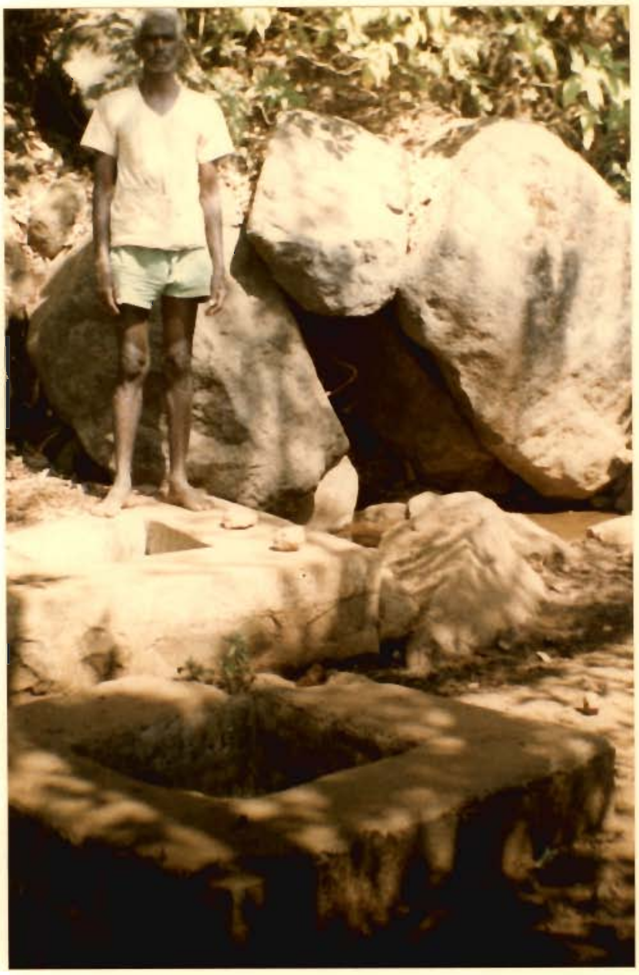


Fig.4.15 : Silting up of the tapping tank at the origin of spring (Jhola Chi Khind-Spring No.13) (elevation 1110m above MSL).

Fig.4.16 : A farmer spring water in a small tank before irrigation at Chikhli (Spring No.12) (elevation 1140m above MSL).

Fig.4.17 : Spring-water flowing a waste (Pimploshi tapping spring Nos. 62 and 63).

Fig.4.18 : A storage tank constructed by Britishers during pre-independence period for storing spring water and supplying it to their bunglaws on hill tops through lift-system (Mahabaleshwar-Spring No.6) (elevation 1240m above MSL).

springs. Based on the examination of 121 spring, it is found that they generally emerge through fractures or the contact between (i) laterite and lithomargic clay, (ii) laterite and poorly lateritised basaltic flow, (iii) vesicular basalt and massive basalt, (iv) highly weathered massive basalt and moderately or poorly weathered massive basalt, (v) weathered massive basalt and redbole and (vi) talus deposits and hard massive basalt or laterite or poorly lateritised basaltic flow.

The springs are distributed at an elevation range of 600 to 1350 m above MSL with maximum concentration (47%) in between 900 to 1000 m elevation. A distinctive break in slope and an extensive hill terrace especially in the south and central part is found above 900 m contour. 22% of the springs occur above an altitude of 1000 m. The springs have a recharge area of 722 sq.km. and frequency of occurrence of one spring per square kilometre.

The mean discharge of the individual springs in winter is about 46m^3/day (range 2.06 to 432 m^{3}ay) as against the mean discharge of 28m^3/day in summer (range 0.94 to 216 m^3/day). Maximum number of high yielding springs (> 72 m^3/day) are located at the elevation range of 1300-1400m above MSL. The annual discharge of springs for the Koyna sub-basin as a whole is estimated to be 14 MCM, out of which 8 MCM accounts for the rainy season, 4 MCM for the winter season and 2 MCM for the summer season. As per Meinzer's classification (1923), mostly the springs of fifth and sixth magnitude are present in the area.

Based on the nature of their emergence, the springs could be classified as contact springs (89%) and fracture springs (11%). However, since the emergence of groundwater in the form of springs is largely controlled by the water-bearing properties of the formations in the study area, it is suggested that these springs be classified based on their source-aquifers. Thus, a simple classification has been suggested which categorises the springs into four types of contact springs, namely (i) laterite springs (9%), (ii) talus springs (23%), (iii)vesicular basalt springs (20%), (iv) massive basalt springs (37%) besides fracture springs (11%) associated with any type of source aquifer.

The springs are used both for drinking and irrigation in the hilly tracts. Generally villagers combine the water of two or more springs and bring it to one channel, which is unlined. While flowing in such open channels down the slope, a major part of water is lost due to seepages on the way. Taking into consideration the terrain conditions and need of the inhabitants, several measures have been suggested for effective harnessing of the spring water in the Koyna sub- basin.

Chapter 5

Hydraulic Parameters And Yield Of Wells In Shallow Aquifers

5.1 HYDRAULIC PARAMETERS

5.1.1 Introduction

Evaluation of hydraulic parameters is an important aspect of any scheme for groundwater resource assessment. Amongst the various hydraulic parameters, Transmissivity and Coefficient of Storage (also termed as Storativity) are the two most important parameters. Transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient (Lohman et al, 1972). The overall capacity of an aquifer to transmit groundwater is dependent on the thickness and hydraulic conductivities of the component parts of the aquifer. The coefficient of storage (S) of an aquifer is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (Karanth, 1987). In the case of a water-table aquifer, the concept of coefficient of storage is analogous to that of specific yield (Sy). If the water table is lowered, water is released by gravity drainage in proportion to the amount of decline, the coefficient of storage being equal to the specific yield of the desaturated material, provided gravity drainage is complete. These can be determined by conducting aquifer or pumping tests at various representative locations in different types of aquifers in the area under investigation. A pumping test involves abstraction of water from a well and observation of water level changes with respect to time in the pumped well and/or in one or more observation wells. An aquifer test is a controlled field experiment for determination of the hydraulic properties of the aquifers and associated rocks.

Exploratory borewells tapping deeper aquifers with a set of observation wells are generally designed for accurate evaluation of aquifer parameters. Although in the Koyna sub-basin many borewells have been drilled for water supply from deeper aquifers, there is paucity of borewells designed especially for pumping tests. These borewells are fitted with hand pumps and are used to extract water only for drinking/domestic purposes. For paucity of submersible pumps and compressor, pumping test could not be carried out in these borewells in this virgin area where no serious hydrogeological studies have so far been carried out.

However, to the author, as an individual, the local farmers provided the much needed help in conducting pumping tests in the dugwells through their centrifugal pumps. These tests were carried out to assess these aquifer parameters namely the transmissivity and the coefficient of storage.

5.1.2 The Pumping Test

Short duration pumping tests could be attempted in 20 dugwells (Fig. 5.1) in different water bearing horizons such as highly weathered and jointed basalt, poorly weathered and highly jointed basalt, poorly weathered and poorly jointed basalt, talus deposits, alluvium and soils. Most of these wells are located downstream of the Koyna dam since in its upstream side springs are mostly used instead of dugwells/borewells.

Depending upon the local conditions and the cooperation of farmers the duration of pumping varied from 60 minutes to 315 minutes and that of the recuperation from 78 minutes to 210 minutes. The details of the wells tested along with the duration of pumping as well as recovery is given in Table 5.1.

Farmers in the area have the common practice of transporting the pumped water for a distance of about 50 to 100 m or even more through delivery pipe due to terrain conditions and convenience in irrigation. At the point of delivery, the water is lifted for about one to two feet vertically before it is put to the field channels. Under such conditions, the discharges were measured at or very close to the well site where the pumped water was discharged more or less horizontally. Accordingly the discharge could be measured only in 8 wells under test pumping sites out of 20 actually conducted. For estimation of the aquifer parameters, i.e. transmissivity and storage coefficients (T&S), only the test data of these 8 wells were taken into consideration.

The available centrifugal pumps of the farmers were used for test pumping. With the use of centrifugal pumps, the discharge of wells continually declined, in general. The per cent decline of discharge from the beginning to end of pumping is given in Table 5.2. A perusal of

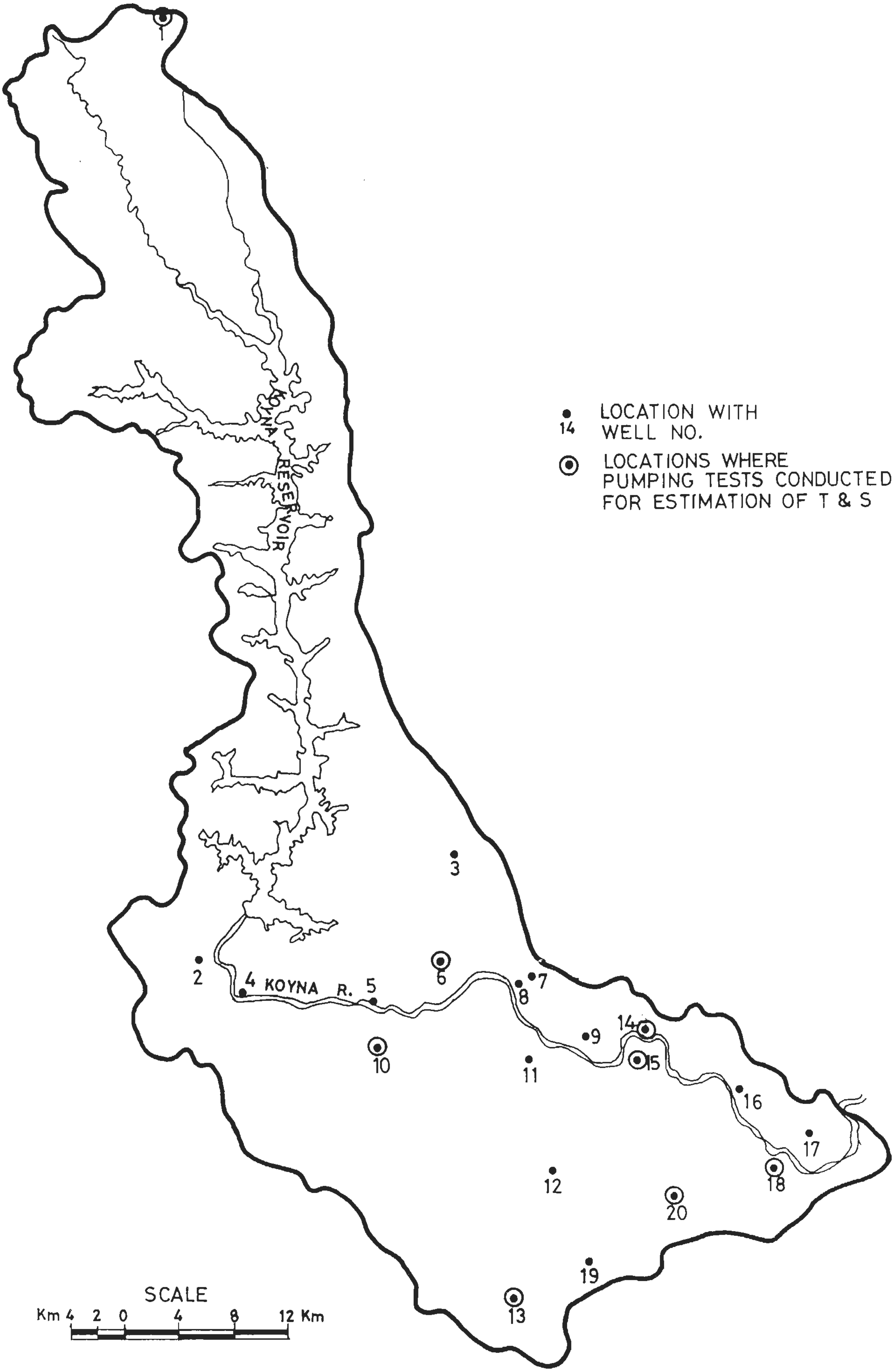


FIG. 5.1 - PUMP-TEST LOCATIONS

TABLE 5.1 . DETAILS OF DUGWELLS WHERE PUMPING TESTS CONDUTED

Well No.	Well Location, (toposheet & Quadrant No.)	Nature of Water bearing horizon	Well depth (mbgl)	Well Diameter (m)	Static Water level (mbgl)	Duration of Pumping (minutes)	Draw down (m)	Duration of Recovery (minutes)	Recovery (m)	% Recovery of draw down
1.	Old Mahabaleshwar (47 G/9 1B)	Talus deposits	5.10	6.25	3.58	113	0.72	78	0.06	08
2.	Kadamvadi (47/G/11 2C)	Highly Weathered and jointed basalt(Flow3)	2.80	4.40	1.21	60	1.15	90	0.49	43
3.	Sasewadi (47G/131B)	Highly Weathered and jointed basalt(Flow3)	3.25	2.25	2.0	83	1.08	90	0.07	06
4.	Ramamala (47 G/15 2A)	Highly Weathered and jointed Basalt(Flow3	8.90	10.00	3.74	175	1.16	120	0.25	22
5.	Shiral (47G/152B)	Alluvium (Flow 2)	5.10	8.40	3.56	150	0.97	210	0.19	20
6.	Mestivadi (47 G/15 2B)	Poorly Weathered and highly jointed	4.00	8.00	1.44	185	2.15	120	0.16	07
7.	Yerphale (47 G/15 2C)	Poorly weathered and poorly jointed basalt (Flow 3)	9.10	7.25	3.45	275	2.30	120	0.20	09
8.	Yerphale * (47 G/15 2C)	Soil (Flow2)	6.25	7.50	4.10	120	1.40	120	0.21	15
9.	Navsar * (47 G/15 2C)	Highly weathired Basalt (Flow 3)	8.05	8.45	1.65	90	0.79	130	0.24	30
10.	Kokisre (47 G/15 3A)	Poorly weathered and poorly jointed Basalt (Fow4)	8.25	4.75	4.60	65	1.92	125	0.26	14
11.	Gavanvadi (47 G/15 3C)	Highly Weathered Basalt.Taps, about 1m section of vesicular basalt (Flow 3/2)	7.15	10.45	3.56	120	0.89	120	0.20	22

12.	Maldan (47 G/16 1C)	Poorly Weathered and highly jointed basalt (Flow 3)	8.00	8.32	6.21	120	1.30	120	0.18	14
13.	Kalgaon (47 G/16 2C)	Poorly Weathered and poorly jointed basalt (Flow 4)	10.75	8.20	7.51	128	1.48	160	0.08	05
14.	Nisre * (47 K/3 2A)	Highly weathered Basalt (taps a section of vesicular basalt)(Flow 2/ Flow 1)	7.95	7.00	2.44	220	2.26	180	0.79	35
15.	Sonachivadi (47 K/3 3A)	Highly Weathered and jointed basalt (starts with redbole bed) (Flow 3/Flow 2)	4.60	9.50	1.70	180	1.78	120	0.20	11
16.	Sakurdi * (47 K/3 3B)	Highly Weathered and jointed basalt (taps a section of vesicular basalt) (Flow 3/Flow 2)	14.00	7.00	3.84	140	0.49	90	0.49	100
17.	Vijaynagar * (47 K/3 3B)	Soil (grades into highly weathered basalt) (Flow 2)	5.70	9.15	3.15	120	1.01	120	0.08	08
18.	Yeravle * (47 K/3 3B)	Highly Weathered jointed basalt (Flow 2)	12.65	11.00	6.48	315	1.78	120	0.50	28
19.	Jambhulvadi (47 K/4 A)	Poorly Weathered and poorly jointed basalt (Flow 4)	8.50	7.15	5.95	82	0.90	82	0.11	12
20.	Kole (47 K/4 1A)	Highly weathered and jointed basalt (Flow 3)	12.00	7.00	6.53	135	1.68	125	0.33	20

* Lies in Command area of the Koyna lift irrigation schemes.

Table 5.2 Decline Of Discharge From The Beginning To The End Pumping

Sl. No.	Well No.	Discharge at the beginning of pumping (m^3/day)	Discharge at the end of (m^3/day)	% Decline of discharge	Average (m^3/day)
1.	1	788	689	13	715
2.	6	711	602	15	665
3.	10	653	544	17	862
4.	13	1138	622	45	956
5.	14	1050	861	18	1007
6.	15	1587	1182	26	1362
7.	18	1253	611	51	910
8.	20	580	492	15	546

Table 5.2 shows that the discharge of the wells at the beginning of pumping is 13 to 51% more than that at the end of pumping phase. It is because at the initial stage of pumping, the water pumped is mostly derived from well storage while at the later stage, the water derived is mainly from the aquifer. Discharge drawdown measurements were made in a number of steps. The average of the discharges measured in each step (Table 5.2) was taken as the discharge of a well for analysis of the pump test data.

5.1.3 Analysis of The Pumping Test Data

Estimation of aquifer parameters through large diameter wells, has been attempted by various workers since long. Some of the important workers are Papadopulos and Cooper (1967), Kumaraswamy (1973), Zhdankus (1975), Boulton and Streltsova (1976), Ruston and Reedshaw (1979), Herbert and Kitching (1981), Ruston and Holt (1981), Ruston and Singh (1983, 1987), Mishra and Chachadi (1984, 1985) and Singh and Gupta (1986, 1988, 1991). The methods formulated have been reviewed time to time by several workers, such as Sammel (1974), Nair (1981), Mishra and Chachadi (1984), Singhal (1984), Sinha et al (1986) and Angadi (1986). Nearly all the methods for the analysis of pumping test data are based on certain assumptions and generalisations, which many times are not satisfied at the existing field conditions.

The analytical methods given by Papadopulos and Cooper (1967), Boulton and Streltsova (1976), Mishra and Chachadi (1985) and Singh and Gupta (1986, 1991) have found common use in the hard rock terrain. In the present investigation, the pumping test data have been analysed using the methodologies given by these workers.

5.1.3.1 Method of Papadopulos and Cooper (1967)

Papadopulos and Cooper (1967) presented for the first time a method for analysis of pumping test data from large- diameter wells taking into consideration the water derived from storage within the well. It is an extension of the non-equilibrium formula of Theis (1935), derived earlier for pumped well of infinitesimal diameter with negligible storage in the well.

This method of testing in large diameter wells, takes into account the well storage and therefore has become very popular to apply in the hard rock terrain (Romani, 1987). Phadtase et al. (1979), on the basis of their investigation in southern part of Maharashtra, have recommended the method for determination of aquifer parameter of shallow water bearing rock mass of basaltic terrain.

The general flow equation describing the drawdown "s" in the vicinity of a large diameter well is given by

$$s = \frac{Q}{4\pi T} F(\theta, \alpha, \phi) \quad \ldots\ldots \quad (1)$$

where Q = Discharge rate of the well,

T = Transmissivity,

s = Drawdown, and

F = A function for which numerical values are

$$\theta = \frac{4Tt}{r^2 S} \quad \ldots\ldots \quad (2)$$

$$\alpha = \frac{r_\omega^2 S}{r_c^2} \quad \ldots\ldots \quad (3)$$

$$\phi = r/r_\omega \quad \ldots\ldots \quad (4)$$

t = time since pumping started

S = Storage co-efficient

r = radius of well

r_c = radius of unscreened part of the well

The drawdown, "s_w" inside the well of large diameter (when $r = r_w$) is given by

$$s_\omega = \frac{Q}{4\pi T} F(\theta_\omega, \alpha, 1)$$

$$= \frac{Q}{4\pi T} W(u) \quad \ldots\ldots \quad (5)$$

which is the equation given by Papadopulos and Cooper (1967).

Papadopulos (1967) presented tables for the function $F(u,\alpha,\phi)$, where $u=1/\theta$ from which the type curves were prepared. Sinha et al (1986) have given family type curves using the tables. The field data of drawdawn (sw) versus time (t) were plotted on log-log paper of the same scale as that of the type curves. The data curve was matched with one of the type curves and the match point was selected. An arbitrary point "A" was chosen for which the values of $F(u,\alpha,\phi)$, $\Theta(1/u)$, sw and t were obtained from the type curve plot and the drawdawn plot. Substituting these values in equations 5 and 2, the T and S values were computed. Q and r_w are known from the field measurements.

Some of the representative data curves are shown in Fig. 5.2 and the computed T and S values are given in Table 5.4. Since the form of the type curve differs only very slightly when "α" differs by an order of magnitude, the value of S determined from the method has questionable reliability.

5.1.3.2 Method of Boulton and Streltsova (1976)

Boulton and Streltsova (1976) gave the most general equation which takes into account the anisotropic nature, compressibility of aquifer and partial penetration of the aquifer by the production well. The assumptions and conditions for application of the method are as follows:

(i) The aquifer is compressible and in general anisotropic, the horizontal and vertical permeabilities being constant

(ii) The aquifer is underlain by a horizontal impermeable bed, which may occur at any known depth below the bottom of the pumped well

(iii) The aquifer is pumped at a constant rate

(iv) The well losses are negligible

The general drawdown equation derived by Boulton and Streltsova is as follows

$$s = \frac{Q}{4\pi T} F(\theta, \rho/\rho_\omega, \rho, l', l_1, y', S) \quad \ldots \quad (6)$$

Substituting,

$$W = F(\theta, \rho/\rho_\omega, \rho, l', l_1, y', S)$$

$$W = \frac{4\pi Ts}{Q} \quad \ldots\ldots\ldots\ldots (7)$$

and $$\theta = \frac{4Tt}{r^2 S} \quad \ldots\ldots\ldots\ldots (8)$$

where Q = constant volume of water per unit time discharge from abstraction well

s = Drawdawn of hydraulic head at any point of aquifer

S = Coefficient at storage for compressible aquifer

T = Coefficient of transmissivity of aquifer

$\rho = \mu r/h$

$\rho_\omega = \mu r_\omega /h$

h = Depth of aquifer below water table

r = Horizontal distance from abstraction well axis to any point

r_w = Radius of abstraction well

l = Distance from water table to bottom of unlined part of abstraction well

l_1 = Distance from water table to top of unlined part of abstraction well

$l' = l/h$ and $l'_1 = l_1/h$

y = Depth of any point below water table

$y' = y/h$

The function W is very complex and involves a large number of parameters. For selected values of the parameters, the computed values of the drawdown function W have been made by Sinha et al (1976) from the table given by Boulton and Streltsova (1976) and family type curves for drawdown function W versus for different values of r/r_w have been plotted on double logarithmic paper. These type curves were used for determination of T and S values.

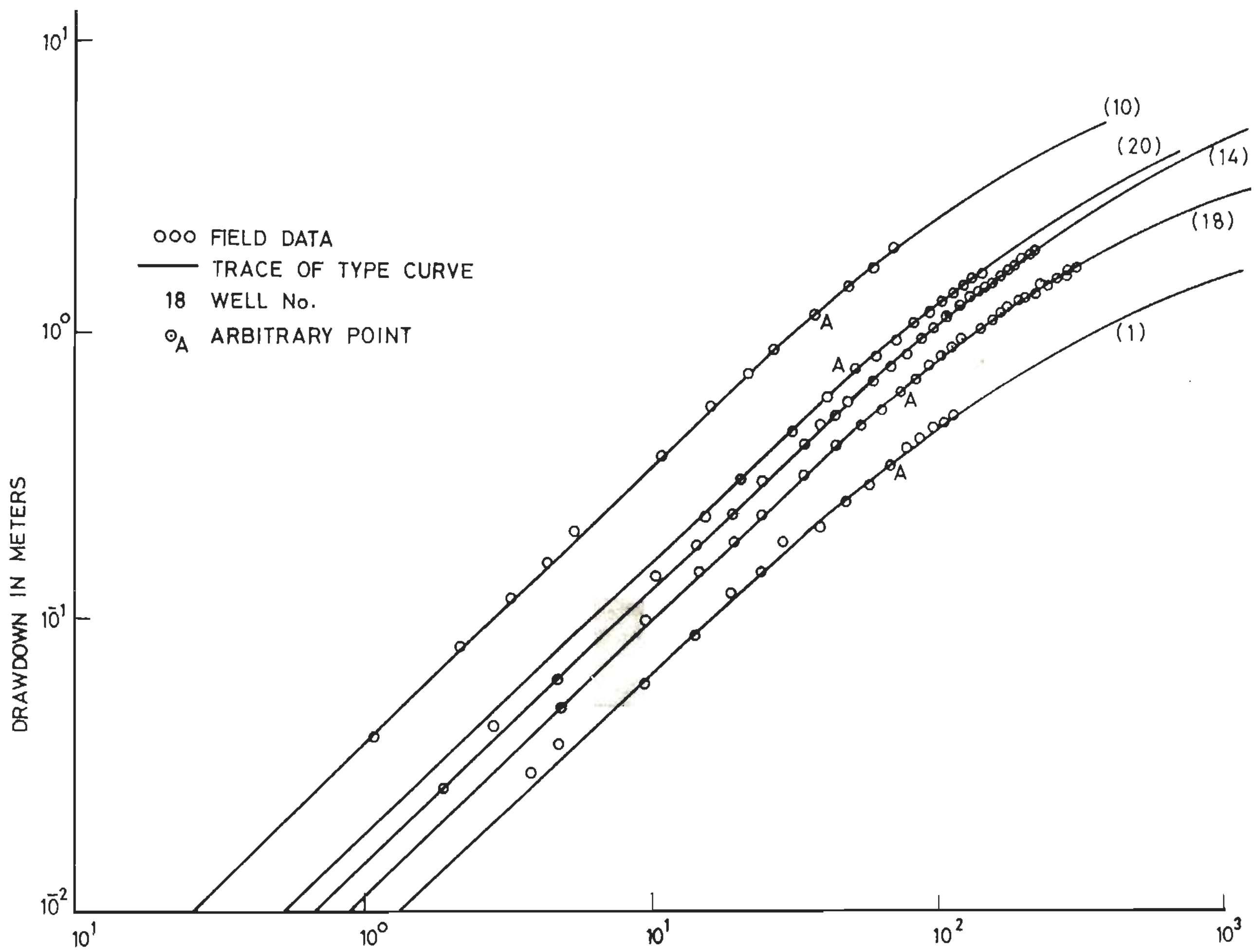


FIG.5·2 – TIME DRAWDOWN PLOTS FOR THE TESTED LARGE DIAMETER WELLS BY PAPADOPULOS COOPER METHOD (1967)

Most of the tested dugwells (well nos. 1, 6, 10, 13 and 15) were fully penetrating, i.e. they were tapping the entire water-bearing zone of the shallow aquifer. Therefore, the value of l', y', ρ and r/r_w were calculated for each dugwell to find appropriate type curves. The parameters calculated for each well are given in Table 5.3. The observed data s versus t were plotted on a sheet of logarithmic paper of the same scale as that of the type curves. The observed data curve was matched with a segment of one of the type curves. An arbitrary point "A" was chosen and the values of W, O, s and t were noted. These values were substituted in equations 7 and 8 to obtain the value of T and S. The match of the observed data curves with those of the type curves are shown in figure 5.3 (a,b & c) and the value of T and S calculated in each test are given in Table 5.4.

5.1.3.3 Method of Mishra and Chachadi (1985)

Unsteady flow to a large diameter well during abstraction as well as recovery phase has been analysed by using discrete kernal approach by Mishra and Chachadi (1985). A family of type curves which include the response of a homogeneous, isotropic and confined aquifer both during abstraction and recovery phase has been presented for various values of α, where α is equal to $(r^2_w/r^2_c)XS$, r_w and r_c are radius of the well screen and the well casing respectively and S is the storage coefficient.

In order to determine the aquifer parameters the time- drawdown and time-recovery data of each well were plotted on a double logarithmic paper of the same scale as that of the type curves. The observed data curves were superimposed individually with one of the type curves for obtaining the best match, particularly for the recovery part of the plot. An arbitrary point "A" was selected for which the value of $W(u)$ and u i.e. $(1/\Theta)$ from the type curves and s and t from the observed data curves were noted. Using these values, the value of T for each site was calculated through Equation-1 given by Papadopulos and Cooper (1967). Since r_w equals r_c in all the dugwells, the value of α remains same as that of the S value. The match of the observed data curves with those of the type curves are shown in Fig. 5.4 and the values of T and S are given in Table 5.4.

5.1.3.4 Method of Singh and Gupta (1986, 1991)

Whereas the methods given by Popadopulos and Cooper (1967), Boulton and Streltsova (1976) and Mishra and Chachadi (1985) require constant discharge - drawdown data, the method of suggested by Singh and Gupta (1986, 1991) is applicable when the discharge is variable. Accordingly this approach has also been attempted in this study.

The numerical method utilizes a forward modelling approach wherein the drawdown and recovery are computed starting from a reasonable guess of hydrogeological parameters. The parameters are iteratively improved by comparing the computed and observed drawdown values. The interpretation procedure, assumes the following conditions to be valid :

(i) a static water level in the well prior to the pumping test,

(ii) pumping well fully penetrates the aquifer

(iii) the flow towards the well is radially symmetrical, implying isotropy and homogeneity of the aquifer

(iv) drawdown is much smaller compared to total saturated thickness, and hence transmissivity is regarded as invariable during the pumping test and

(v) the system is linear which permits application of the principle of super-position.

The entire period of pumping test is divided into a number of discrete time steps of equal intervals during each of which the pumping rate may be assumed to be constant though it may vary for different time steps. The pumping rate for each time step should be known. The total pumpage from the well upto the end of the nth time step can be written as the sum of the contribution from the aquifer and that from the well storage.

Thus,

$$\sum_{i=1}^{n} Q_i \, \Delta t = \sum_{i=1}^{n} Q_i^{\omega} \, \Delta t + \sum_{i=1}^{n} Q_i^{a} \, \Delta t \quad \ldots\ldots\ldots \quad (9)$$

where Q_i is the pumping rate from the well ith step.

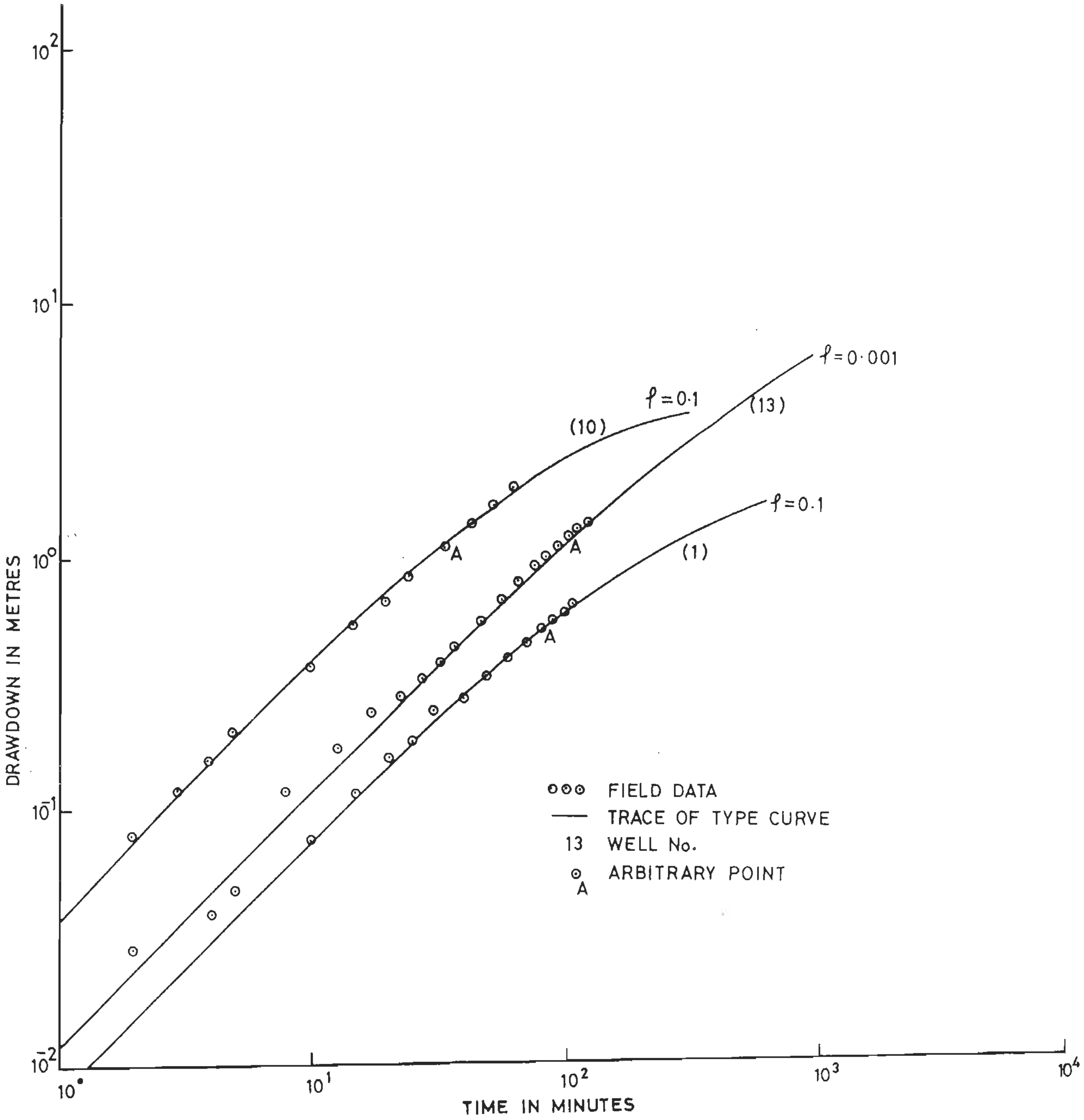


FIG.5·3a -TIME DRAWDOWN PLOTS FOR LARGE DIAMETER WELLS BY BOULTON-STRELTSOVA METHOD (1976)

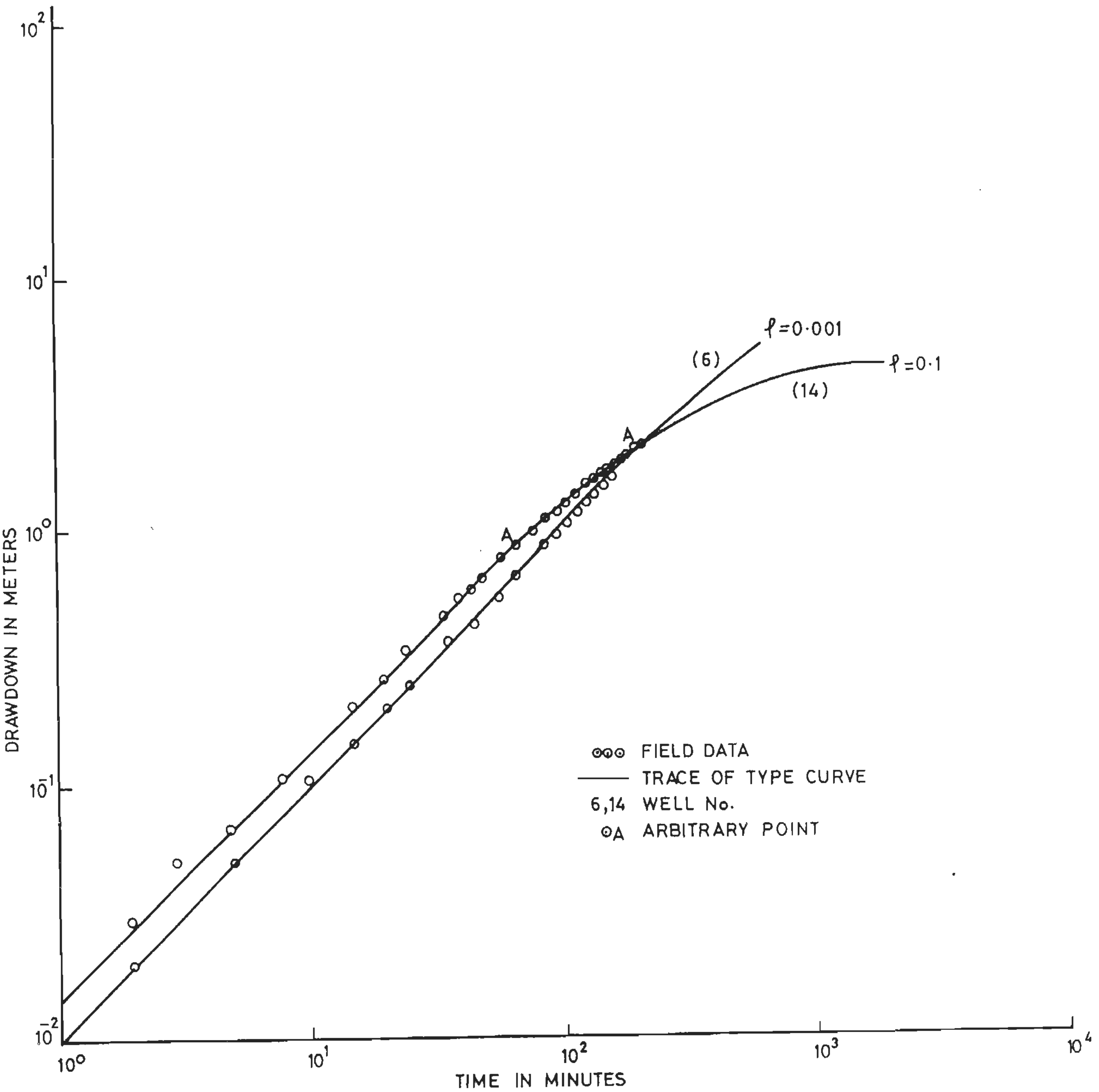


FIG.5·3b–TIME DRAWDOWN PLOTS FOR LARGE DIAMETER WELLS BY BOULTON-STRELTSOVA METHOD (1976)

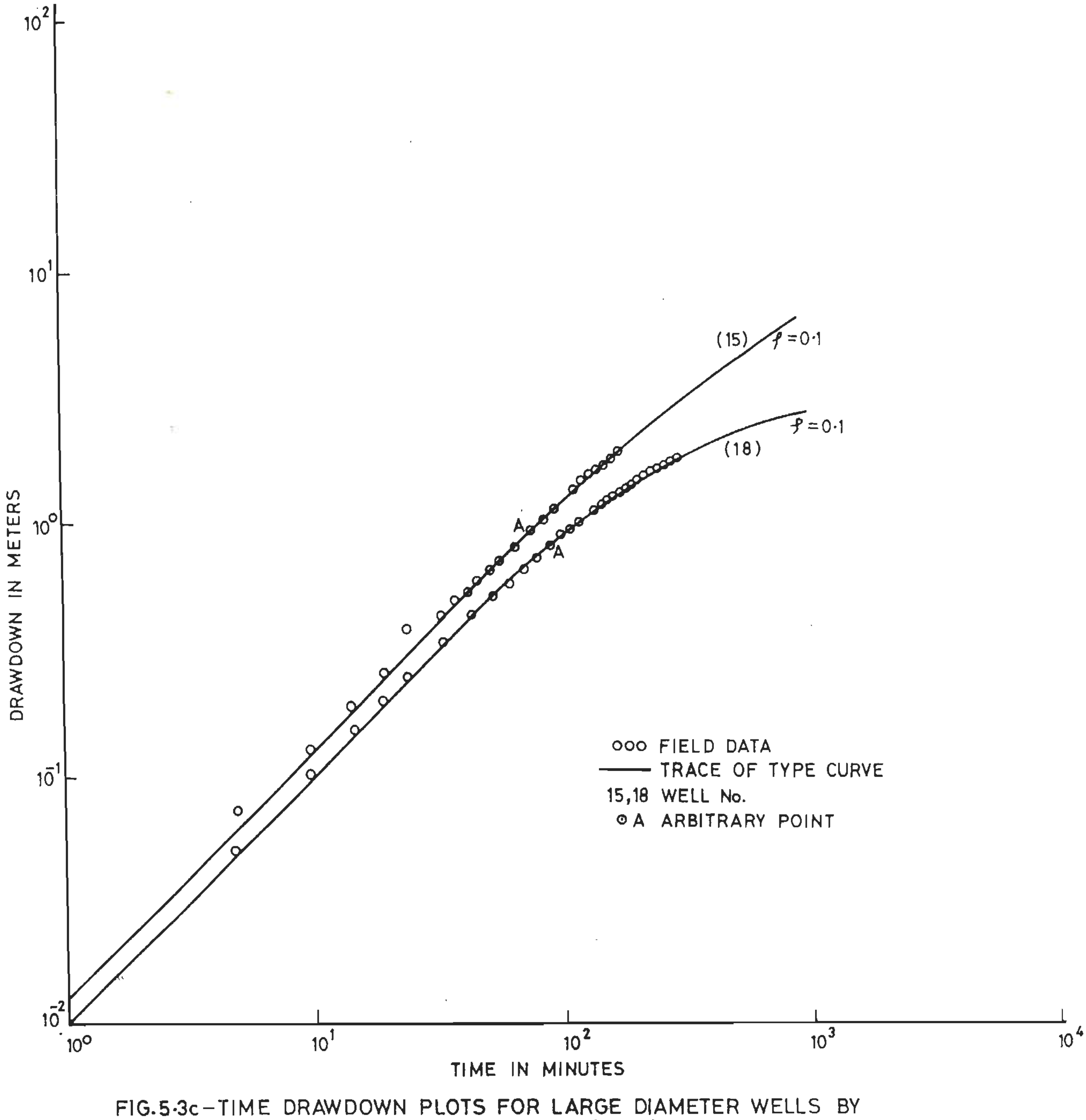


FIG.5·3c–TIME DRAWDOWN PLOTS FOR LARGE DIAMETER WELLS BY BOULTON STRELTSOVA METHOD (1976)

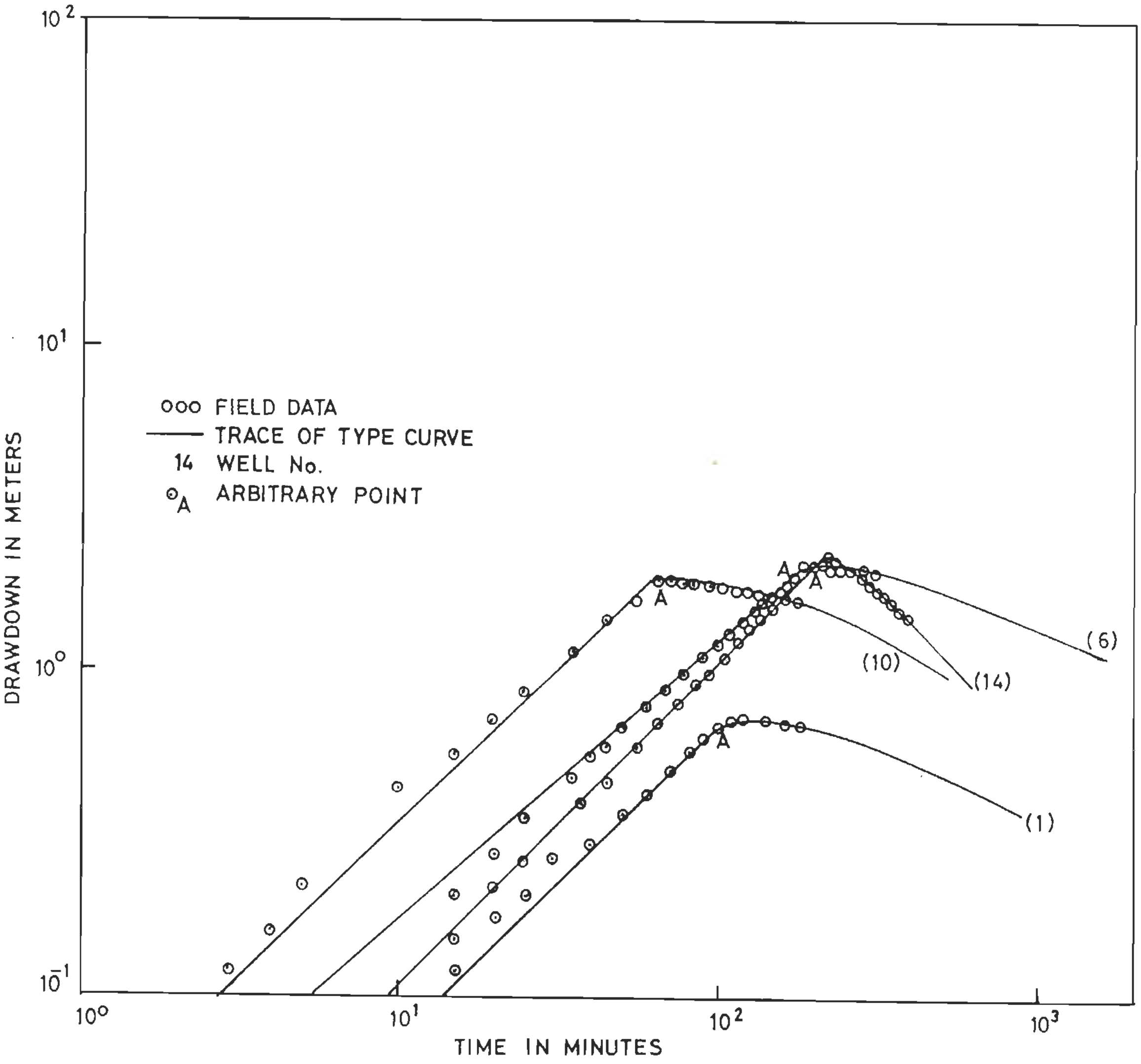


FIG.5·4a-TIME DRAWDOWN PLOTS FOR LARGE DIAMETER WELLS BY MISHRA CHACHADI METHOD (1985)

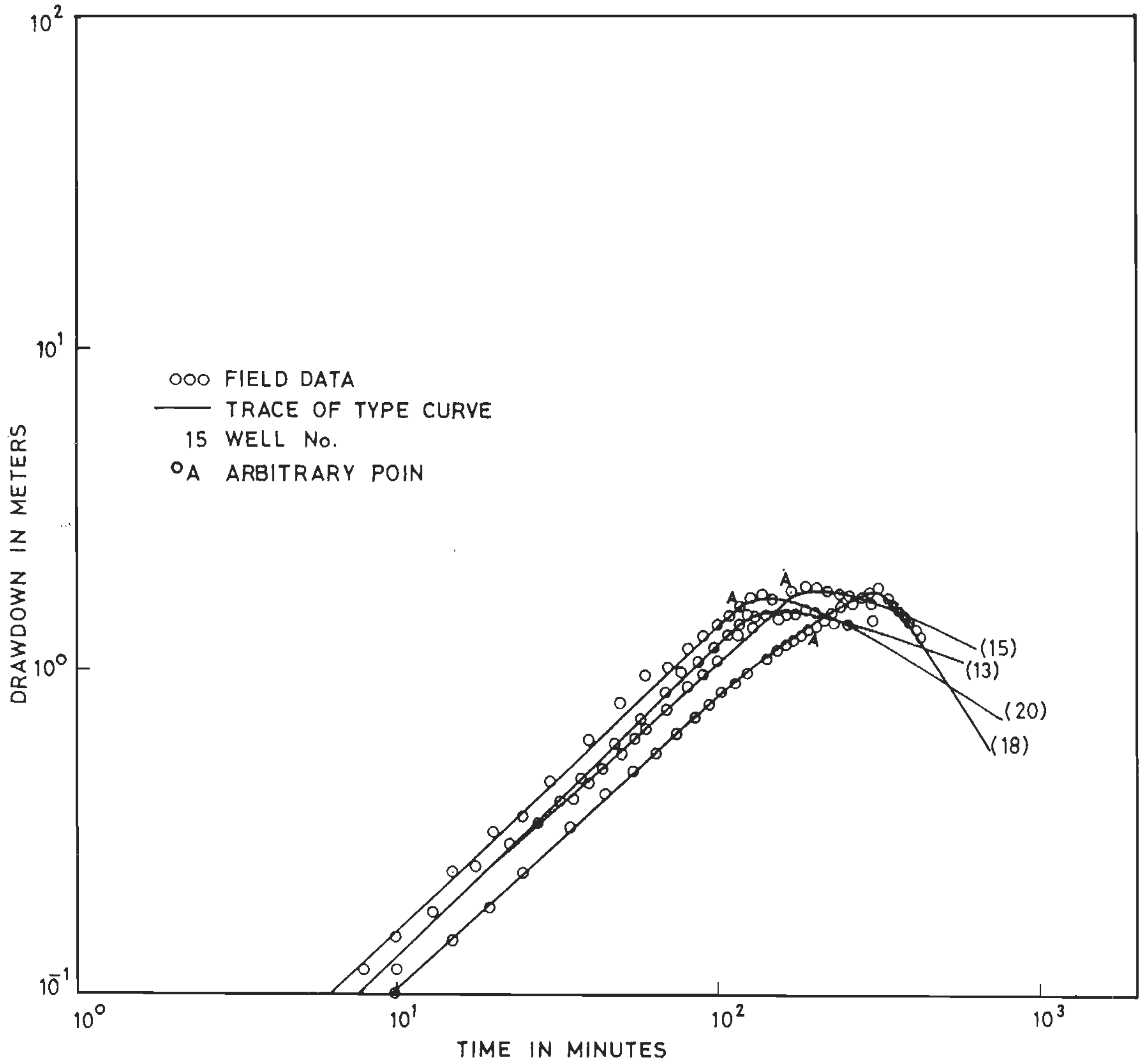


FIG. 5·4 b – TIME DRAWDOWN PLOTS FOR LARGE DIAMETER WELLS BY MISHRA-CHACHADI METHOD (1985)

Table 5.3 Values of Parameters used to apply Boulton-Streltosva Method of analysis (1976)

Sl. No.	Well No.	h (m)	l (m)	l'	l_1'	y	y'
1.	1	1.52	1.52	1	0	0.60	0.4
2.	6	2.56	2.56	1		0.00	0.4
3.	10	3.65	3.65	1	0	1.46	0.4
4.	13	3.24	3.24	1	0	1.30	0.4
5.	14	12.56	5.51	0.40	0	2.51	0.2
6.	15	4.80	9.50	0.6	0	1.44	0.3
7.	18	9.52	6.17	0.6	0	2.86	0.3
8.	20	8.47	5.47	0.6	0	2.50	0.3

Q^w_i and Q^a_i are the rate of contribution from the well storage and aquifer respectively for the same time step, and Δt is the time step.

If the net drawdown after n^{th} time step in the well is s_2, the amount of water withdrawn from the well storage is $\pi r^2 w^s$ where r_w is the well radius. The net drawdown in the well at the end of nth time step can, thus, be written as :

$$s_n = \frac{\Delta t}{\pi r_\omega^2} \sum_{i=1}^{n} Q_i^\omega \quad \ldots\ldots\ldots\ldots \quad (10)$$

This drawdown may also be expressed as

$$s_n = \frac{1}{4\pi T} \sum_{i=1}^{n} Q \; [\Delta\omega \; (n-i+1)] \quad \ldots\ldots\ldots \quad (11)$$

where $$\Delta\omega(n-i+1) = W\left[\frac{y}{(n-i+1)\Delta t}\right] - W\left[\frac{y}{(n-i)\Delta t}\right] \quad \ldots \quad (11a)$$

$$y = r_\omega^2 \; S/(4T) \quad \ldots \quad (11b)$$

$$W(1) = W(\frac{y}{\Delta t}) \quad \ldots\ldots \quad (11c)$$

$$W(u) = \int_u^\infty \frac{e^{-v}}{v} \, dv \quad \ldots\ldots \quad (11d)$$

$$u = r_\omega^2 \; S/4Tt \quad \ldots\ldots \quad (11e)$$

combining equations 9, 10, 11, and 12, Q^a and Q^w can be calculated and then the drawdawn can be found out using equation (11).

A computer programme in BASIC is given by Singh and Gupta (1991) for calculation of the drawdawn/recovery. These drawdawn/recovery are compared with the observed drawdawn and recovery. The aquifer parameters are progressively modified until a satisfactory match was obtained between the observed drawdawn/recovery and the computed values. The T and S values determined from this method are given in Table 5.4.

5.1.3.5 Results and Discussion

With a view to compare estimated aquifer parameters using the methods of Papadopulos-Cooper (1967), Boulton-Streltsova (1976), Mishra-Chachadi (1985) and Singh-Gupta (1986, 1991), the transmissivity (T) and Storage Coefficient (S) have been presented in Table 5.4. A perusal of this Table indicates that the T values derived from all the methods for individual test sites lie in comparable range and therefore for each test site the average value of T was considered. Accordingly, the transmissivity of the shallow aquifers in the area varies between 28 to 135 m^2/day.

The transmissivity of the highly jointed basalts is expected to be higher, but at Mestivadi (Well No. 6) it is found to be low (i.e. 28 m^2/day). It is because, as discussed in the section on occurrence of groundwater, in the hilly areas or at higher elevations, generally all the layers within the present day weathered zone are not seen. The upper highly weathered portions are eroded away and what remains at the shallow level is the poorly weathered massive basalt followed by or with highly jointed portion which soon grades into the hard massive basalt. In such cases local occurrences of ground water are found only in joints and T is low. The well at Mestivadi lies in a relatively higher elevation, has a depth of only 4 m and mostly the water is stored. Therefore, due to all above factors the well shows a very low transmissivity for highly jointed basalt, which may not actually represent this water-bearing horizon.

Table 5.4 : Transmissivity (T) and Storage Coefficient (S) of Aquifers, as determined by various Methods

Sl. No.	Well No.	Aquifer/ Nature of water-bearing horizons	Papadopulos-Cooper Method (1976)		Boulton-Streltova Method (1976)		Mishra-Chachadi Method (1985)		Singh-Gupta Method (1986, 1991)		Average	
			T (m2/day)	S	T (m2/day)	S	T (m2/day)	S	T (m2/day)	S	T (m2/day) Mean	S Mode
1.	(1) Old Mahabaleshwar	Talus deposits	154.18	0.01	86.25	3.07	129.38	0.000001	144	0.014	128	0.014
2.	(6) Mestivadi	Poorly weathered & highly jointed basalt	-	-	23.39	1.20	37.24	0.000001	20	0.001	28	-
3.	(10) Kokisre	Poorly weathered & poorly jointed basalt	59.68	0.01	59.68	1.35	62.02	0.000001	45	0.000001	57	-
4.	(13) Kalgaon	Poorly weathered & poorly jointed basalt	40.18	0.01	59.0	1.40	77.78	0.000001	49	0.00001	56	-
5.	(14) Nisre	Highly weathered & jointed basalt	72.24	0.01	90.08	2.06	91.19	0.01	75	0.0001	82	0.01
6.	(15) Sonachivadi	Highly weathered & jointed basalt	62.18	0.01	60.24	1.92	83.41	0.001	50	0.001	64	0.01
7.	(18) Yeravle	--do--	147.17	0.01	124.20	1.12	168.49	0.01	100	0.001	135	0.01
8.	(20) Kole	--do--	55.73	0.01	60.86	0.90	38.36	0.001	40	0.0001	49	0.01

Similarly, the well at Kole (Well No. 20) although taps highly weathered and jointed basalt shows a poor T value of 49 m^2/day. Here, the discharge was measured at about 100 m away from the well due to field constraint. Moreover, the pump (3 H.P. electric engine) was fitted at a relatively deeper level which was beyond the full efficiency of the motor and therefore, the discharge (Q) measured was very low, i.e. only 546 m^3/day, the lowest of all the pump tests conducted (Table 5.2). Therefore, the T of about 50 m^2/day may not represent the highly weathered and jointed basalt.

For talus deposits, only one test could be conducted at Old Mahabaleshwar and a high value of about 128 m^2/day is obtained. Although it is risky to conclude that the talus deposits possess such a relatively high value of transmissivity, the value does not look unconvincing for an aquifer which is supposed to be one of the most permeable in the area.

From the above discussion it follows that the poorly weathered and poorly jointed non-vesicular (massive) basalts in the area have a transmissivity value of about 57 m^2/day while the highly weathered and jointed basalts have a transmissivity range of about 64 to 135 m^2/day. This range compares well with the T values obtained by various workers elsewhere in the Deccan basalts (Table 5.5.).

The values of storage coefficient (S) derived by these methods are, however, of doubtful reliability. In Papadopulos-Cooper Method (1967) it is invariably 0.01 for all the test sites. In Boulton-Streltsova method (1976) it is of the order of 0.90 to 3.07 which is quite high. In case of Mishra-Chachadi Method (1985) and Singh - Gupta Method (1986, 1991) it goes upto the minimum value of 0.000001, which is quite low. The methods insist on long-duration pumping test. The test duration of 435 minutes in case of well No. 18 and 400 minutes for well No. 14 appears reason-able though not sufficient. For these two wells the S value obtained by Papadopulos-Cooper method (1967) and Mishra - Chachadi method (1985) is found to be 0.01. Thus, it may be inferred that the specific yield value of the shallow basal tic aquifers in the area is of the order of 0.01.

In case of Papadopulos-Cooper method (1967), if the field data plot falls completely on the almost straight part of the type curve due to the effect to well storage, it cannot be analysed (e..g well No. 6). Since the form of the type curve differs only very slightly even for relatively larger variation of α, it sometimes becomes difficult as to which curve to choose. Therefore from the knowledge of hydrogeological set up, the magnitude of S can be calculated. To solve this problem of curve matching the Mishra- Chachadi method has a definite advantage, since in this method recovery data is also plotted along with the drawdawn which helps in effective curve-matching. Both these methods, however, require long duration of pumping test. While the Papadopulos Cooper method gives more emphasis on long duration of pumping, the Mishra-Chachadi method rely highly on long-duration of recovery for effective curve-matching. Therefore, the selection of these methods is based on these two options, i.e. long duration of pumping or long duration of recovery.

Boulton-Streltsova method (1976), is the most generalised method for an unconfined aquifer, which takes into account the anisotropic nature of aquifer and partial penetration unlike the Papadopulos-Cooper and Mishra-Chachadi methods. In basaltic terrain these conditions are generally fulfilled except that most of the wells are fully penetrating. In the present study (including the fully penetrating wells, i.e. wells No. 1, 6, 10, 13 and 15), in almost all the tests, the value of T derived by this method lies in between those derived by the other two analytical methods. Due to higher degree of freedom, this method is very complex and time-consuming. Nevertheless, this appears to be one of the most reliable methods for determination of transmissivity of the Deccan Basalts provided all parameters as required by the method are known.

While applying the numerical method of Singh-Gupta (1986, 1991) on pumping test data of the 8 wells, match between the computed and the observed drawdawn could be obtained only for 3 pump test locations namely Old Mahabaleshwar (Well No. 1), Nisre (Well No. 14) and Sonachivadi (Well No. 15). For other five test data virtually the match was not as good. Therefore, in such cases the nearest matching points were only taken. In case of other methods, which are analytical type, exact matching between the observed drawdawn and the type curves was possible.

Table 5.5 Transmissivity values for shallow aquifers obtained through pumping test analyses of large diameter wells in Deccan Basalts.

Type	Reference	Area	Transmissivity (T) (m^2/day)
Weathered Basalt	Rao (1975)	Pune and Ahmednagar districts, Maharashtra	100 - 140
--do--	Deolankar (1978-79)	--do--	90 - 200
--do--	Angadi (1986)	Ghataprabha basin, Bijapur and Belgaum districts, Karnataka	53 - 109
Fractured/ jointed basalt	Deolankar (1978-79)	Pune and Ahmednagar districts Maharashtra	20 to 60
Vesicular basalt	Rao (1975)	--do--	50 to 70
--do--	Adyalkar and Mani (1971-72)	Pune, Sholapur districts Maharashtra	100 to 190
--do--	Angadi (1986)	Ghataprabha basin, Bijapur and Belgaum districts, Karnataka	106 to 289
Basalt (in general)	Adyalkar and Mani, (1972, 1974)	Sholapur districts Maharashtra	49.18 to 181.33
--do--	Adyalkar and Srihani Rao (1979)	Ahmednagar districts, Maharashtra	40.64
Basalt (in general)	Venugapal, (1979)	Karanja basin, Bidar district, Karnataka	10.75 to 178.66
Basalts (in general)	Sharma and Seetharam (1980)	Karnataka	49.68

Singh-Gupta method (1986, 1991) is an elegant method which takes variable abstraction rate of the centrifugal pumps from the well into consideration. In other methods the discharge has to be constant, for which care has been taken in the present study to average out the discharges, which were measured very closely during the pumping phase of the tests. If the computed drawdawn matches exactly with that of observed drawdawn, it is certainly a better method compared to others for estimation of Transmissivity.

5.2 YIELD OF WELLS

Dugwells are basically production wells. Therefore, an attempt has been made to estimate the productivity of dugwells in various aquifers and compare these aquifers in terms of their productivities. Various workers such a Slichter (1906), Walton (1962), Narasimhan (1965) and Singhal (1973) have given various estimates of productivity of dugwells. A brief description of these parameters is presented herewith.

5.2.1 Parameters for Estimating Productivity

5.2.1.1 Specific Capacity

The production capacity of a well is rated by its specific capacity (Freeze and Cherry, 1979). It is defined as the volume of water pumped per unit time (yield) per unit drawdawn. Specific capacity is preferred to yield as a measure of productivity because it accounts for the loss in head that is associated with pumping the water (Knopman and Hollyday, 1993).

The specific capacity depend on several factors such as lithology, topographic setting, well depth, duration of pumping, transmissivity, storativity and saturated thickness of the aquifer tapped, cross-sectional area of the well, well looses etc. A good account of the natural and artificial variables controlling specific capacity is given by Knopman and Holly day (1993).

According to them, primary water use and duration of discharge are the most important single variables in explaining variation in specific capacity, exceeding topographic setting, well depth and even lithology. However, their work is mainly valid for the borewells tapping deeper aquifer system.

Slichter (1906) has given an expression for determination of the specific capacity with the help of recovery data. The Slichter's formula is given by the equation.

$$C = 2.3 \frac{A}{t} \log_{10} \frac{s_1}{s_2}$$

where C = specific capacity of well in litres per minute per metre of drawdawn

A = Cross-sectional area of the well in m^2

t = time since pumping stopped in minutes

s_1 = drawdawn of the water level in metres before pumping stopped

s_2 = residual drawdown in metres at time t.

Sammel (1974) opine that Slichter's formula is expressed as a linear function of time and a logarithmic function of drawdown. He suggests that comparison of performance of wells of similar types under similar geological set up can be made through the Slichter's formula. Specific capacity derived by this formula cannot be used for computing transmissivity.

For porous media, the expression for specific capacity as given by Theis et al (1963) is as follows :

$$\frac{Q}{s} = \frac{T}{2.64 \log (Tt/1.87\, r_{\omega}^2\, S) - 65.5}$$

where Q/s = specific capacity in gallons per minute per foot of drawdown,

T = transmissivity in gallons per minute per foot of aquifer thickness

S = storativity in dimensionless units

r_w = effective well radius in feet, and

t = duration of discharge in minutes

The advantage of Theis equation is that specific capacity values can be used to directly estimate transmissivity. In fractured media, however, the Theis equation has a poor representation of the relation between specific capacity and transmissivity (Huntley et al, 1992).

5.2.1.2 Specific Capacity Index

Walton (1962) introduced the concept of specific capacity index. The specific capacity divided by the aquifer thickness penetrated is the specific capacity index. It is expressed as litres per minute per metre of drawdown per metre depth of penetration. The specific capacity index values are useful in comparing the relative productivity of different units in a multi-layer system and also in predicting the well yield from a given thickness of aquifer.

5.2.1.3 Unit Area Specific Capacity

Singhal (1973) suggested to divide the specific capacity by the total surface area of the aquifer ($2\pi rh$) tapped by the well (where r = radius of the well and h = saturated thickness of the penetrated aquifer). This incorporates variations both in the diameter of the well and thickness of the aquifer and hence will give better idea of the yield characteristics of different rock types. He calls this parameter as specific capacity index.

Narasimhan (1965) introduced the concept of unit area specific capacity. The specific capacity divided by the cross-sectional area of the well gives unit area specific capacity. When the two wells of different diameters are pumped at the same rate, a large diameter well may yield more quantity of water for a given drawdown and withstand more hours of pumping than a well of small diameter. Therefore, the unit area specific values will be better indicators of the permeability of aquifers. Thus, unit area specific capacity is a better way of judging the productivity of the aquifers.

5.2.2 Estimation of Specific Capacity

During the pumping phase contribution from the well storage remains significant in the dugwells. In the recovery phase the inflow into the well largely depends on the aquifer transmissivity and the hydraulic gradient created during the pumping phase. Thus, as mentioned earlier, in the case of a large-diameter well, recovery data is more important than the pumping data for the estimation of hydrogeological parameters of an aquifer (Singh and Gupta, 1991). In view of this Nair (1981) stresses on the use of Slichter's formula for estimation of the specific capacity values. The Slichter's formula takes only the recovery phase of a pump test into consideration. Many workers such as Wenzel (1942), Raghunath (1982), Karanth (1987), Arumugam(1990) and Chakrapani and Parthasarthy (1990) have used the Slichter's formula for estimating specific capacity of the dugwells.

Using Slichter's formula for individual test sites, the values of t and s_1/s_2 were plotted on a semi- logarithmic paper with t on arithmetic scale and s_1/s_2 on logarithmic scale. A straight line was fitted to the plotted points. The values of t and s_1/s_2 were noted from these plots. Using equation 9 specific capacity values were computed. Semilogarithmic plots of data from some representative wells are shown in Figure 5.5. The specific capacity values obtained for each test site are given in Table 5.6. The unit area specific capacity and specific capacity index as defined by Narasimhan (1965), Waltan (1962) and Singhal (1973) have been estimated and given in Table 5.6.

5.2.3 Results and Discussions

The Tables 5.6 and 5.7 indicate that the specific capacity of dugwells in the area varies between 18.2 to 269.2 ℓpm/m for the wells tapping poorly weathered, poorly jointed basalts and highly weathered jointed basalts respectively. A very high value of specific capacity of 968 epm/m is observed at Sakurdi (Well No. 16) tapping highly weathered jointed basalt and a section of vesicular basalt in its saturated thickness. This well shows a unit area specific capacity of 25.2 epm/m/m^2 and specific capacity index (Walton, 1962) value of 95.28 lpm/m/m. Similarly, very low specific capacity values of 23.5 at Sasewadi (Well No. 3) for highly weathered and jointed basalt may be attributed to the geomorphological location of the well site which is in the recharge zone and in sloping ground in the dissected plateau. The derived values match well with those of other workers in Deccan basalts (Table 5.8).

The production capacity of a well depends on the nature of aquifer it taps, its location with respect to topography, permeability of the aquifers and its thickness tapped by the well. With the help of Table 5.7, the aquifers could be arranged with respect to their decreasing production capacity, as (1) highly weathered and jointed basalts (which includes highly weathered basalts also), (2) alluvium, (3) talus deposits, (4) soils, (5) poorly weathered, highly jointed basalts and (6) poorly weathered, poorly jointed basalts. Normally, talus deposit exhibit higher specific capacity. In the present case the low values may be attributed to small thickness (about 1.50m) penetrated by the well.

Since specific capacity depends on the radius of wells also (Narasimhan, 1965), it is not possible to compare them if the wells are of different diameters even for the same aquifer. Hence, unit area specific capacity, which takes into account the radius of well and therefore the area of cross-section of well, appears to be a better parameter. This is clearly brought out by well No. 8 and 9 which tap soil and highly weathered basalt respectively. Highly weathered basalt has a higher production capacity than soil as confirmed from other pump test data and observations in the field. But, the specific capacity index values for these two wells are 1.1 and 1.0 lpm/m/m^2 (Singhal, 1973) and 26.93 and 26.72 lpm/m/m (Walton, 1962) respectively. However, the unit area specific capacity for these two wells are 1.3 and 3.0 lpm/m/m^2 respectively, which clearly differentiate the productivities of these two wells. Similarly for well Nos. 2 and 16, both of which tap highly weathered and jointed basalt, the productivity of well No. 16 is more as confirmed from field observations (100% recovery in just 90 minutes). The specific capacity index values for these two wells are 4.6 and 4.3 lpm/m/m^2 (Singhal, 1973) and

63.96 and 95.28 lpm/m/m (Walton, 1965) respectively. These values are nearly the same for these two wells. But the unit area specific capacity value of 6.7 for well No. 2 and 25.2 lpm/m/m^2 for well No. 16, clearly distinguishes these two wells in terms of their productivities.

Well yields in terms of structures (i.e. lineaments) and hydrogeomorphic features have already been discussed in chapter 3. The hydrogeomorphic features compared to lineament, have a better control over the productivities of the shallow dugwells. Dugwells in the deep buried pediments are more producing than those in the other geomorphic features.

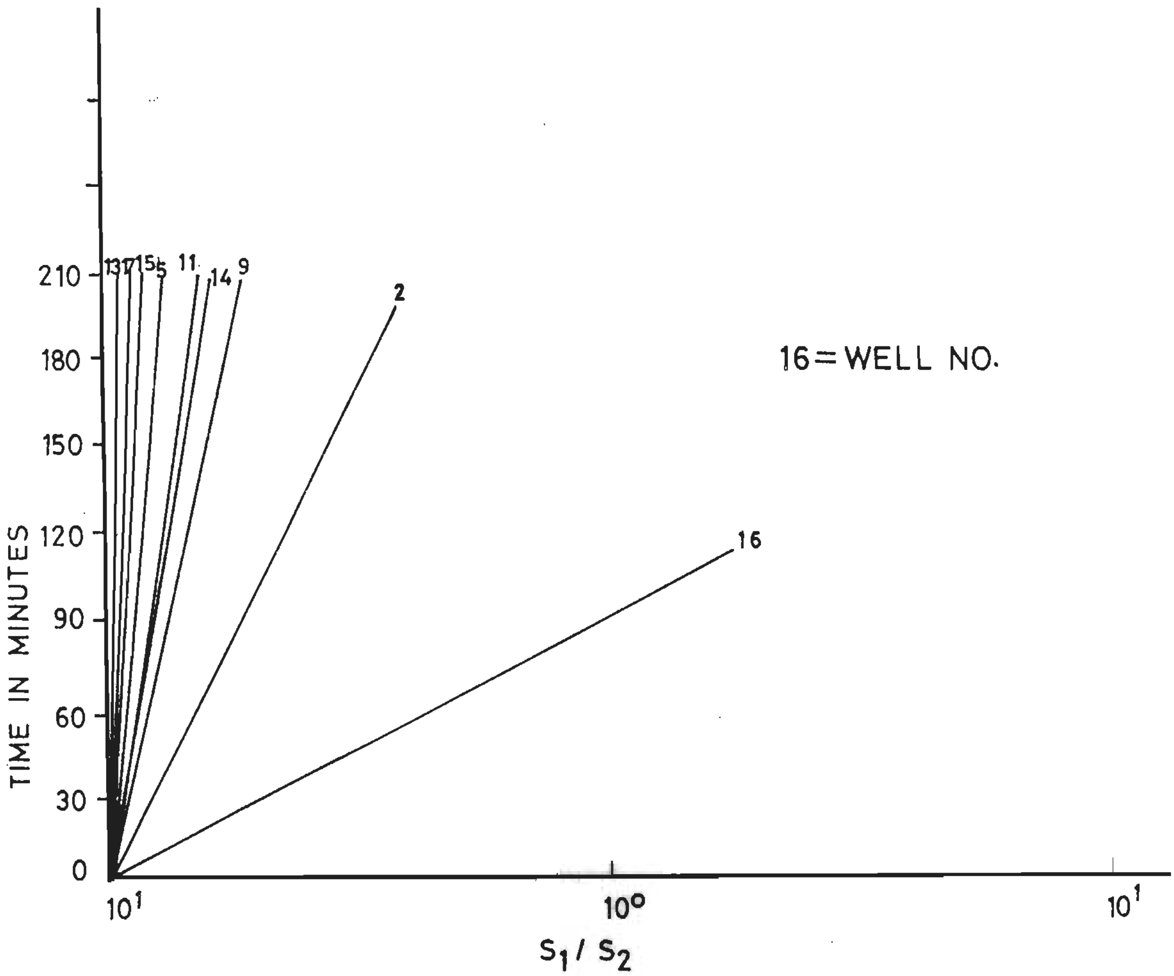


FIG.5·5-SEMILOGARITHMIC PLOTS OF S_1/S_2 VERSUS TIME

TABLE 5.6 SPECIFIC CAPACITY, UNIT AREA SPECIFIC CAPACITY AND SPECIFIC CAPACITY INDEX FOR DUGWELLS

No.	Nature of Aquifer	Depth of well (mbgl)	Saturated Thickness (m)	Cross-sectional Area (m^2)	Surface Area of Aquife tapped (m^2)	Specific Capacity (lpm/m)	Unit Area Specific Capacity (lpm/m/m^2)	Specific Capacity Index Singhal, (1973) (lpm/m/m^2)	Specific Capacity Index (Walton, 1962), (lpm/m/m
1.	Talus deposits	5.10	1.52	30.69	29.86	36.8	1.2	1.2	24.21
2.	Highly weathered and jointed basalt (Flow-3)	2.80	1.59	15.21	21.99	101.7	6.7	4.6	63.96
3.	-do-	3.25	1.25	26.89	22.98	23.50	0.9	1.0	18.8
4.	-do-	8.90	5.16	78.57	162.17	157.9	2.0	1.0	30.60
5	Alluminum	5.10	1.54	55.44	40.66	74.8	1.4	1.8	48.57
6.	Porly weathered and highly jointed basalt (Flow-3)	4.00	2.56	50.29	64.37	33.5	0.7	0.5	13.09
7.	Poorly weathered and poorly jointed basalt (Flow-2)	9.10	5.65	41.30	128.74	32.8	0.8	0.3	5.81
8.	Soil (Flow-2)	6.25	2.15	44.20	50.68	57.9	1.3	1.1	26.93
9.	Highy weathered basalt (Flow-3)	8.05	6.40	56.10	169.97	171.0	3.0	1.0	26.72
10.	Poorly weathered and poorly jointed basalt (Flow-4)	8.25	3.65	17.73	54.49	23.1	1.3	0.4	6.33
11.	Highly weathered basalt (Flow-3)	7.15	3.59	85.80	59.75	173.8	2.0	1.5	48.41
12.	Poorly weathered and highly jointed basalt (Flow-3)	8.00	1.79	54.39	46.81	66.8	1.2	1.4	37.32
13.	Poorly Weathered and poorly jointed basalt (Flow-4)	10.75	3.24	52.83	83.50	18.2	0.3	0.2	5.62

14.	Highly weathered basalt (Flow-2/1)	7.95	5.51	38.50	121.22	90.20	2.3	0.7	16.37
15.	Highly weathered and jointed basalt (Flow-3/2)	4.60	2.90	70.91	86.59	67.80	1.0	0.8	23.37
16.	-do-	14.0	10.16	38.50	223.52	968.0	25.2	4.3	95.28
17.	Soil(Flow-2)	5.70	2.55	65.78	72.91	47.9	0.7	0.7	18.78
18.	Highly weathered and jointed basalt (Flow-2)	12.65	6.17	95.07	213.30	269.2	2.8	1.3	43.63
19.	Poorly weathered and poorly jointed basalt (Flow-4)	8.50	2.55	40.17	57.30	47.3	1.2	0.8	18.55
20.	Highly weathered and jointed basalt (Flow-3)	12.00	5.47	38.50	120.34	70.2	1.8	0.6	12.83

Table 5.7 : Ranges of Specific Capacity, Unit Area Specific Capacity and Specific Capacity Index

Nature of Aquifer	No. of wells tested	Specific Capacity (lpm/m)	Unit Area Specific Capacity ($lpm/m/m^2$)	Specific Capacity Indiex	
				Singhal, 1973 ($lpm/m/m^2$)	Walton, 1962 (lpm/m/m)
Talus deposits	1	36.8	1.2	1.2	24.21
Soil	2	47.9 - 57.9	0.7 - 1.3	0.7 - 1.1	18.78 - 26.93
Alluvium	1	74.8	1.4	1.8	48.57
Basalts					
(a) Poorly weathered, poorly jointed	4	18.2 - 47.3	0.3 - 1.3	0.2 - 0.8	5.62 - 18.55
(b) Poorly weathered, highly jointed	2	33.5 - 66.8	0.7 - 1.2	0.3 - 1.4	13.09 - 37.32
(c) Highly weathered, and jointed or only highly weathered	10	*67.8 - 269.2** (Exceptional * = 23.5 ** = 968.0)	0.9 - 6.7** (Exceptional ** = 25.2)	0.6 - 4.6	12.83 - 63.96** (Exceptional ** = 95.28)

Table 5.8 : Specific Capacity and Specific Capacity Index Values of Large Diameter wells in Basaltic Terrain in Different Parts of India.

	Location	Specific Capacity (lpm/m)	Specific Capacity Index (Singhal, 1973) (lpm/m/m^2)	Author
1.	Parts of Central Maharashtra	50 - 150	1.0 - 2.0	Singhal, 1973
2.	Parts of Karnataka	13 - 199	0.25 - 1.43	Viswanathiah and Shastri 1978
3.	Karanja and Chikahagani Basin of Karnataka	43 - 555	0.52 - 11.23	Venugopal 1979
4.	Karnataka	19 - 326	-	Sharma and Seetharam, 1981
5.	Ghataprabha river basin, Karnataka	29 - 364	0.16 - 3.02	Angadi, 1986
6.	Koyna sub-basin, Maharashtra	18 - 269* (exceptional 968)	0.2 - 4.6	Present Author

5.3 SUMMARY

Among the various hydraulic parameters, Transmissivity (T) and Storage Coefficient (S) have been estimated for the shallow aquifers of the study area with the help of 8 pumping tests conducted in large-diameter wells (dugwells). The methods suggested by Papadopulos-Cooper (1967), Boulton and Streltsova (1976), Mishra and Chachadi (1985) and Singh and Gupta (1986, 1991) have been used in the present study for estimating these two most important hydraulic parameters. The Transmissivity values derived from all the four methods for individual test sites lie in comparable range and therefore for each test site the average of T is considered. Accordingly, the Transmissivity of shallow aquifers in the area in general varies between 28 to 135 m^2/day. It is found to be of the order of 128 m^2/day for talus deposits, 64 to 135 m^2/day for the highly weathered and jointed basalts, 57 m^2/day for the poorly weathered and poorly jointed massive basalts. The values of Storage Coefficient (S) derived by these methods are, however, of doubtful realiability. It is found to be of the order of 0.01 for the shallow aquifers of the area.

The yields of the dugwells were tested with the help of their specific capacity, unit area specific capacity and specific capacity index values. The methods suggested by Slichter (1906) for estimation of specific capacity, by Narasimhan (1965) for unit area specific capacity, by Singhal (1973) and Walton (1962) for specific capacity index values were used in the present study. The unit area specific capacity is found to be better parameter as compared to others for assessment of the productivities of the dugwells. For the dugwells tapping talus deposits, black cotton soils, alluvium and basalts, the unit area specific capacity values are found to be of the order of 1.2, 0.7 to 1.3, 1.4 and 0.3 to 6.7 (exceptional 25.2) lpm/m/m^2 respectively. In the dugwells tapping basalts alone, it is found to be of the order of 0.3 to 1.3 lpm/m/m^2 for the poorly weathered and poorly jointed basalts, 0.7 to 1.2 lpm/m/m^2 for the poorly weathered and highly jointed basalts and 0.9 to 6.7 (exceptional 25.2) lpm/m/m^2 for the highly weathered and jointed basalts. With the help of unit area specific capacity, the aquifers could be arranged in terms of their decreasing production capacity as highly weathered and jointed basalts, alluvium, talus deposits, soils, poorly weathered and highly jointed basalts and poorly weathered poorly jointed basalts. The production capacity of the dugwells largely depand on their location with respect to hydrogeomorhpic units and water-bearing properties of the horizons tapped.

Chapter 6

Chemical Quality of Groundwater

6.1 INTRODUCTION

Quality of groundwater is as important as its quantity. It determines the usefulness of water for the purpose of drinking, irrigation and industrial use.

The chemical quality of groundwater is influenced to a considerable extent by the chemical composition of rocks and soil mass through which it moves under various physico-chemical conditions. As the water percolates downwards through the zone of aeration, not much changes in composition of groundwater are expected as it moves faster in this zone. Water movement is usually very slow in the underground reservoirs and therefore, it gets sufficient time for the reaction with the rocks to take place (Fetter, 1988). The groundwater also undergoes frequent changes in chemical composition by secondary phenomena such as base exchange, concentrations, reduction etc., which may modify the composition of water (Schoeller, 1959). Schoeller (1959, 1967), Hem (1970), Matthess (1982) and Lloyd and Heathcote (1985) have discussed the nature of groundwater in different rock types.

In order to asses the chemical quality of the water resources of the Koyna sub-basin, 147 samples from various locations (Fig. 6.1) were collected for chemical analysis of the major constituents. Besides these samples, 40 water samples were also collected exclusively for iron content in waters. The details of the source of these samples are given in Table 6.1.

Apart from the determination of Hydrogen ion concentration (pH), Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Total Hardness (TH) as Calcium Carbonate ($CaCO_3$), the major inorganic constituents analysed included the cations such as Sodium (Na^+), Potassium (K^+), Calcium (Ca^{++}), Magnesium (Mg^{++}) and anions such as Carbonate (CO_3^{--}), Bicarbonates (HCO_3^-), Chloride (Cl^-), Sulphate (SO_4^{--}) and Nitrate (NO_3^{--}). The samples collected for iron-analysis were acidified with concentrated nitric acid.

The detailed analytical results of the chemical analysis are given in Table 6.2.

The mean concentration of the chemical constituents found in the water samples taken from dug wells penetrating different types of aquifers in basalts, laterites, talus deposits; alluvium and black cotton soils, water samples from borewells is basalts, water samples from springs in basalts, laterites, and talus deposits and surface water samples from Koyna river are given in Table 6.3. It may be mentioned that basalt is the main source material for most of the aquifers found in the area. A perusal of Table 6.2 indicates that Ca^{++} is the main cation that is dominant in waters associated with all types of rock materials except that of alluvium. Their major source is expected from the basaltic mass. The concentration of calcium exceeds the concentration of magnesium. In almost all the samples Ca/Mg ratio is greater than one. The concentration of Na^{+} is next to Ca++ in general and is always higher than that of K^{+}. CO_3^{--} and SO_4^{--} are very low and in many cases these are found to be almost negligible.

6.2 GRAPHICAL PRESENTATION AND CLASSIFICATION OF WATER

Hydrochemical studies involve synthesis and interpretation of a mass of analytical data. In order to examine large matrix of chemical constituents and samples, the analytical data are represented by diagrams. For a single water samples the dominant ions such as Ca, Mg, Na + K, CO_3 + HCO_3, SO_4 and Cl can be represented in several ways. In all such diagrams the epm values are mostly utilised. The most commonly used diagram is the Collins' Bar diagram (1923) because of its simplicity and better representation.

6.2.1 Collins' Bar Diagram (1923)

In Collins Bar Diagram (1923), the analysis of the cation and anions are shown separately in adjoining vertical bars as shown in Fig.6.2a for a sample of water from dugwell in soil. The epm values of various cations and anions of this sample are given below.

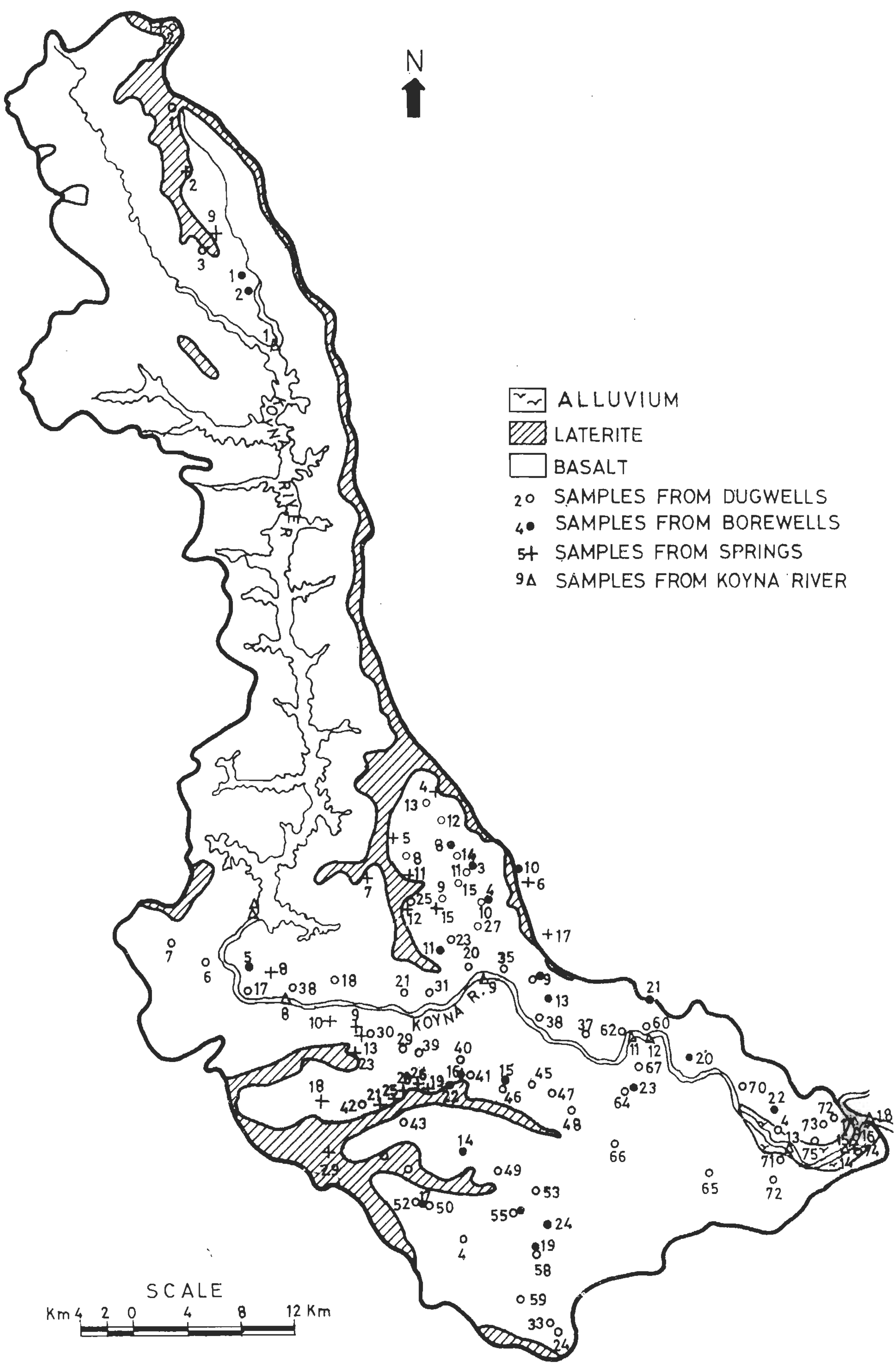


FIG. 6.1 LOCATIONS OF WATER SAMPLES COLLECTED

Table 6.1 - Water Samples from Different Sources

Source	No. of water samples for detailed analysis	No. of water samples for iron analysis
Dugwell (shallow water)	76	13
Borewell (deep water)	24	05
Spring	29	19
Surface Water	18	03
	147	40

Table 6.2 Analytical data of water samples collected from different sources

Source : Dugwell

Sl	Village	pH	EC m.mhos/cm at 25°C	TDS in ppm	TH as $CaCO_3$ in ppm	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NO_3	Fe	Aquifer
						ppm										
1	Mahabaleshwar	7.70	210.0	115.0	85.0	9.0	4.0	26.0	5.0	-	73.0	32.0	-	-	-	Laterite
2	Old M'shwar	7.78	140.0	70.0	4.0	3.0	Tr	16.0	5.0	-	67.0	11.0	0	Tr	-	Talus
3	Taldev	8.60	110.0	57.0	50.0	4.0	-	14.0	4.0	12.0	31.0	7.0	-	-	-	Basalt
4	Nayasupane	8.67	440.0	210.0	165.0	23.0	3.0	16.0	30.0	24.0	146.0	39.0	Tr	Tr	0.1	Basalt
5	Manachnagar	8.10	120.0	70.0	50.0	6.0	1.0	16.0	2.0	-	55.0	14.0	-	-	-	Basalt
6	Kadamvadi	8.80	60.0	30.0	25.0	2.0	Tr	8.0	1.0	6.0	12.0	7.0	0	Tr	-	Basalt
7	Dhankal	8.0	80.0	40.0	30.0	5.0	<0.5	6.0	4.0	-	37.0	7.0	-	-	0.3	Basalt
8	Jungti	7.60	90.0	45.0	35.0	4.0	-	6.0	5.0	-	43.0	7.0	0	Tr	0.2	Talus
9	Ambavne	7.40	200.0	95.0	85.0	7.0	Tr	18.0	10.0	-	104.0	7.0	0	Tr	-	Basalt
10	Sakhre	8.15	310.0	150.0	130.0	9.0	1.0	38.0	8.0	-	177.0	7.0	Tr	Tr	-	Basalt
11	Mendoshi	8.43	250.0	125.0	105.0	9.0	-	30.0	7.0	24.0	79.0	14.0	0	Tr	-	Basalt
12	Mandure	8.10	230.0	120.0	85.0	11.0	5.0	20.0	8.0	-	98.0	21.0	Tr	4	-	Basalt
13	Nivkane	8.22	170.0	95.0	75.0	10.0	<0.5	18.0	7.0	-	99.0	11.0	-	-	-	Talus
14	Sasewadi	7.70	280.0	140.0	125.0	9.0	1.0	32.0	11.0	-	140.0	18.0	-	-	0.2	Basalt
15	Mendoshi	8.44	320.0	180.0	130.0	14.0	<0.5	34.0	11.0	24.0	112.0	18.0	5.0	-	-	Basalt
16	Jungti	7.80	90.0	45.0	40.0	3.0	<0.5	8.0	5.0	-	43.0	7.0	-	-	-	Talus
17	Ramamala	8.48	270.0	125.0	120.0	9.0	10.5	26.0	13.0	18.0	104.0	14.0	-	-	-	Basalt
18	Dhansarwadi	7.80	200.0	120.0	80.0	9.0	<0.5	45.0	4.0	-	104.0	11.0	-	-	-	Basalt
19	Dhansarwadi	8.44	280.0	130.0	125.0	7.0	-	30.0	12.0	12.0	128.0	17.0	-	-	-	Basalt
20	Patan	8.35	310.0	145.0	130.0	13.0	-	34.0	11.0	24.0	110.0	18.0	-	-	-	Basalt
21	Shiral	7.70	240.0	115.0	100.0	8.0	-	24.0	10.0	-	128.0	7.0	0	2	-	Alluvium
22	Patan	7.70	250.0	120.0	105.0	8.0	Tr	28.0	8.0	-	122.0	14.0	Tr	Tr	-	Basalt
23	Katavdi	7.40	210.0	100.0	85.0	8.0	Tr	18.0	10.0	-	98.0	14.0	Tr	Tr	-	Basalt
24	Morgiri	7.00	300.0	180.0	110.0	18.0	5.0	30.0	9.0	-	98.0	28.0	0	38	-	Basalt
25	Bhondri	8.30	140.0	80.0	65.0	7.0	<0.5	14.0	7.0	Tr	85.0	7.0	0	-	-	Basalt
26	Bhondri	7.52	310.0	160.0	125.0	13.0	3.0	40.0	6.0	-	146.0	25.0	-	-	-	Basalt
27	Bibi	8.36	260.0	155.0	115.0	12.0	2.0	22.0	15.0	12.0	118.0	11.0	5.0	-	-	Basalt
28	Kavadevadi	7.98	130.0	700.0	50.0	8.0	-	12.0	5.0	-	67.0	7.0	-	-	0.2	Basalt
29	Yerad	7.90	250.0	140.0	100.0	9.0	2.0	30.0	6.0	-	128.0	14.0	-	-	-	Basalt
30	Manevadi	8.0	300.0	150.0	125.0	12.0	<0.5	32.0	11.0	-	171.0	7.0	-	-	-	Basalt
31	Tamkade	8.46	300.0	135.0	130.0	9.0	-	26.0	16.0	18.0	120.0	14.0	-	-	-	Basalt
32	Mendheghar	8.46	240.0	115.0	105.0	7.0	2.0	34.0	5.0	18.0	86.0	14.0	-	-	-	Basalt
33	Kolgevadi	8.07	360.0	200.0	135.0	21.0	2.0	34.0	12.0	-	186.0	25.0	-	-	-	Basalt
34	Mutlavadi	8.33	380.0	180.0	160.0	13.0	<1.0	46.0	11.0	24.0	146.0	21.0	-	-	-	Basalt
35	Mhavshi	8.20	320.0	180.0	135.0	9.0	<0.5	36.0	11.0	-	183.0	11.0	-	-	-	Basalt
36	Adul	8.24	280.0	155.0	120.0	10.0	-	22.0	16.0	Tr	153.0	11.0	-	-	-	Basalt
37	Navsare	8.35	270.0	150.0	120.0	12.0	<0.5	30.0	11.0	18.0	110.0	14.0	-	-	-	Basalt
38	Marul	7.87	110.0	55.0	40.0	5.0	-	12.0	2.0	-	37.0	14.0	0	Tr	-	Basalt
39	Vadikotavde	8.20	230.0	130.0	110.0	6.0	1.0	28.0	7.0	-	128.0	14.0	-	-	-	Basalt
40	Warekarvadi	8.00	320.0	170.0	145.0	12.0	2.0	36.0	13.0	-	183.0	14.0	-	-	0.3	Basalt
41	Pawarvadi	8.42	400.0	200.0	175.0	12.0	1.0	42.0	17.0	12.0	101.0	11.0	0	0	0.5	Basalt
42	Gokul	8.39	320.0	150.0	135.0	13.0	2.0	34.0	12.0	24.0	104.0	25.0	-	-	-	Basalt
43	Salve	8.57	450.0	220.0	150.0	12.0	4.0	72.0	4.0	30.0	140.0	43.0	-	-	-	Basalt
44	Tamine	7.90	100.0	55.0	40.0	5.0	<0.5	10.0	4.0	-	43.0	11.0	-	-	-	Laterite
45	Marli	7.68	330.0	180.0	95.0	26.0	11.0	32.0	4.0	-	165.0	18.0	5.0	-	-	Talus
46	Sonavde	8.30	270.0	150.0	110.0	12.0	<0.5	32.0	7.0	Tr	153.0	11.0	-	-	-	Basalt
47	Dudugadevadi	8.00	350.0	175.0	75.0	13.0	<0.5	34.0	16.0	-	195.0	11.0	0	0	0.45	Talus

48	Divshi	7.80	410.0	230.0	160.0	21.0	<0.5	38.0	16.0	-	232.0	11.0	-	-	-	Basalt
49	Naikba	7.80	280.0	175.0	100.0	16.0	1.0	65.0	9.0	-	122.0	25.0	0	0	0.25	Basalt
50	Savantvadi	8.21	310.0	155.0	125.0	13.0	-	32.0	11.0	Tr	165.0	14.0	Tr	Tr	-	Basalt
51	Karle	7.90	130.0	65.0	50.0	7.0	<0.5	8.0	7.0	-	61.0	11.0	-	-	-	Laterite
52	Jinti	8.16	310.0	175.0	130.0	13.0	1.0	38.0	9.0	-	174.0	14.0	-	-	-	Basalt
53	Dhebevadi	8.20	350.0	180.0	150.0	12.0	<0.5	26.0	21.0	-	153.0	21.0	-	23	-	Basalt
54	Gudhe	8.13	440.0	245.0	175.0	19.0	<0.5	40.0	18.0	-	180.0	35.0	10.0	-	-	Basalt
55	Babuchivadi	8.00	320.0	160.0	140.0	9.0	1.0	38.0	11.0	-	177.0	11.0	-	-	Tr	Basalt
56	Babuchivadi	7.70	130.0	65.0	50.0	7.0	1.0	8.0	7.0	-	67.0	7.0	-	-	-	Basalt
57	Babuchivadi	8.20	480.0	265.0	185.0	21.0	1.0	50.0	15.0	-	21.0	39.0	10.0	-	-	Basalt
58	Dhamni	8.38	370.0	205.0	135.0	17.0	13.0	22.0	19.0	18.0	118.0	35.0	5.0	-	-	Basalt
59	Kalgaon	8.25	480.0	240.0	215.0	12.0	2.0	54.0	19.0	Tr	232.0	35.0	-	-	-	Basalt
60	Nisre	9.16	500.0	240.0	200.0	23.0	0	26.0	33.0	48.0	159.0	28.0	0	1.8	-	Basalt
61	Andharwadi	8.40	346.0	280.0	145.0	14.0	0.5	22.0	22.0	15.0	162.0	18.0	7.5	-	-	Basalt
62	Malharpeth	8.40	400.0	185.0	155.0	22.0	0.8	32.0	18.0	30.0	140.0	25.0	0	<.1	-	Basalt
63	Malharpteh	8.50	555.0	404.0	240.0	20.0	0.5	54.0	26.0	24.0	201.0	15.0	5.0	-	-	Basalt
64	Marul Haveli	8.50	408.0	306.0	165.0	19.0	0.5	22.0	27.0	24.0	152.0	14.0	5.0	-	-	Basalt
65	Kole	7.90	593.0	380.0	230.0	22.0	3.9	52.0	24.0	305.0	21.0	3.0	-	-	-	Basalt
66	Sidrukvadi	7.91	400.0	195.0	165.0	16.0	1.0	42.0	14.0	-	213.0	14.0	Tr	Tr	-	Basalt
67	Sonachivadi	7.95	310.0	150.0	135.0	9.0	-	34.0	12.0	159.0	14.0	0	2	-	-	Basalt
68	Sonachivadi	7.95	300.0	150.0	130.0	9.0	Tr	46.0	4.0	-	152.0	14.0	Tr	2	-	Basalt
69	Kese	8.0	700.0	330.0	300.0	2.0	Tr	70.0	30.0	342.0	32.0	20.0	2	-	-	Basalt
70	Sakurdi	8.15	410.0	200.0	170.0	16.0	Tr	32.0	22.0	-	260.0	18.0	Tr	5	-	Basalt
71	Yeravle	8.40	690.0	360.0	135.0	95.0	1.0	22.0	19.0	12.0	299.0	42.0	10.0	8	-	Basalt
72	Mundhe	8.50	768.0	546.0	155.0	92.0	1.6	16.0	28.0	24.0	171.0	85.0	54.0	-	-	Basalt
73	Vijaynagar	8.45	680.0	345.0	235.0	48.0	-	40.0	35.0	36.0	244.0	39.0	18.0	7.5	-	Soil
74	Karad	8.40	1120.0	575.0	255.0	138.0	-	40.0	38.0	30.0	494.0	35.0	40.0	-	-	Alluvium
75	Kese	9.24	1030.0	555.0	125.0	177.0	Tr	10.0	24.0	30.0	304.0	60.0	50.0	8	-	Basalt
76	Ving	8.60	970.0	772.0	325.0	47.0	13.0	48.0	50.0	6.0	207.0	117.0	34.0	-	-	Basalt
77	Julewadi														0.25	Laterite
78	Dhadanwadi														0.25	Laterite
79	Janganwadi														0.25	Laterite
	Mean	8.14	356.8	185.7	125.9	18.1	2.1	31.6	13.6	9.3	141.3	20.5	3.8	-		
						Source : Borewell										
80	Khambilchorge	7.76	170.0	90.0	70.0	7.0	3.0	26.0	1.2	-	79.0	14.0	-	-	-	Basalt
81	Vingle	8.56	220.0	110.0	95.0	7.0	-	32.0	4.0	18.0	85.0	7.0	-	-	-	Basalt
82	Jinti	9.12	540.0	285.0	140.0	60.0	2.0	40.0	10.0	-	268.0	35.0	-	-	-	Basalt
83	Sakhre	8.07	300.0	155.0	110.0	18.0	3.0	28.0	10.0	-	146.0	21.0	-	-	-	Basalt
84	Mendoshi	9.62	230.0	120.0	45.0	32.0	-	14.0	2.4	30.0	55.0	14.0	0	Tr	-	Basalt
85	Yerad	7.92	280.0	150.0	100.0	20.0	1.0	20.0	12.0	-	153.0	11.0	-	-	-	Basalt
86	Gojegaon	8.29	290.0	150.0	120.0	13.0	1.0	28.0	12.0	Tr	159.0	11.0	-	-	-	Basalt
87	Rasati	8.27	190.0	100.0	85.0	6.0	-	24.0	6.0	Tr	104.0	7.0	-	-	-	Basalt
88	Keral	7.98	280.0	145.0	35.0	46.0	1.0	8.0	4.0	-	11.0	28.0	-	-	-	Basalt
89	Yerphale	8.17	570.0	285.0	240.0	19.0	4.0	48.0	29.0	281.0	35.0	5.0	-	-	-	Basalt
90	Manevadi	8.29	450.0	245.0	120.0	51.0	1.0	38.0	6.0	Tr	220.0	32.0	Tr	-	0.3	Basalt
91	Sadabaghapur	7.98	180.0	95.0	75.0	7.0	2.0	16.0	9.0	-	92.0	11.0	-	-	-	Basalt
92	Mestivadi	7.75	260.0	135.0	105.0	11.0	2.0	24.0	11.0	-	128.0	18.0	-	-	0.2	Basalt
93	Ludugadevadi	7.84	300.0	165.0	60.0	43.0	1.0	16.0	5.0	-	146.0	21.0	-	-	0.8	Basalt
94	Sanbur	8.12	600.0	300.0	270.0	16.0	2.0	60.0	29.0	-	336.0	21.0	-	-	-	Basalt
95	Sonavde	8.27	230.0	120.0	90.0	11.0	2.0	22.0	9.0	Tr	116.0	14.0	-	-	-	Basalt
96	Pawarvadi	8.30	480.0	240.0	170.0	25.0	1.0	42.0	16.0	Tr	244.0	28.0	0	0	0.5	Basalt
97	Babuchivadi	8.04	240.0	125.0	70.0	23.0	2.0	14.0	9.0	-	122.0	14.0	-	-	0.2	Basalt

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98	Dhamni	8.08	930.0	480.0	320.0	60.0	11.3	82.0	28.0	-	476.0	43.0	5.0	9.5	-	Basalt
99	Urul	8.10	700.0	375.0	300.0	23.0	-	74.0	28.0	-	244.0	71.0	20.0	32	-	Basalt
100	Mhopre	8.08	680.0	355.0	230.0	51.0	-	76.0	10.0	-	384.0	18.0	0	>.3	-	Basalt
101	Nayasupane	7.94	620.0	310.0	220.0	41.0	-	58.0	18.0	-	360.0	11.0	0	Tr	-	Basalt
102	Kumbhargaon	7.94	190.0	105.0	25.0	33.0	1.0	6.0	3.0	-	98.0	11.0	-	-	-	Basalt
103	Marulhaveli	7.68	180.0	95.0	75.0	7.0	1.0	16.0	9.0	-	98.0	7.0	-	-	-	Basalt
Average		8.17	379.9	197.3	132.1	26.2	1.7	33.8	11.7	2.0	188.1	21.0	1.2	-		

Soruce : Spring

104	Old Mahabaleswar	8.13	180.0	100.0	35.0	25.0	5.0	12.0	1.2	0	79.0	14.0	0	5	-	-
105	Chikhli	8.3	170.0	80.0	75.0	4.0	-	12.0	11.0	Tr	83.0	11.0	0	Tr	-	Basalt
106	Taldev	8.00	170.0	85.0	75.0	5.0	0.5	22.0	5.0	-	92.0	7.0	-	-	-	Basalt
107	Aral Nivkane	7.93	150.0	80.0	65.0	5.0	-	18.0	5.0	-	67.0	14.0	-	-	-	-
108	Dhangarvadi	7.80	120.0	60.0	55.0	2.0	<0.5	14.0	5.0	-	61.0	7.0	0	0	0.7	Laterite
109	Virwadi	7.90	180.0	95.0	75.0	7.0	-	28.0	1.0	-	92.0	11.0	0	0	0.3	Laterite
110	Ghanbi	7.31	110.0	55.0	50.0	2.3	-	14.0	4.0	-	55.0	7.0	-	-	-	Talus
111	Payatyacha	8.00	170.0	90.0	75.0	5.0	0.5	28.0	1.0	-	85.0	11.0	0	0	0.25	-
112	Kusavde	8.11	320.0	160.0	140.0	10.0	0.8	36.0	12.0	-	177.0	11.0	0	0	Tr	-
113	Lendori	8.10	160.0	80.0	75.0	4.0	-	20.0	6.0	-	79.0	11.0	0	0	0.7	-
114	Malevadi	7.81	150.0	75.0	60.0	7.0	-	14.0	6.0	-	67.0	14.0	-	-	-	Basalt
115	Bhodri	7.90	150.0	75.0	65.0	5.0	<0.5	16.0	6.0	-	73.0	11.0	0	Tr	-	Laterite
116	Jhakde	8.00	200.0	100.0	85.0	7.0	<0.5	30.0	2.0	-	104.0	11.0	0	0	0.3	Talus
117	Jaichevadi	7.80	140.0	70.0	65.0	4.0		16.0	6.0	-	67.0	11.0	0	Tr	-	Laterite
118	Chiteghar	7.92	160.0	80.0	65.0	7.0	-	20.0	4.0	-	85.0	7.0	-	-	-	Basalt
119	KKatavdewadi	7.42	90.0	50.0	40.0	2.3	-	14.0	1.2	-	31.0	14.0	0	Tr	-	Laterite
120	Kaikevadi	7.90	190.0	100.0	85.0	5.0	2.0	30.0	2.0	-	92.0	14.0	0	0	-	Basalt
121	Kodal	7.80	230.0	120.0	100.0	8.0	1.0	30.0	7.0	-	128.0	7.0	0	0	1.5	Basalt
122	Natoshi	8.10	240.0	120.0	105.0	8.0	<0.5	28.0	5.0	-	128.0	11.0	0	0	0.3	Basalt
123	Amragi	8.10	100.0	55.0	40.0	5.0	<0.5	12.0	2.0	-	49.0	7.0	0	0	0.7	Basalt
124	Gokul	8.20	190.0	95.0	80.0	4.0	<0.5	22.0	6.0	-	98.0	11.0	0	0	0.7	-
125	Kusrund	7.90	240.0	125.0	100.0	9.0	2.0	34.0	4.0	-	122.0	14.0	0	0	0.3	-
126	Kokisre	7.80	180.0	95.0	75.0	7.0	1.0	26.0	2.0	-	92.0	11.0	0	0	0.4	-
127	Kolekarvadi	8.10	220.0	115.0	90.0	10.0	<0.5	30.0	4.0	-	122.0	7.0	0	0	0.2	-
128	Varpevadi	7.70	160.0	82.0	65.0	7.0	1.0	22.0	2.0	-	73.0	14.0	-	-	Tr	Basalt
129	Natoshi	7.70	140.0	75.0	50.0	7.0	4.0	14.0	4.0	-	67.0	11.0	-	-	0.3	Basalt
130	Chugulevadi	8.00	210.0	105.0	80.0	12.0	<0.5	20.0	7.0	-	110.0	11.0	0	0	0.3	-
131	Chugulevadi	8.00	260.0	130.0	100.0	14.0	,0.5	24.0	10.0	-	134.0	11.0	-	-	2	-
132	Paneri	7.80	70.0	35.0	30.0	2.0	0.5	10.0	1.0	-	31.0	7.0	-	-	0.45	Talus
Average		7.91	174.1	89.2	72.4	6.8	0.6	21.2	4.6	0	87.7	10.6	0	0		

Source . River

133	Tapole	7.20	90.0	50.0	30.0	7.0	-	10.0	1.0	-	37.0	11.0	0	0	
134	Koyna Dam	7.57	50.0	30.0	20.0	3.0	1.0	4.0	2.4	-	18.0	7.0	-	-	Tr
135	Koyna Dam	7.82	200.0	110.0	75.0	14.0	2.0	20.0	6.0	-	110.0	11.0	-	-	
136	Koyna Dam	7.54	80.0	45.0	30.0	4.0	1.0	6.0	4.0	-	31.0	11.0	-		
137	Koyna Dam	7.68	50.0	30.0	20.0	3.0	1.0	4.0	2.4	-	18.0	7.0	-	-	Tr
138	Koyna Dam	7.67	50.0	30.0	20.0	3.0	-	4.0	2.4	-	18.0	7.0	-	-	
139	Konya Dam	7.73	60.0	35.0	25.0	3.0	1.0	6.0	2.4	-	24.0	7.0	-		

140 Vanzole	7.87	110.0	56.0	40.0	7.0	-	8.0	5.0	-	49.0	11.0	-	-
141 Patan	8.00	140.0	70.0	55.0	7.0	-	14.0	5.0	-	61.0	14.0	-	-
142 Sangvad	7.65	120.0	65.0	50.0	5.0	1.0	14.0	4.0	-	61.0	7.0	-	-
143 Malharpeth (Storage Tank)	7.94	300.0	155.0	100.0	23.0	1 0	28.0	7.0	-	165.0	11.0	-	-
144 Nisre	8.00	110.0	56.0	45.0	5.0	-	12.0	4.0	-	55.0	7.0	-	-
145 Kese	8.10	150.0	80.0	65.0	5.0	-	22.0	2.4	-	67.0	14.0	-	-
146 Karad 1	7.45	190.0	95.0	80.0	7.0	0.5	18.0	9.0	-	98.0	11.0	0	Tr
147 Karad 2	8.30	180.0	90.0	70.0	9.0	-	14.0	9.0	Tr	85.0	14.0	-	-
148 Karad 3	7.86	140.0	75.0	60.0	6.0	0.5	20.0	2.4	-	67.0	11.0	-	-
149 Karad 4	8.22	150.0	76.0	65.0	5.0	0.5	18.0	5.0	Tr	73.0	11.0	0	Tr
150 Karad 5	7.90	140.0	70.0	60.0	5.0	0.5	20.0	2.4	-	73.0	7.0	0	Tr
Average	7.81	128.3	67.7	50.6	6.7	0.6	13.4	4.2	0	61.7	9.9	0	-

Table 6.3 Mean Chemical Constituents of Waters and their ranges in different sources.

Source of Water	Aquifer	pH	EC (m.mhos/cm at 25°C)	TDS	TH as $CaCo_3$	Na	K	Ca	Mg	Co_3	HCo_3	Cl	So_4	Fe
				←-----				ppm						----->
Dug-well	Basalt (64-Samples)	8.18 (7.40-9.24)	368 (60-1030)	192 (30-772)	130 (25-325)	170 (2-177)	02 (0-13)	34 (6-72)	14 (2-50)	10 (0-36)	142 (12-494)	21 (7-117)	3.5 (0-54)	- (Tr-0.5)
	Laterite/ Lateritic Soil (3 Samples)	7.83 (7.70-7.90)	147 (100-210)	78 (55-115)	58 (40-85)	07 (05-09)	02 (0.5-04)	15 (8-26)	4 (4-7)	0	59 (43-73)	18 (11-32)	0	Not Determined
	Talus/ Colluvium (6-Samples)	7.85 (7.60-8.0)	195 (90-350)	102 (45-180)	63 (40-95)	10 (03-26)	02 (0-11)	19 (6-34)	07 (4-16)	0	102 (43-195)	11 (7-18)	01 (0-5)	- (0.2-0.45)
	Alluvium (2-Samples)	8.05 (7.70-8.40)	680 (240-1120)	345 (115-575)	118 (100-255)	73 (08-138)	0 -	32 (24-40)	24 (10-38)	15 (0-30)	311 (128-494)	21 (7-35)	20 (0-40)	-
	Black Cotton Soils (1-Sample)	8.45	6.80	345	235	48	-	40	33	36	244	29	18	-
Bore-well	Basalt (24-Samples)	8.17 (7.75-8.56)	380 (170-930)	197 (90-300)	132 (25-320)	26 (06-60)	02 (0-113)	34 (6-82)	12 (1.2-29)	02 (0-30)	188 (55-476)	21 (7-71)	01 (0-53)	- (0.2-0.8)
Spring	Basalt (21-Samples)	7.97 (7.42-8.20)	190 (100-320)	97 (55-160)	78 (40-140)	08 (4-25)	0.70 (0-4)	23 (12-36)	05 (1-12)	0	97 (31-177)	11 (7-14)	0	- (0.2-2.0)
	Laterite (5-Samples)	7.76 (7.42-7.90)	136 (9-180)	70 (50-95)	60 (40-75)	04 (02-7)	0.20 (0-0.5)	18 (14-28)	04 (1.2-06)	0	65 (31-92)	11 (7-14)	0	- (0.25-0.7)
	Talus/ Colluvium (3 Samples)	7.58 (7.31-8.0)	1 27 (70-200)	63 (35-100)	55 (30-85)	04 (02-07)	0.30 (0-0.5)	18 (10-30)	02 (01-04)	0	63 (31-104)	8 (7-11)	0	- (–-4.5)
River*	-	7.79 (7.20-8.30)	118 (50-200)	63 (30-110)	48 (30-80)	06 (03-14)	0.60 (0-2.0)	13 (4-20)	04 (1.2-09)	0	56 (18-110)	10 (07-14)	0	- (0-Tr)

Note

1. Abbreviations : EC = Electrical Conductivity
   TDS = Total Dissolved Solids
   TH = Total Hardness
2. Figures in bracket indicate range of chemical constituents
3. * Malharpeth water sample (Sample No.11), which has been collected from the storage tank for water supply has not been considered.

TDS = 180 ppm

Cation in epm		Anion in epm	
Ca	2.00	CO_3	1.2
Mg	2.70	HCO_3	4.0
Na	2.10	Cl	1.1
K	0	SO_4	0.5
Total	6.80	Total	6.80

In Collins' Bar Diagram the height of the bar is proportional to the total epm concentration of the cations and anions which will be equal.

Karanth (1987) modified the Collins' Bar Diagram in which percent epm values can be represented to show the relative proportion of the chemical constituents as shown in Fig.6.2.b. Here, the vertical height is fixed taking a unit scale for each percent of the cation or anions.

The already modified Collins' Bar Diagram (Karanth, 1987) can further be modified by introducing TDS expressed in ppm in the diagram. For a particular TDS value the height of the bar can be accordingly fixed. For example, for a TDS value of 345 ppm, the height of a bar will be 11.5cms in the scale of 1 cm = 30 ppm as shown in Fig.6.2c. The cations and anions are shown in their percent epm values in this case as well, but the TDS value of that particular water samples even though expressed in ppm can be safely used to define its height.

In the Collins Diagram (Fig. 6.2a) and Modified Collins Diagram by Karanth (Fig. 6.2b), the height of the bar is fixed without considering the TDS values of the water sample. Through the newly modified Collins Diagram a number of water samples can be easily compared as the height of the bars on a given scale represent the salinity of the water samples. Thus the newly modified diagram has a definite advantage over the earlier diagrams in this respect. As per the newly modified diagram, analytical data of some of the representative samples from different sources have been shown in Fig.6.3 (a,b,c & d). The mean values of the constituents in different sources are shown in Fig.6.4.

6.2.2 Hill-Piper Diagram

Piper (1944) suggested a method of plotting analysis in a trilinear diagram. The Piper's diagram consists of three distinct fields i.e. two triangular fields at the lower left and lower right and one central diamond shaped field (Fig. 6.5). In the triangular field at the lower left, the percent epm values of the three cation groups (Ca^{++}, Mg^{++}, Na^{+} + K^{+}) are plotted as a single point. Similarly three anion groups ($CO3^{--}$ + $HCO3^{-}$, $SO4^{--}$, Cl^{-}) are plotted in the triangular field at the lower right. The position of these two points is projected in the central diamond shaped field which gives the overall chemical character of the water samples. The central diamond shaped field has been further divided into nine parts (Fig. 6.5 Table 6.4) or subareas. Distinct water quality types can readily be identified by their plottings in different parts of the diamond shaped field.

Analytical data of 76 samples from dugwells, 24 samples from borewells, 29 samples from springs and 18 samples from Koyna river system have been plotted in the Hill-Piper diagram (Fig. 6.5 to Fig. 6.8). The percentage of water samples lying in different sub-areas are shown in Table 6.5. A perusal of the table shows majority of the water samples, 95% from dug-wells, 83% from borewells, 97% from springs and 100% from Koyna river, are dominated by alkaline earths (Ca^{++}, Mg^{++}) and weak acids (HCO_3^{-}, CO_3^{-}). No water sample fall in sub-area 4, 6 and 7 except one sample from dugwell (sample No. 76) indicating, thereby that chemical properties are dominated by alkaline earths and weak acids and carbonate hardness exceeds 50% as shown in area 5. Only a meager percent of water samples, i.e. 5% from dugwell, 17% from borewells and 3% from springs fall in area 2, thus indicating that in these water samples alkalies (Na^{+}, K^{+}) exceed the alkaline earths (Ca^{++}, Mg^{++}). Only a meager 4% of water samples in borewell indicate that carbonate alkali exceeds 50% in these water samples, i.e. the water of these samples are inordinately soft in proportion to their content of dissolved solids. In case of

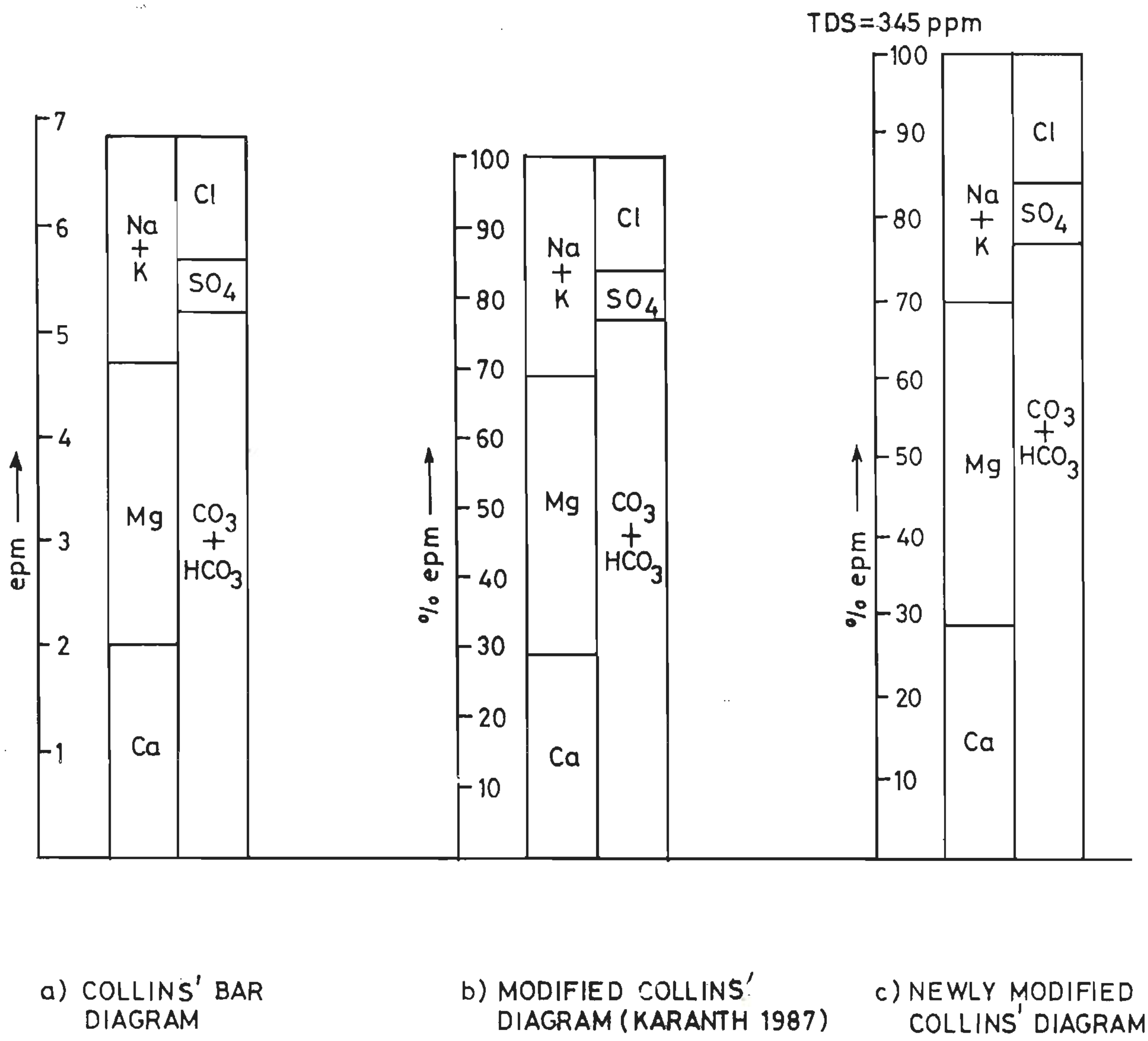


FIG. 6·2–PLOT OF ANALYTICAL DATA IN COLLINS' DIAGRAM, MODIFIED COLLINS' DIAGRAM (1987) AND NEWLY MODIFIED COLLINS' DIAGRAM

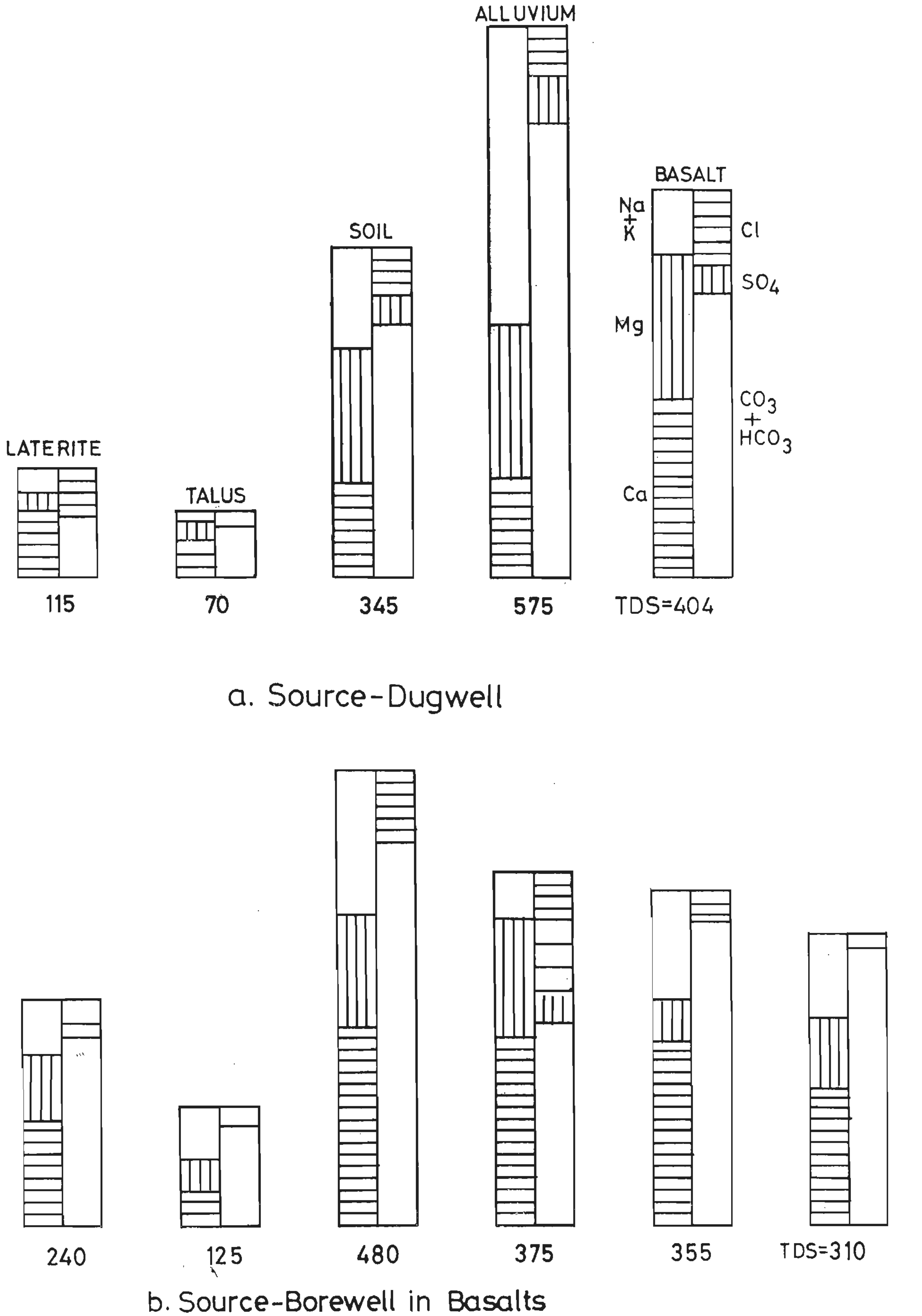
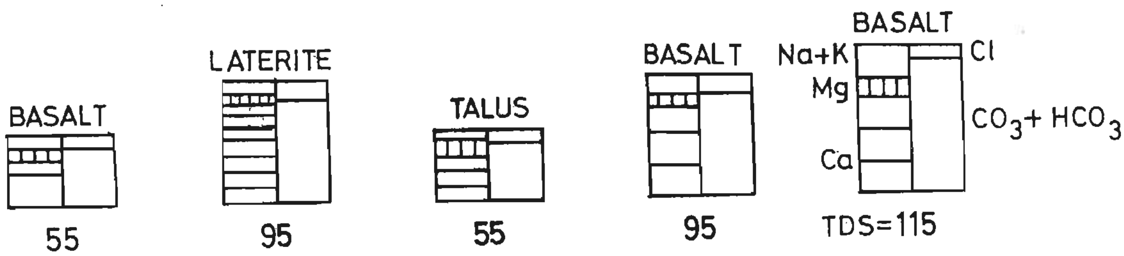
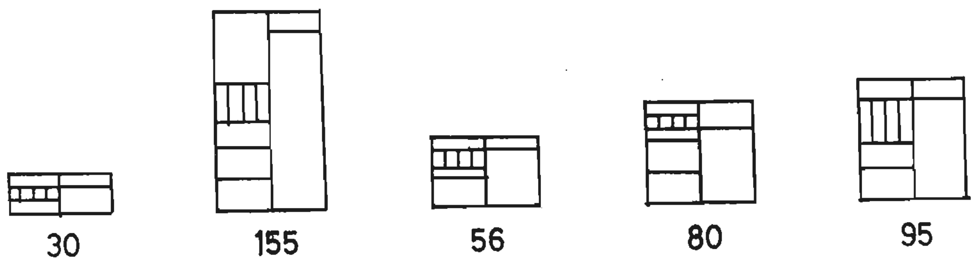


FIG. 6·3 (a, b)- PLOT OF REPRESENTATIVE WATER SAMPLES FROM DIFFERENT SOURCES IN THE NEWLY MODIFIED COLLINS DIAGRAM



c. Source-Spring



d. Source-River

FIG.6·3 (c,d)–PLOT OF REPRESENTATIVE WATER SAMPLES FROM DIFFERENT SOURCES IN THE NEWLY MODIFIED COLLINS' DIAGRAM

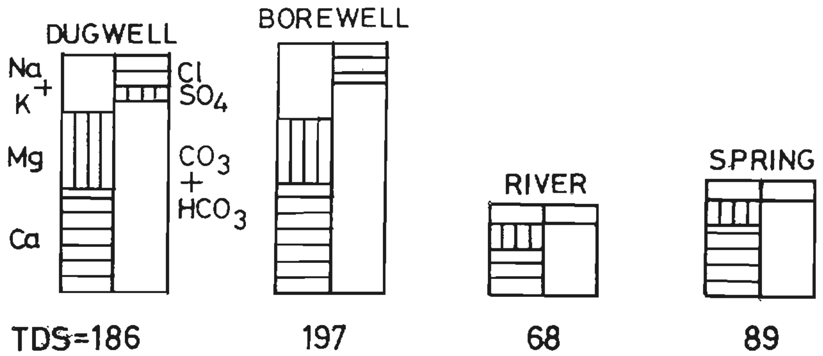


FIG.6·4–PLOT OF MEAN VALUES OF THE CONSTITUENTS IN DIFFERENT SOURCES ON NEWLY MODIFIED COLLINS' DIAGRAM

Table 6.4 Types of water in different sub-areas in Hill-Piper Diagram (Fig 6.5)

Area 1 Alkaline earths exceed alkalies.

Area 2 Alkalies exceed alkaline earths.

Area 3 Weak acids exceed strong acids.

Area 4 Strong acids exceed weak acids.

Area 5 Carbonate hardness exceeds 50%, i.e. chemical properties of the water are dominated by alkaline earths and weak acids.

Area 6 Non-carbonate hardness exceeds 50%.

Area 7 Non-carbonate alkali exceeds 50%, i.e. chemical properties are dominated by alkalies and strong acids.

Area 8 Carbonate alkali exceeds 50%. Waters are inordinately soft in proportion to their content of dissolved solids.

Area 9 No or single cation-anion pair exceeds 50%.

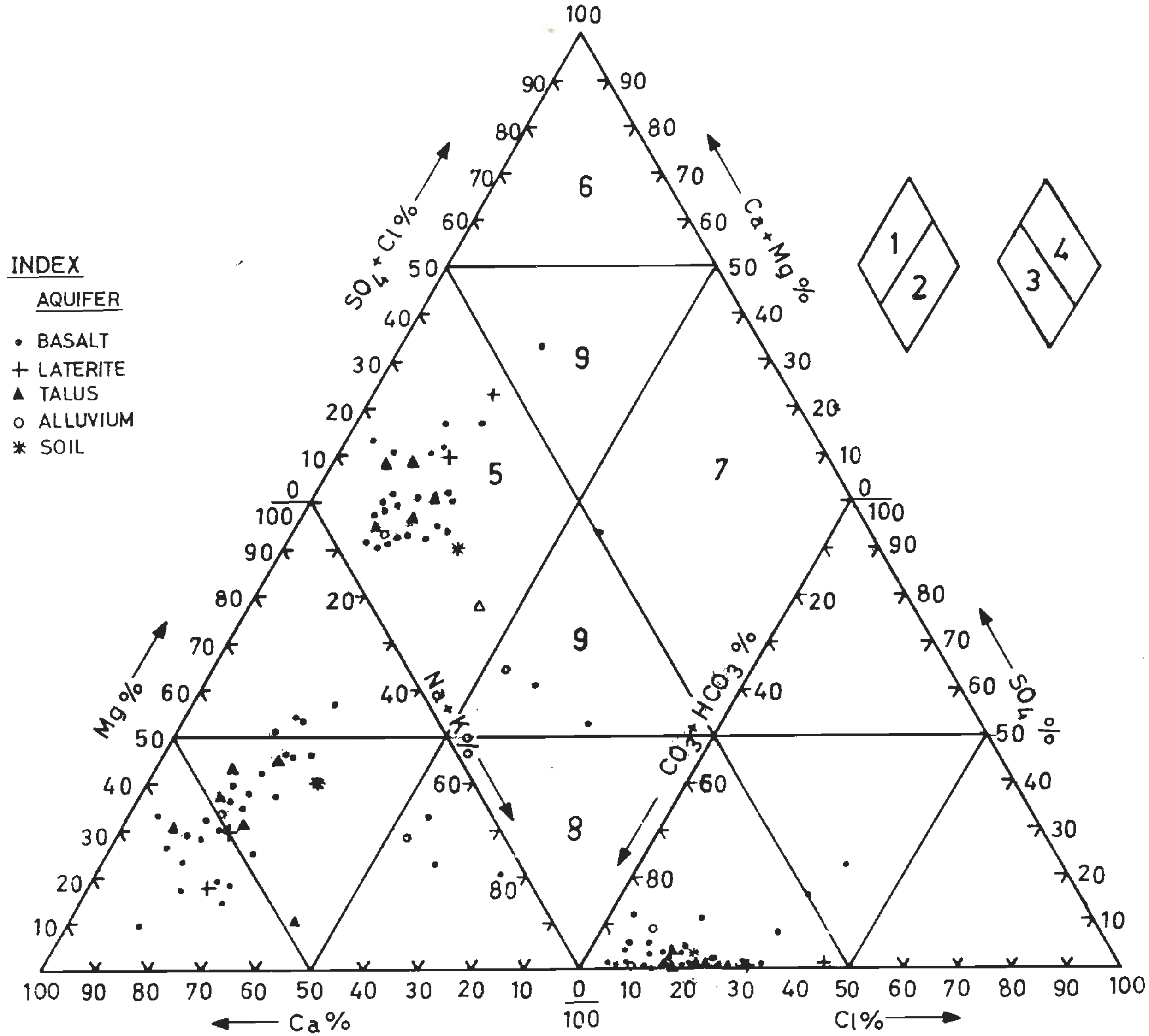


FIG: 6·5 – PLOT OF ANALYSIS OF DUG WELL WATER SAMPLES ON HILL-PIPER DIAGRAM.

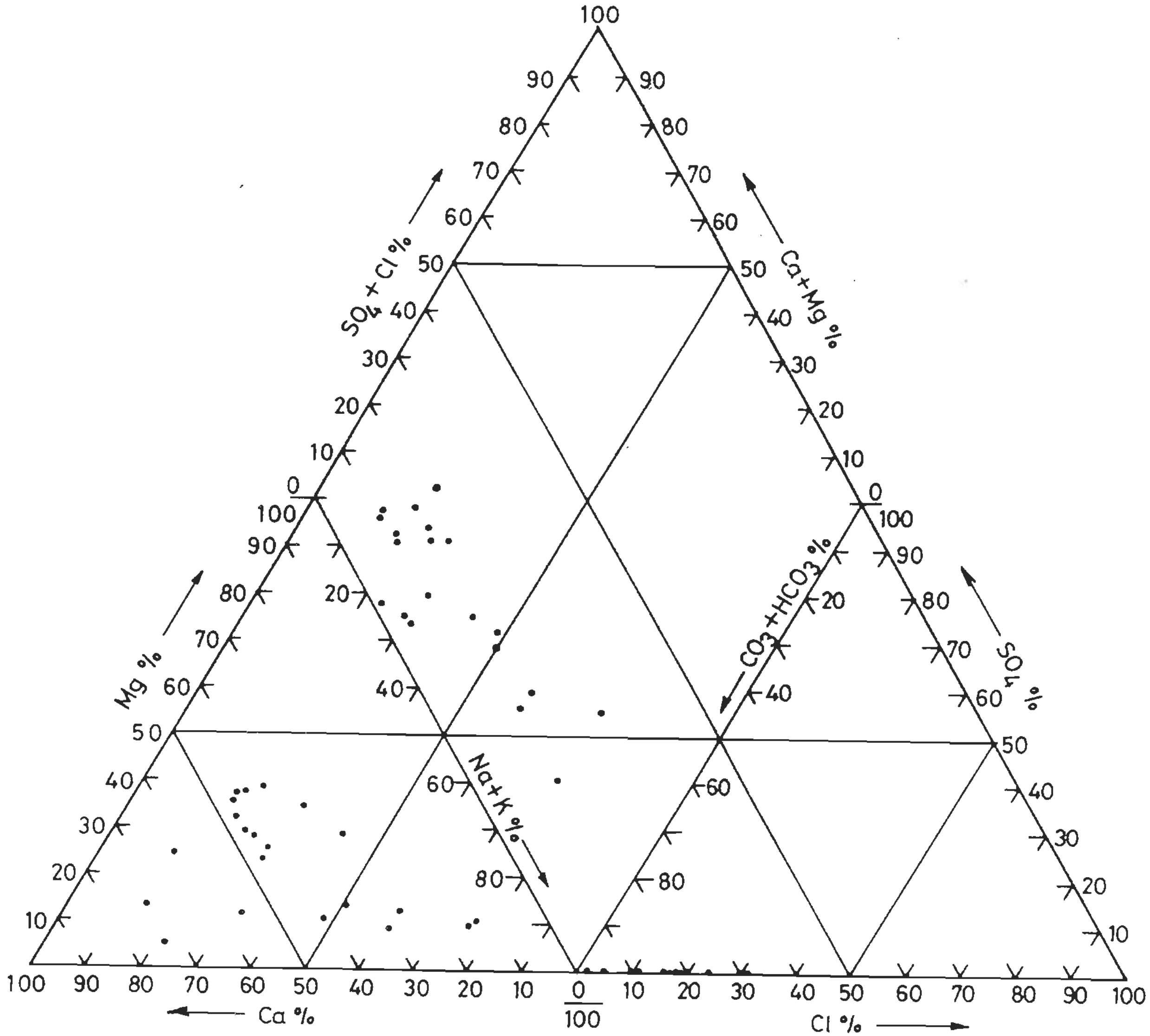


FIG.6·6-PLOT OF ANALYSIS OF BOREWELL WATER SAMPLES ON HILL-PIPER DIAGRAM

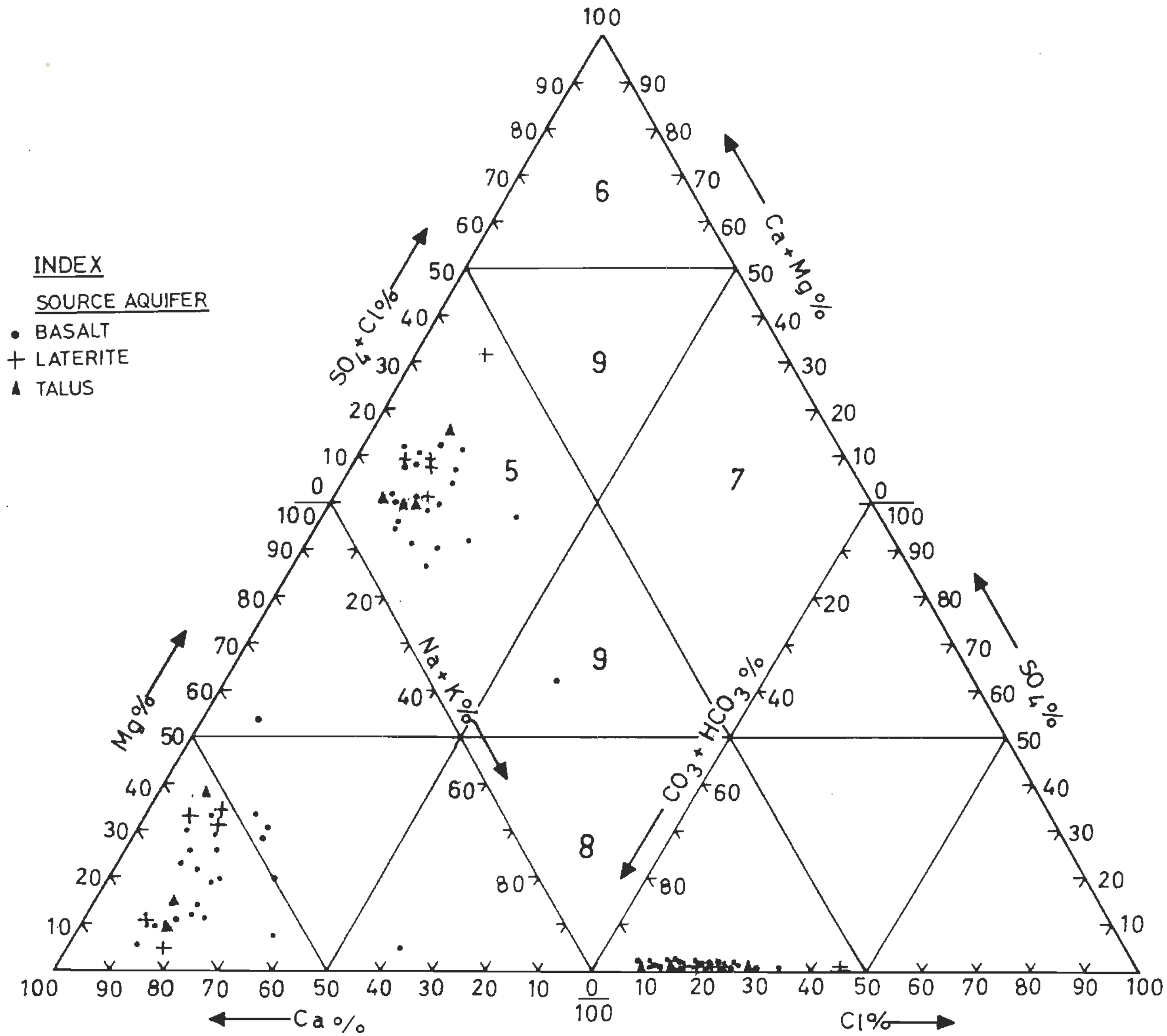


FIG: 6·7 — PLOT OF ANALYSIS OF SPRING WATER SAMPLES ON HILL-PIPER DIAGRAM.

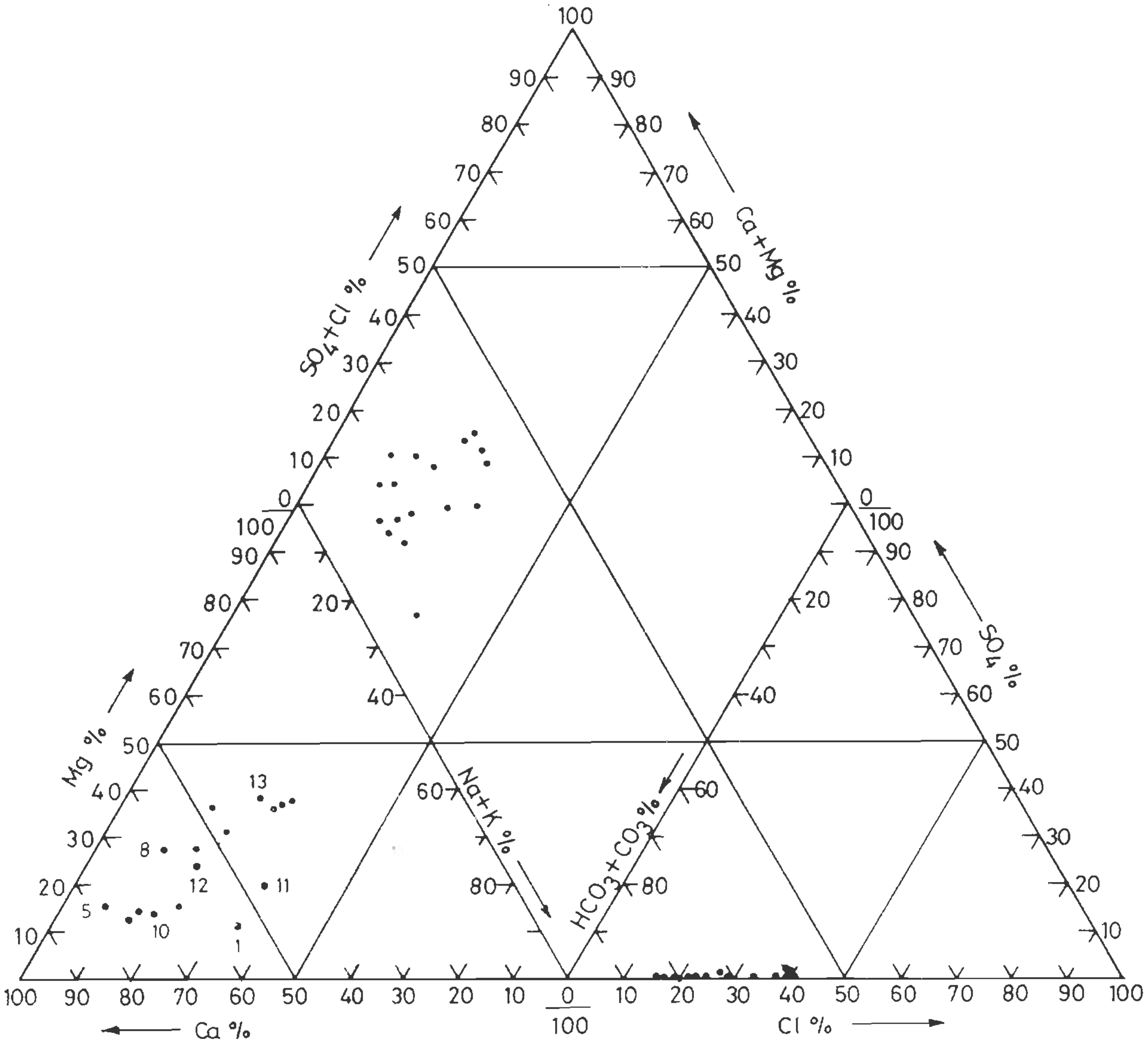


FIG.6·8-PLOT OF ANALYSIS OF SURFACE WATER SAMPLES ON HILL PIPER DIAGRAM

Table 6.5 Classification of Water according to Hill-Piper Diagram.

Source	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8	Area 9
Dugwell	95%	5%	99%	1	93%	0	0	0%	7%
Borewell	83%	17%	100%	0	83%	0	0	4%	13%
Spring	97%	3%	100%	0	97%	0	0	0	1%
Koyna River	100%	0	100%	0	100%	0	0	0	0

7% of samples from dugwell, 13% from borewell and 1% from spring, no one cation-anion pair exceeds 50%. These 7% of dugwell water samples have been taken from the lower reaches of the Koyna sub-basin where there is already near water logging condition existing.

From the above discussion it follows that majority of the water samples from this basaltic terrain are characterised by the dominance of Ca^{++}, Mg^{++} and $HCO3^{-}$. Such type of waters are common in basalt as also reported by Schoeller (1956) and Angadi (1986).

6.2.3 Modified Hill-Piper Diagram (Romani, 1981)

The nine types of water given by Piper (1944) show essential chemical character of water rather than grouping them into different classes. Further, there are effectively only 5 classes. The classes 1 to 4 are but repetitions of other classes though in broader groups. Romani (1981) proposed a diagram in modification of the Piper's diagram which classifies the cation and anion triangles into 7 classes, each with respect to hydrochemical facies (Fetter, 1988) and groups the waters into two, depending on their primary character.

Instead of equilateral triangles, Romani (1981) has used right angled isosceles triangles for plotting the cation and anions (Fig. 6.9). Here, the resulting central field showing the primary character is square instead of diamond shaped. The two right angled triangles, one for cations and other for anions are essentially used for classification of waters. The three sides of each triangle, divided into 100 equal parts, represent the percentage reacting values (expressed in terms of epm) of cation and anion groups. The 7 classes each in the cation and anion triangles are given in Table 6.6 and shown in figure. 6.9.

The central square field gives the overall character of water. The water falling in Group I will have alkaline earths (Ca, Mg) exceeding the bicarbonates. Such water will show permanent hardness and will not have bicarbonate hazard for irrigation. On the other hand, the water of Group II will have temporary hardness and have residual sodium carbonates.

The plots of the water samples from various sources as per this diagram are shown in Figures 6.9 to 6.12. With the help of Table 6.7, it is seen that the samples from shallow aquifers are generally calcium-bicarbonate type (53%) and calcium-magnesium-bicarbonate (27%) type. In case of deeper aquifer they are mostly calcium-magnesium- bicarbonate type (29%), sodium-bicarbonate type (24%), calcium-bicarbonate type (19%), calcium-magnesium-sodium-bicarbonate type (19%) and sodium-calcium-bicarbonate (9%). While comparing the Piper's diagram with that of Romani's it is seen that the water classes are more defined in case of the later. In anion triangle almost all the samples are classified as bicarbonate type except 1 sample (no.11) from deeper aquifer which is sulphate type.

While classifying water with respect to their primary character it is found that about 90% of the samples in case of borewells (deep aquifers), show temporary hardness and possess residual sodium carbonate.

6.3 VARIATION OF WATER QUALITY WITH TIME

Monitoring of groundwater quality with time is being carried out by Central Ground Water Board, Central Region, Nagpur in selected hydrograph stations. Long- term analytical data of two hydrograph stations established at Patan in weathered basalts in the middle reaches and at Mahabaleshwar in laterite in the upper reaches have been given in Table 6.8 (a and b). Other hydrograph station in the area have been established recently and long-term analytical data are not available. Groundwater sampling from these stations have been discontinued since 1990 and as such chemical data beyond this year are not available. Also for the years 1983 and 1985 in case of Mahabaleshwar, water samples were not collected. Trend-analysis of the chemical constituents of ground water at Hydrograph Station Patan for the last 10 years (Fig. 6.13) indicates a general decline of the chemical concentration in case of all the constituents except Sodium (Na) (Fig. 6.13). Patan lies in the command area of the Koyna lift irrigation schemes and the topography is gently sloping towards the Koyna river. Although the water level at the

Table 6.6 Types of water in different sub-areas in Romani's diagram

Cation Triangle

C1 : Calcium type

C2 : Magnesium type

C3 : Sodium type

C4 : Sodium-calcium type

C5 : Calcium-Magnesium type

C6 : Sodium-Magnesium type

C7 : Calcium-Magnesium-Sodium type

Anion Triangle

A1 : Bicarbonate type

A2 : Sulphate type

A3 : Chloride type

A4 : Chloride-Bicarbonate type

A5 : Bicarbonate-Sulphate type

A6 : Chloride-Sulphate type

A7 : Bicarbonate-Sulphate-Chloride type

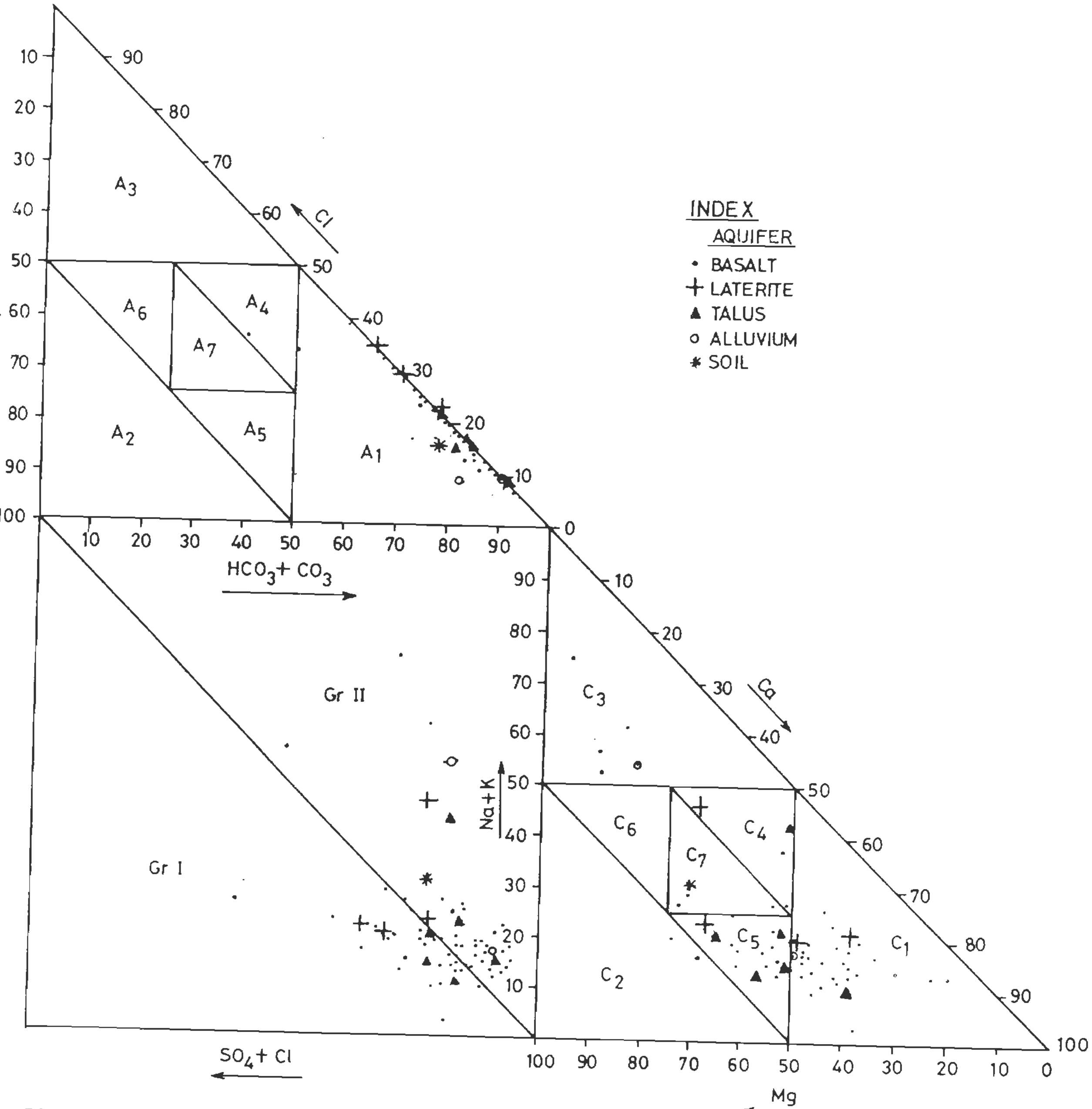


FIG. 6·9 — PLOT OF ANALYSIS OF DUGWELL WATER SAMPLES ON ROMANI'S DIAGRAM

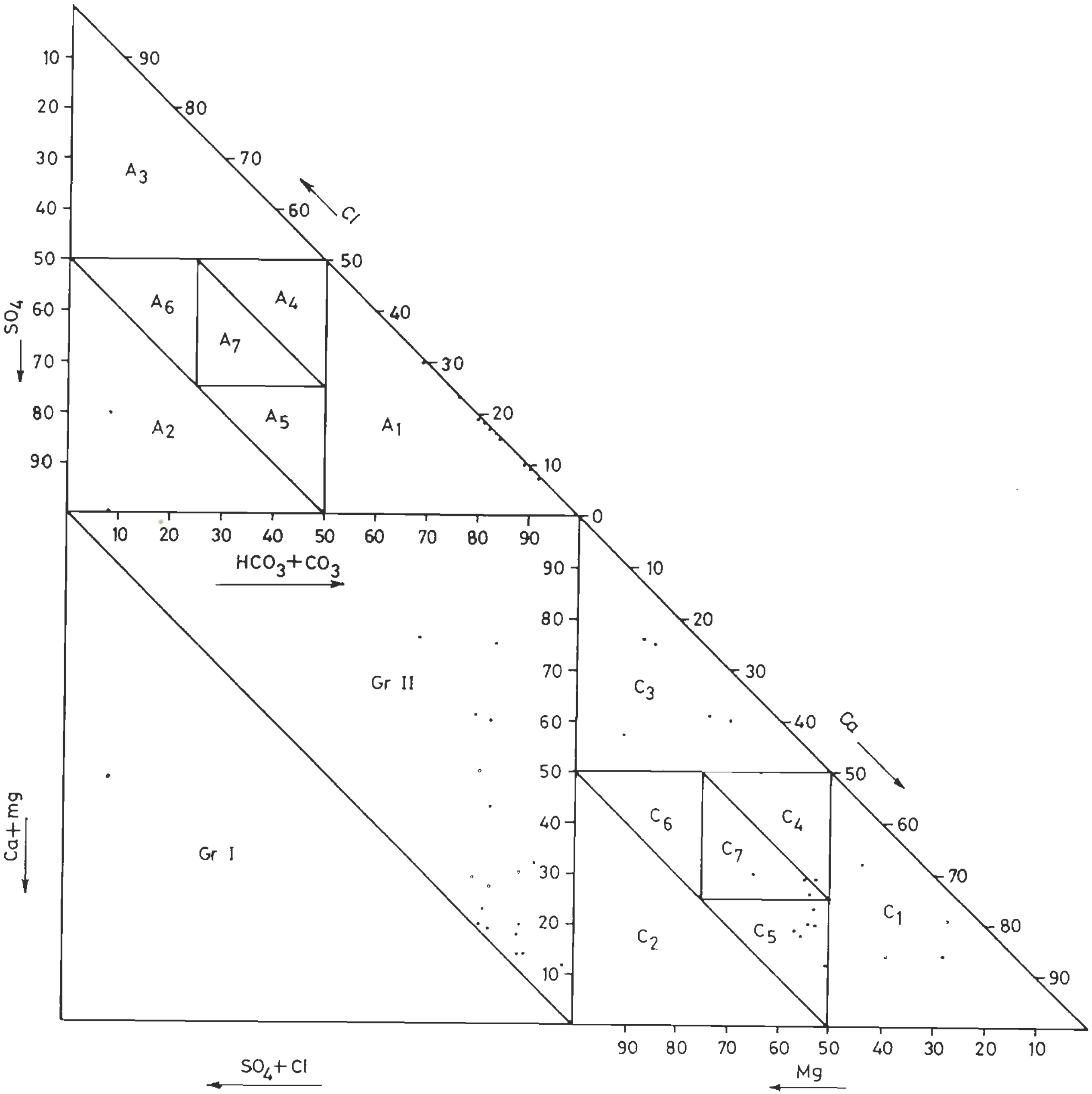


FIG. 6·10- PLOT OF ANALYSIS OF BOREWELL WATER SAMPLES ON ROMANI'S DIAGRAM

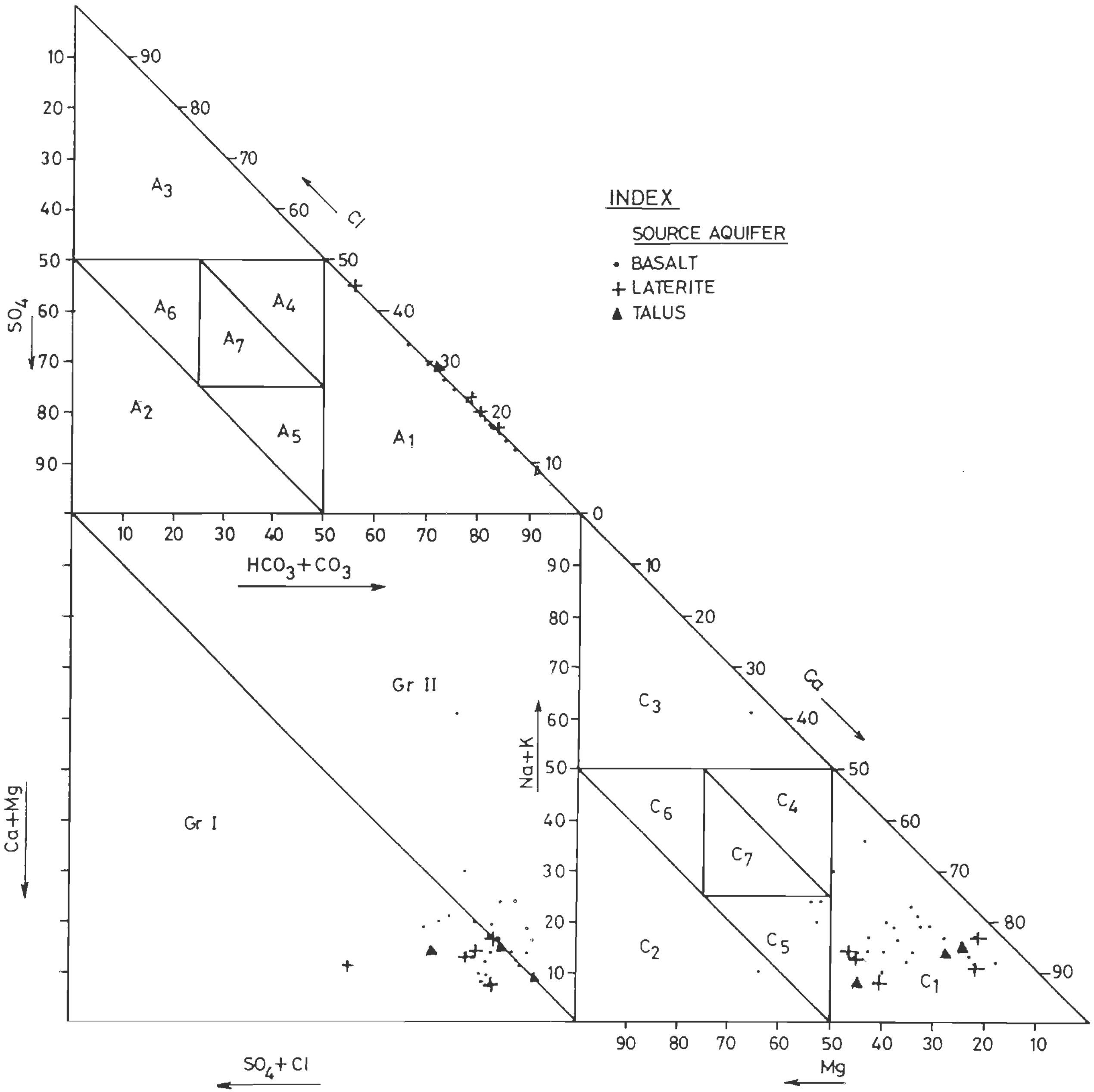


FIG.6·11–PLOT OF ANALYSIS OF SPRING WATER SAMPLES ON ROMANI'S DIAGRAM

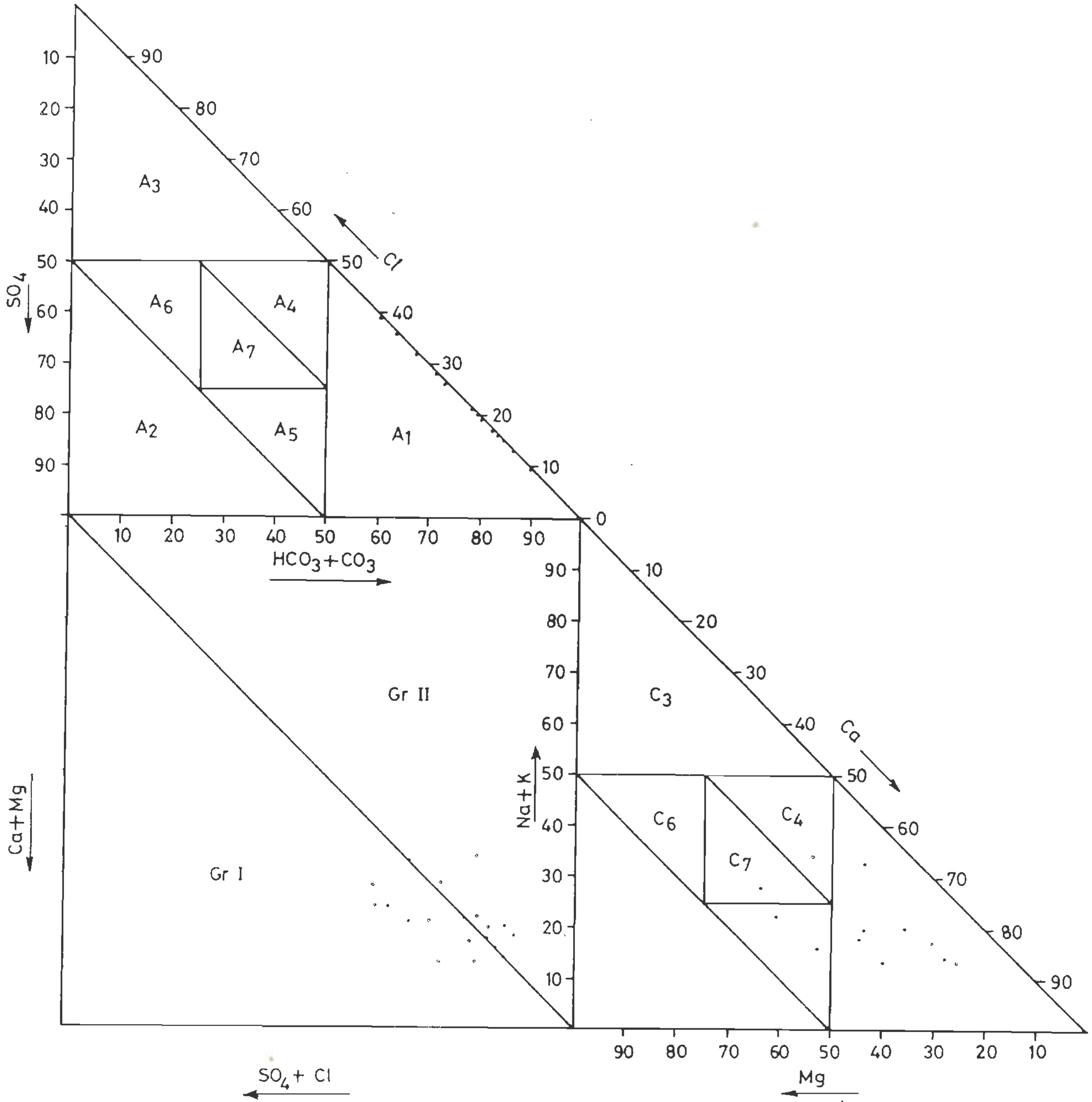


FIG.6·12-PLOT OF ANALYSIS OF RIVER WATER SAMPLES ON ROMANI'S DIAGRAM

Table 6.7 Classification of water as per Romani's Diagram

Source	Cation Trianlge							Anion Triangle							GrI	GrII
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	A_1	A_2	A_3	A_4	A_5	A_6	A_7		
Dugwell	53%	4%	6%	3%	27%	0	7%	100%							39%	61%
Borewell	19%	0	24%	9%	29%	0	19%	96%	4%						10%	90%
Spring	84%	3%	3%	0	10%	0	0	100%							48%	52%
River	44%	0	0	6%	44%	0	06%	100%							58%	42%

Table 6.8a Variation of Water Quality With Time (Station - Patan) (Aquifer - Weathered basalt)

Year	pH	EC (m.mhos/ cm at 25°C)	TDS	TH as $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3
			ppm										
May 1981	8.2	320	180	145	40	11	13	2	0	177	25	Tr.	
May 1981	7.2	270	200	190	24	32	21	<1	0	177	60	Tr.	
May 1982	7.9	305	170	130	34	11	10	1	0	153	25	5	
May 1983	7.3	350	193	165	46	12	9	3	0	183	18	13	
May 1984	7.7	253	150	130	34	11	7.0	<1	0	146	14	5	
May 1985	7.8	290	160	115	22	15	14	0	0	153	14	Tr.	
May 1986	7.94	330	160	145	34	15	9.2	0	0	177	14	0	
May 1987	7.23	250	150	110	30	8	10	12	0	153	14	0	
May 1888	8.35	310	145	130	34	11	13	0	0	110	18	0	
May 1989	6.90	230	135	65	24	1.2	23	<.1	0	104	11	0	20
May 1990	7.74	260	ND*	ND*	18	9	ND*	ND*	0	140	11		

*ND : Not determined

Table 6.8b Variation of Water Quality With Time (Station - Mahabaleshwar) (Aquifer - Laterite)

Year	pH	EC (m.mhos/ cm at 25°C)	TDS	TH as $CaCO_3$	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3
			ppm										
April 82	7.7	260	145	110	34	6	7	2	0	110	25	2	ND
April 83	ND												
April 84	8.3	110	60	40	10	3.6	5.4	<1	Tr.	24	18	0	ND
April 85	ND												
April 86	7.10	150	77	70	18	6	3	0	0	43	28	0	ND
April 87	6.33	150	85	50	16	3	7	6	0	49	21	0	ND
April 88	7.70	210	115	85	26	5	9	4	0	73	32	0	ND
April 89	8.10	140	85	60	12	7	6	<0.5	0	24	25	0	23
April 90	7.64	180	ND	-	18	7	ND	ND	0	61	28	ND	ND

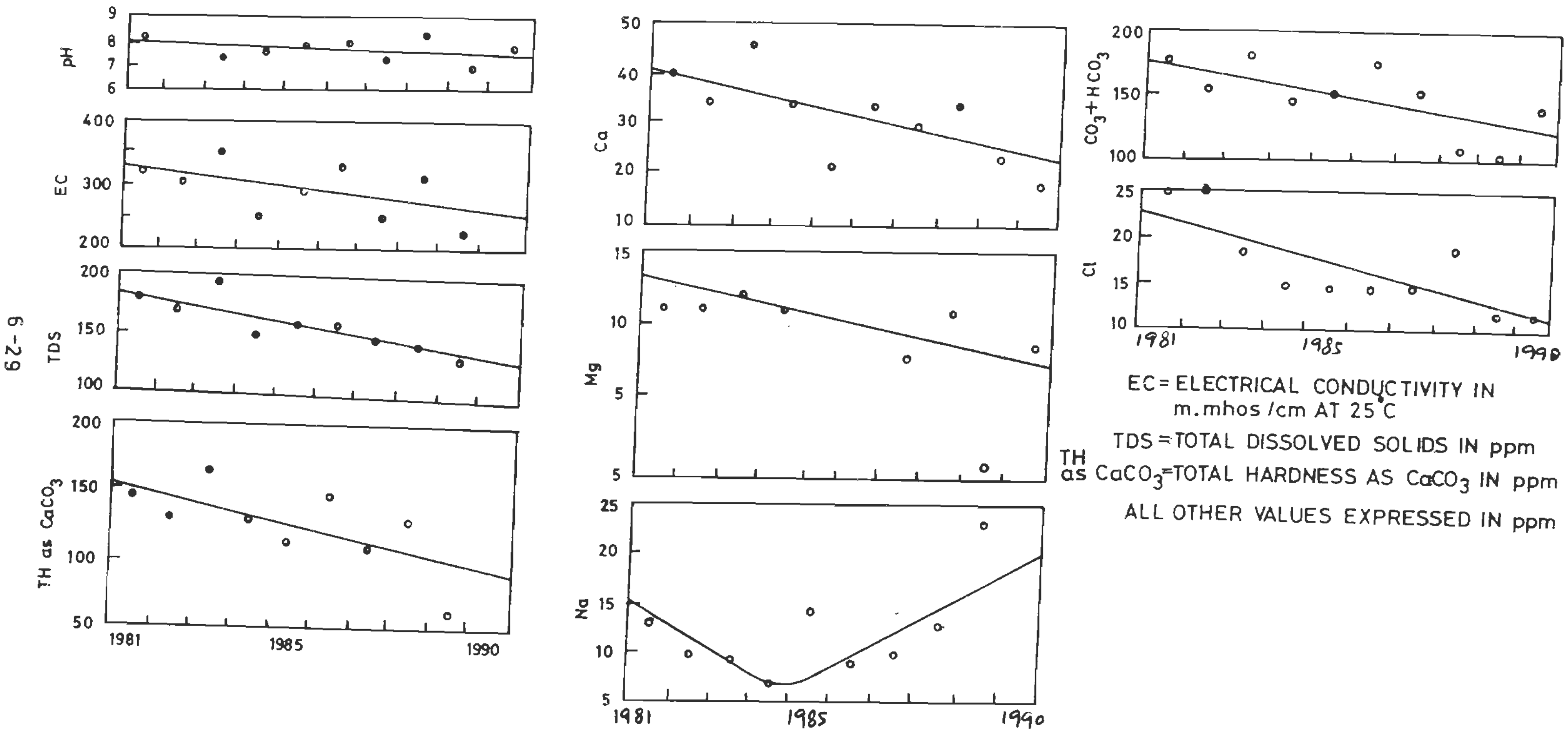


FIG.6·13 - LONG-TERM TRENDS OF ATTRIBUTES OF WATER QUALITY (HYDROGRAPH STATION - PATAN) hydrograph station is rising at a steady rate, the groundwater is not stagnant due to continual inflow of fresh river water inside the well, which dilutes the chemical constituents of the well water. There is also regular flushing of the well water to the Koyna river due to effluent nature of the groundwater and surface-slope conditions. This allows more inflow inside the well. Due to these reasons, there is no quality deterioration in the well water of Patan and the chemical constituents are in a declining trend. Perennial irrigation started in this area in mid-eighties after which the water level started showing drastic rise (Fig. 3.21). The Na-value shows a declining trend upto 1984, after which it shows a rising trend. Thus, the rise of Na may be attributed to the use of Na-rich fertilizers around the well. Na has a regular passage inside the well due to continual irrigation ever since perennial irrigation started in the area in mid-eighties.

6.4 QUALITY OF WATER FOR DOMESTIC USE

The Bureau of Indian Standards (1983) has given standard quality of water for domestic purposes (Table 6.9). As per this standard, the water should be chemically soft and low in dissolved solids.

Comparison of water quality data from various sources of the study area has been made with that of the Bureau of Indian Standards (Table 6.10). In general, the groundwater and surface water in the area are suitable for drinking. However, the groundwater contains high amount of iron. It may be due to the presence of laterites, lateritic soils and redbole beds, all of which are ferruginous by nature. In case of dugwell and borewell, the iron content does not exceed the maximum permissible limit of 1.0 ppm. However, in case of spring water, 10% of the water samples (i.e. 2 out of 19 water samples collected for iron analysis), exceed this limit. 32% of the spring water samples fall within the 'highest desirable' (i.e. 0.3 ppm) and 'maximum permissible' (i.e. 1.0 ppm) limit. Although normal amount of iron is essential for human nutrition, abnormally larger amount adversely effects the human system and results in a condition known as hemochromatosis where in tissues are damaged due to iron accumulation

(Kumar and Dhoolappa, 1991). Apart from this, iron deposition in the skin gives rise to characteristic pigmentation. Although no health problem due to iron has been detected in the area so far, it may ultimately in the long run lead to some adverse health hazard in future. Preventive measures therefore, must be initiated to take care of such an eventuality.

6.5 SUITABILITY OF WATER FOR IRRIGATION

Several chemical constituents affect the suitability of water for irrigation. Some of these are ;

i. The total concentration of soluble salts (which is broadly related to the specific conductance of water).

ii. The relative proportion of sodium to calcium and magnesium.

iii. The relative proportion of bicarbonate to calcium and magnesium.

iv. The concentration of boron.

Whether a particular water may be used without deleterious effects or not, depends also on factors not directly related to water quality, such as nature and composition of water-table, topography, climate, type of crop, etc. (Karanth, 1987). When present beyond certain limits, salts in water applied for irrigation may harm plant growth by toxicity, or by changing soil properties.

Some of the important and commonly used methods to gauge the water quality in terms of its suitability for irrigation, are presented herewith. .

Table 6.9 Standards for Chemical Quality of Drinking Water as prescribed by Bureau of India Standards (1983).

Constituents	Highest Desirable	Maximum Permissiable
pH	6.5 to 8.5	6.5 to 9.2
TDS (ppm)	500	1500
TH as CaCO (ppm)	300	600
Ca (ppm)	75	200
Mg (ppm)	30	100
Chloride (ppm)	250	1000
Sulphate (ppm)	150	Up to 400, if Mg does not exceed 30 ppm.
Nitrate (ppm)	45	No relaxation
Iron (ppm)	0.3	1.0

Table 6.10 Comparison of the quality of water samples with that of prescribes standards

Constituents	%age of water samples falling under 'highest desirable' category				%age of water samples falling between 'highest desirable' and 'maximum permissible' limits			
	Dugwell	Borewell	Springs	Konya River	Dugwell	Borewell	Springs	Konya River
pH	95	92	100	100	4	4	0	0
TDS (ppm)	100	100	100	100	0	0	0	0
TH as $CaCO_3$ (ppm)	100	96	100	100	0	4	0	0
Ca (ppm)	100	92	100	100	0	8	0	0
Cl (ppm)	100	100	100	100	0	0	0	0
SO_4 (ppm)	100	100	100	100	0	0	0	0
NO_3 (ppm)	100	100	100	100	0	0	0	0
Fe (ppm)	83*	-	58**	-	17*	-	32**	-

* out of 12 scattered samples
** out of 19 scattered samples

6.5.1 Wilcox Diagram (1955)

The total dissolved solids content, measured in terms of specific electrical conductance, gives the 'salinity hazard' of irrigation water. Besides the salinity hazard, excessive sodium content in water renders it unsuitable for soils containing exchangeable Ca and Mg ions. If the percentage of Na^+ with respect to $Ca^{++} + Mg^{++} + Na^+ + K^+$ is considerably above 50 in irrigation waters, soils containing exchangeable calcium and magnesium take up sodium in exchange for calcium and magnesium causing deflocculation and impairment of the tilth and permeability of soils. Wilcox (1955) expresses the percent sodium value as given in equation

$$\%Na^+ = \frac{(Na^+ + K^+)\,100}{(Ca^{++} + Mg^{++} + Na^+ + K^+)}$$

where all the constituents are expressed in epm.

Under the above scheme the suitability is judged on measurements of electrical conductivity (expressing total dissolved solids) and sodium content reported as percent sodium. Table 6.11 gives the quality classification of water resources from different sources for irrigation as per Wilcox (1955).

As per Wilcox diagram (1955) based on per cent sodium and electrical conductivity (indicative of TDS), the plot of samples (Figs. 6.14 to 6.17) from various water resources of the area are categorised mainly as excellent for irrigation. In the lower reaches of the Koyna valley, where the area tends towards water logging conditions, the shallow water fall under "permissible to doubtful" category due to poor drainage condition, excessive irrigation and constant use of fertilizers. Comparison of the shallow water and deeper level water in borewells indicate that the former are more suitable for irrigation than the later. The borewell water represents the mixed water from different aquifers.

6.5.2 U.S. Salinity Laboratory Diagram

The United States Salinity Laboratory of the Department of Agriculture (1954) recommends the sodium adsorption ratio (SAR) as a measure to assess the adsorption of sodium by soil. It is defined by

$$SAR = \frac{Na}{[(Ca + Mg)/2]^{1/2}}$$

where the concentration of the constituents are expressed in epm.
Recommended water classifications for SAR are given in Table 6.12. A perusal of Table 6.12 indicate that the water samples fall under "Excellent" category for irrigation.

On the basis of SAR values, the U.S. Salinity Laboratory (1954) has given a diagram for evaluation of the irrigation water. The values of SAR are plotted against electrical conductivity (EC) with EC on logarithmic scale in figures 6.18 to 6.21. Based on the salinity hazard and sodium hazard, the suitability of water for irrigation can be judged.

6.5.3 Residual Sodium Carbonate (RSC)

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by formula (Richards (ed.), 1954) :

$$RSC = (HCO_3^- + CO_3^-) - Ca^{++} + Mg^{++}$$

where the concentrations are expressed in epm.

Table 6.11 Quality Classification of water for Irrigation (after Wilcox, 1955)

Water Class	Percent Sodium	% age of water samples Dugwell	Borewell	Spring	River	ECx10⁶ m.mhos/cm at 25°C	% age of water samples Dugwell	Borewell	Spring	River
Excellent	<20	63	33	76	40	<250	32	38	93	100
Good	20-40	30	38	20	60	250-750	63	58	07	0
Permissible	40-60	04	12	0	0	750-2000	05	04	0	0
Doubtful	60-80	03	17	04	0	2000-3000	0	0	0	0
Unsuitable	>80	0	0	0	0	>3000	0	0	0	0

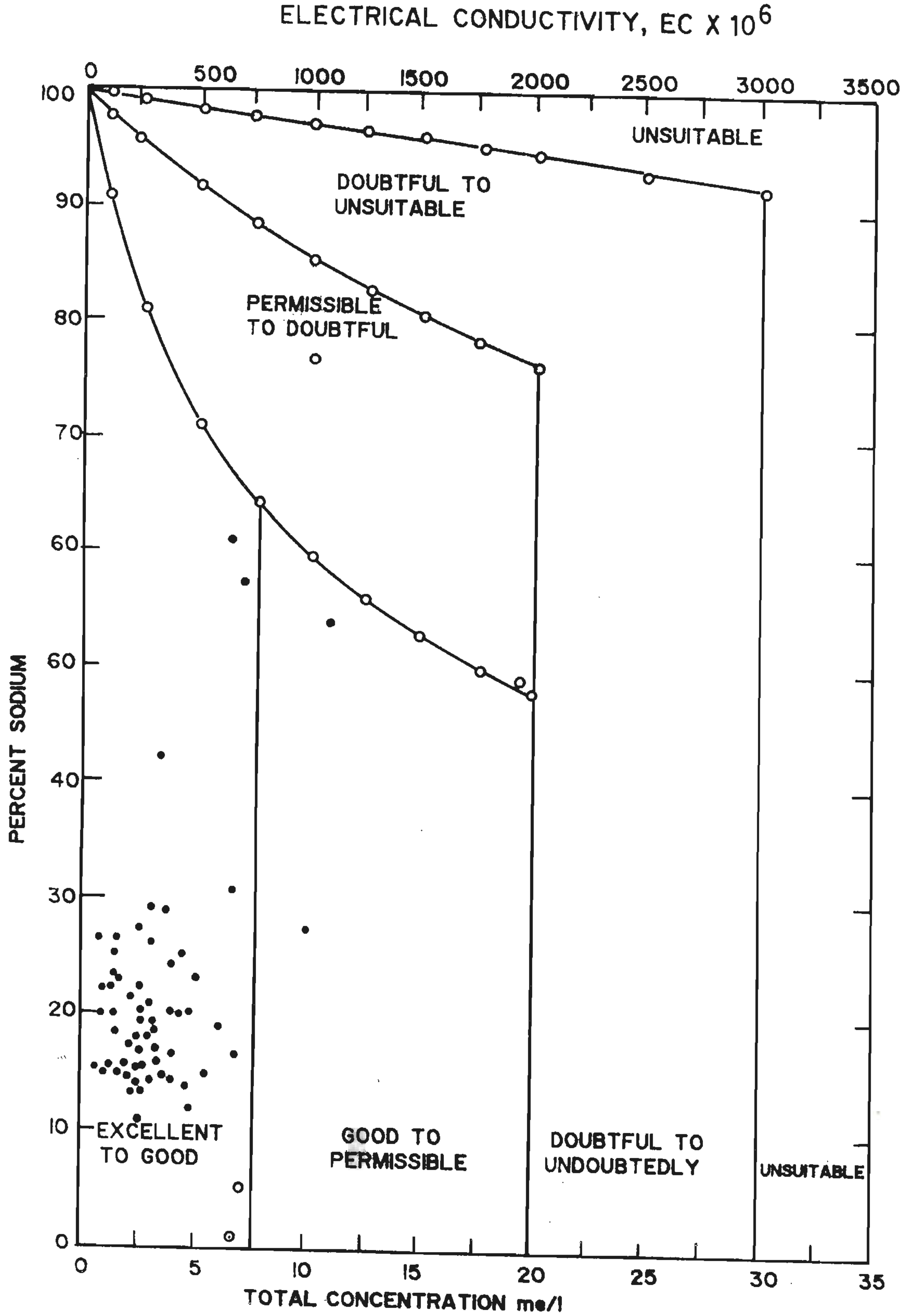


FIG. 6.14 — CLASSIFICATION OF GROUNDWATER (SOURCE-DUGWELLS) BASED ON ELECTRICAL CONDUCTIVITY AND PERCENT SODIUM (AFTER WILCOX 1955)

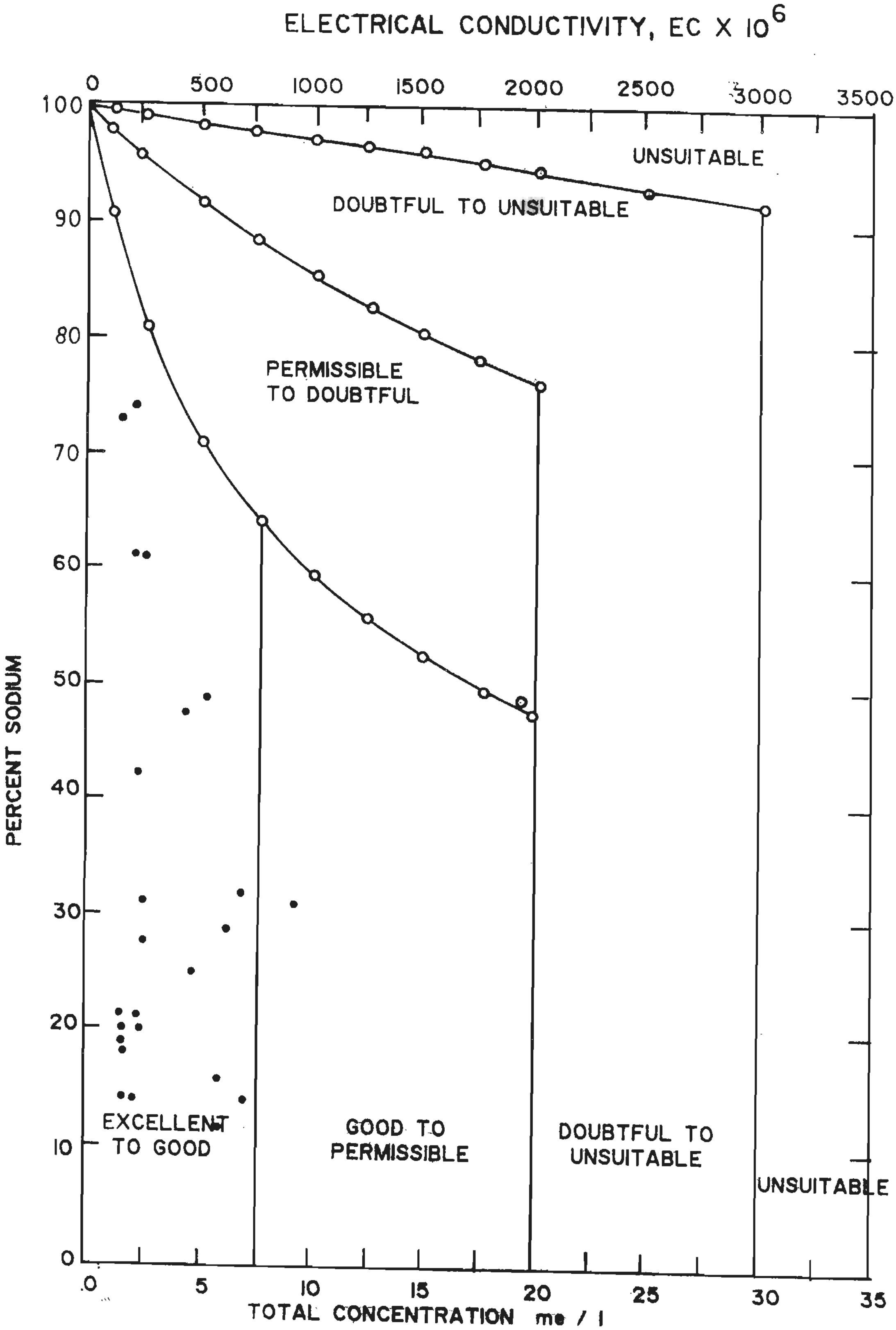


FIG. 6·15 — CLASSIFICATION OF GROUNDWATER (SOURCE-BOREWELLS) BASED ON ELECTRICAL CONDUCTIVITY AND PERCENT SODIUM (AFTER WILCOX 1955)

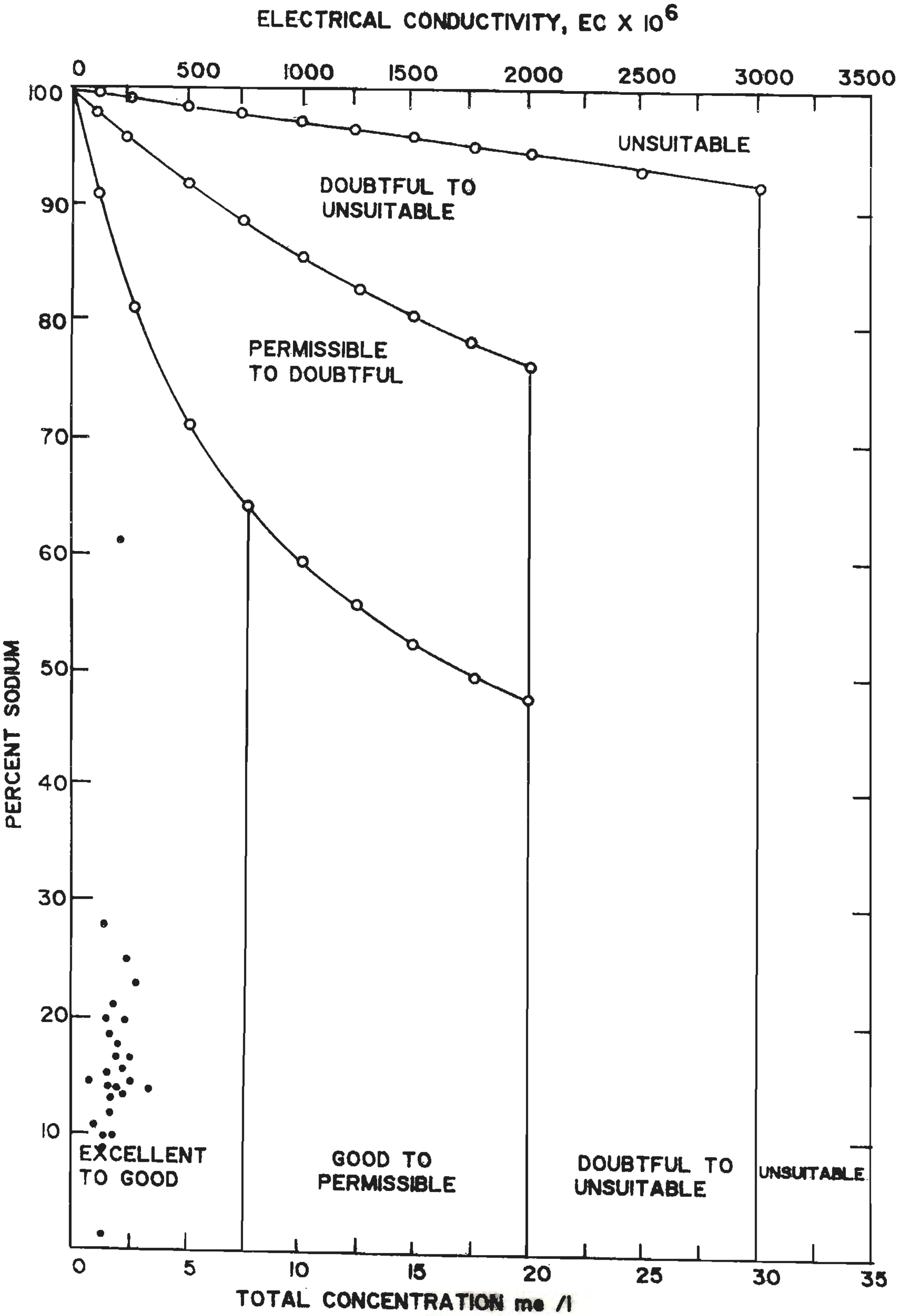


FIG. 6·16 – CLASSIFICATION OF GROUNDWATER (SOURCE-SPRINGS) BASED ON ELECTRICAL CONDUCTIVITY AND PERCENT SODIUM (AFTER WILCOX 1955)

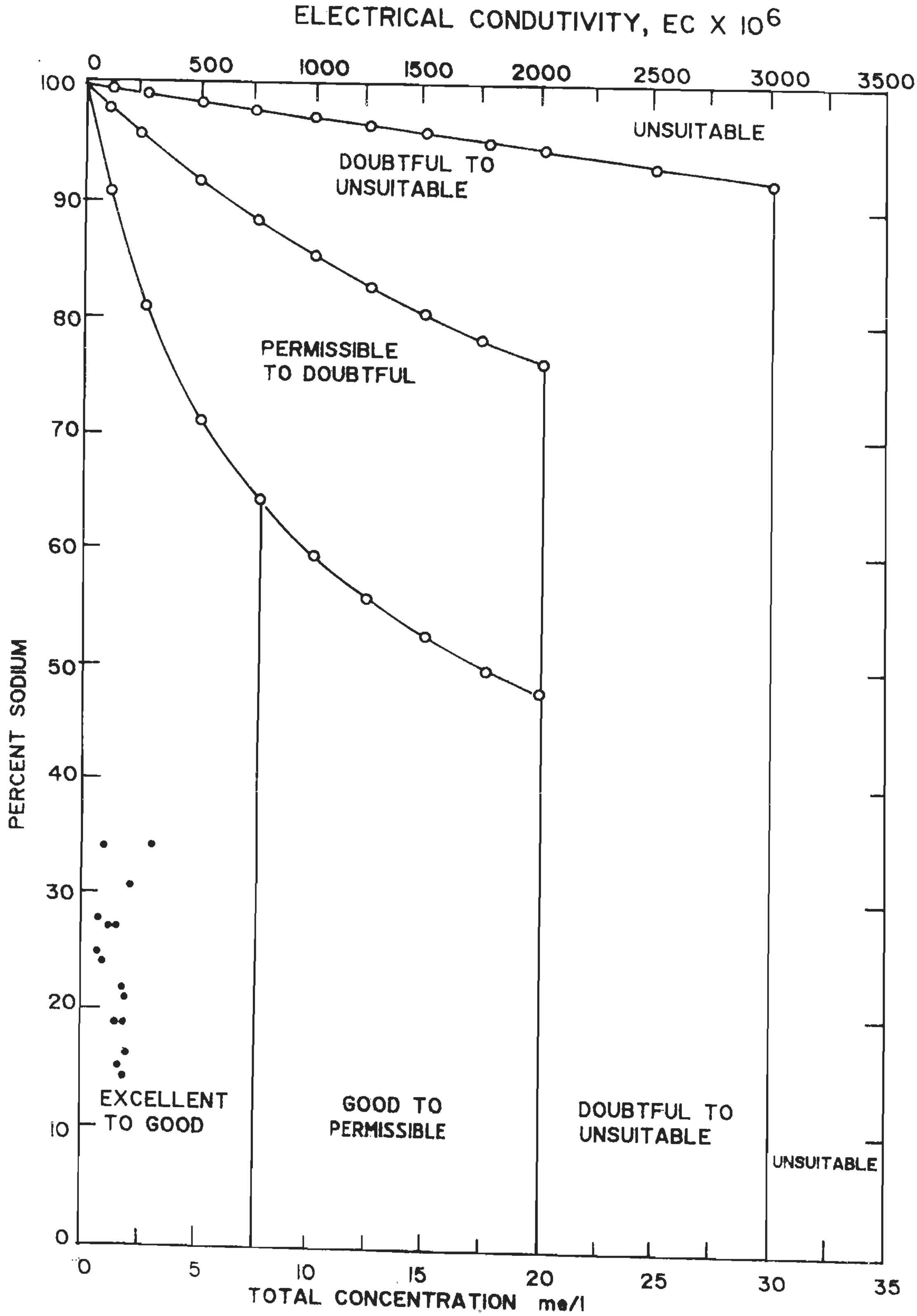


FIG. 6-17—CLASSIFICATION OF SURFACE WATER BASED ON ELECTRICAL CONDUCTIVITY AND PERCENT SODIUM (AFTER WILCOX 1955)

Table 6.12 Quality Calssification of Water based on SAR value

SAR	Water Class	% age of water samples Dugwell	Borewell	Spring	River
< 10	Excellent	100	100	100	100
10-18	Good	0	0	0	0
18-26	Fair	0	0	0	0
> 26	Poor	0	0	0	0

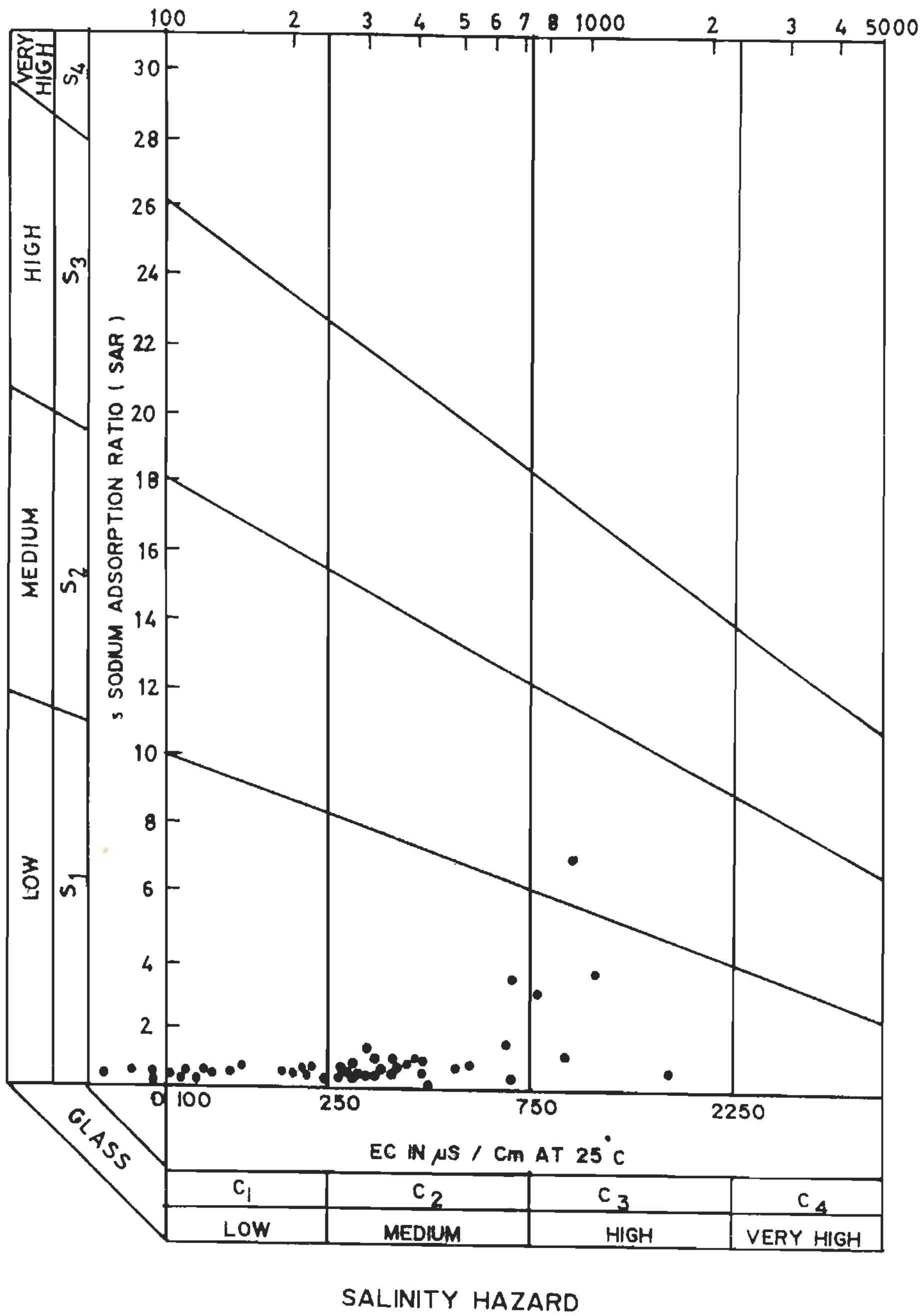


FIG.6·18–PLOT OF S.A.R. Vs E.C. OF THE DUGWELL WATER SAMPLES (AFTER US SALINITY LABORATORY)

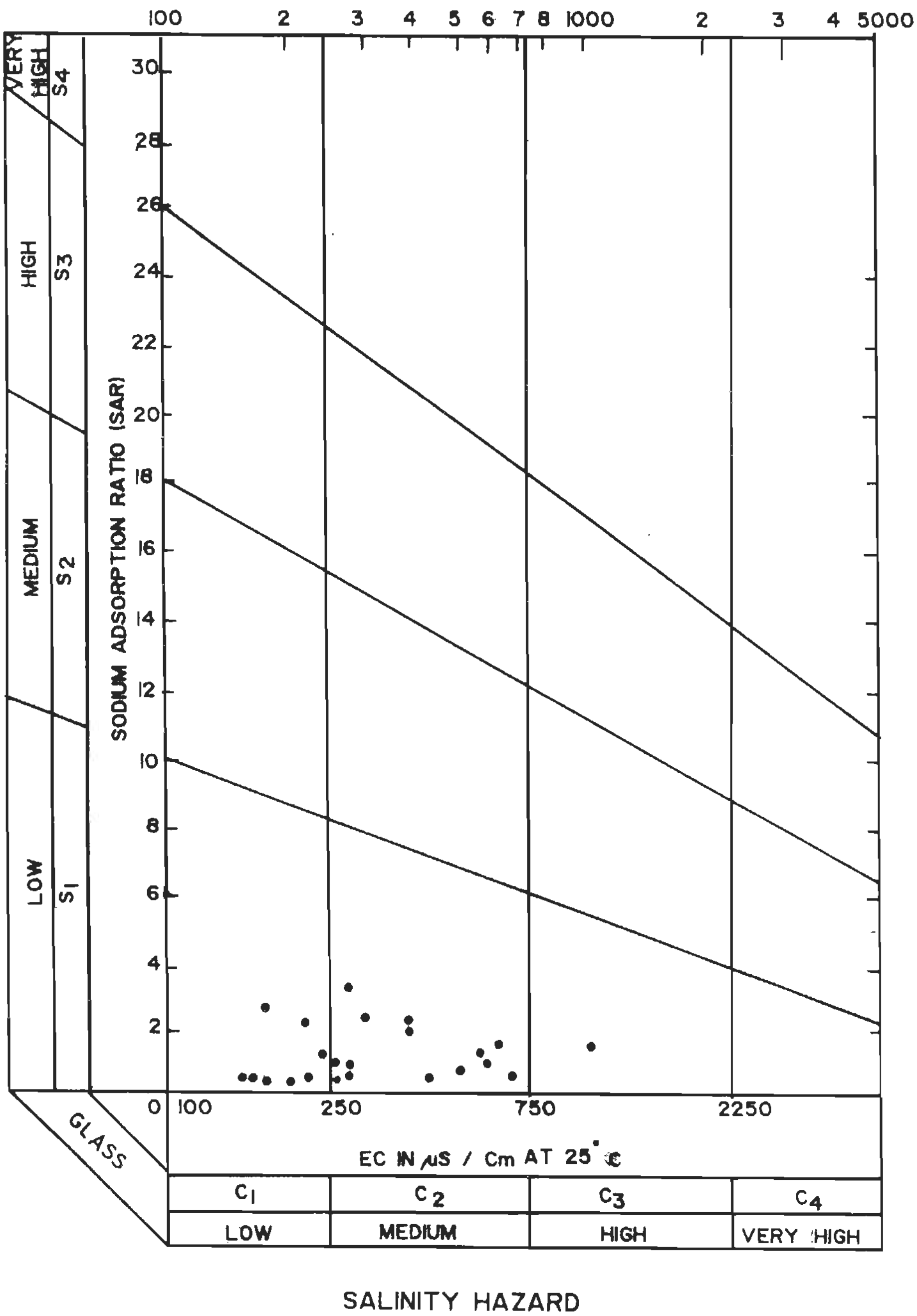


FIG. 6·19–PLOT OF S.A.R. Vs E.C. OF THE BOREWELL WATER SAMPLES (AFTER US SALINITY LABORATORY)

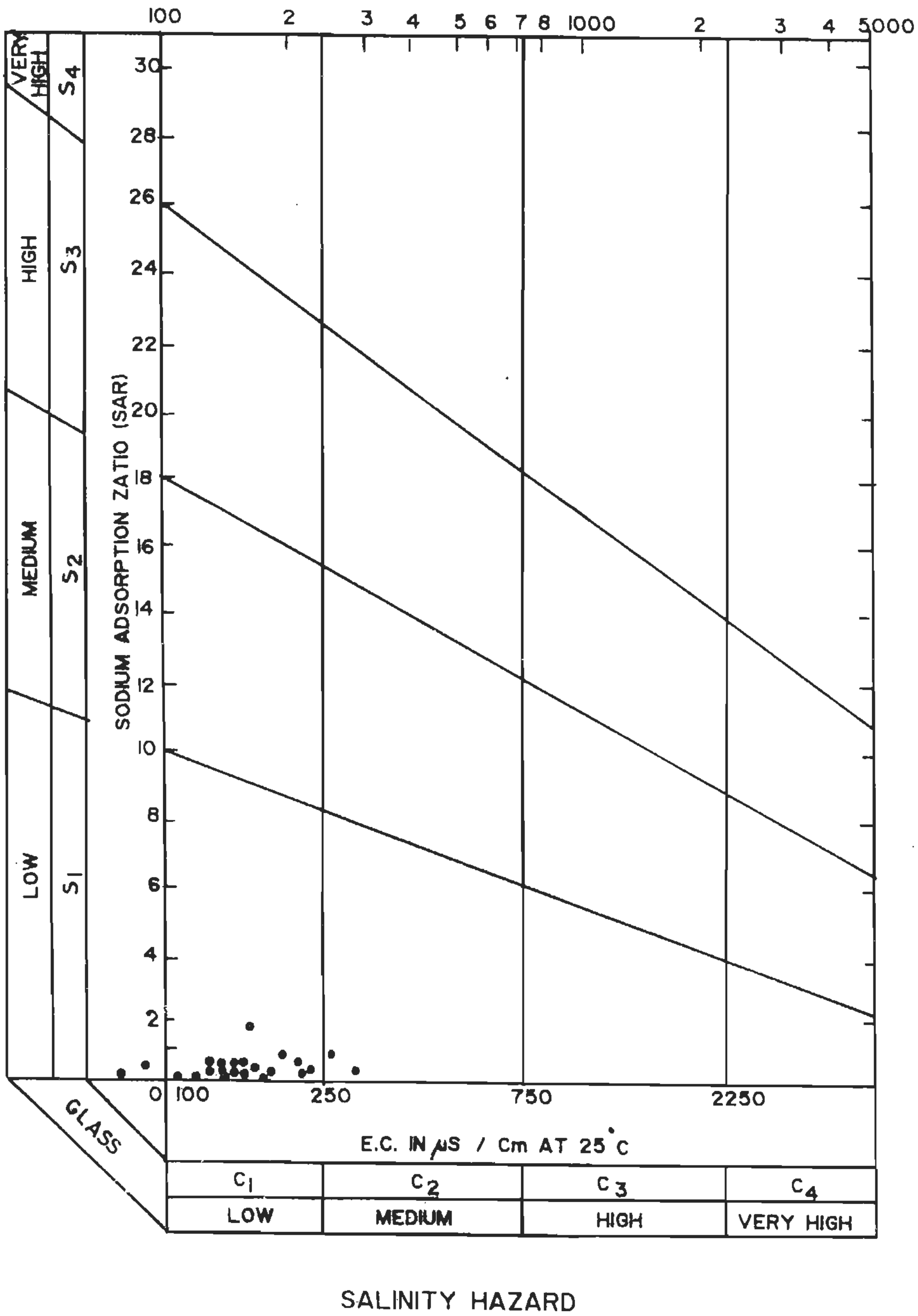


FIG.6·20-PLOT OF S.A.R. Vs E.C. OF THE SPRING WATER SAMPLES (AFTER US SALINITY LABORATORY)

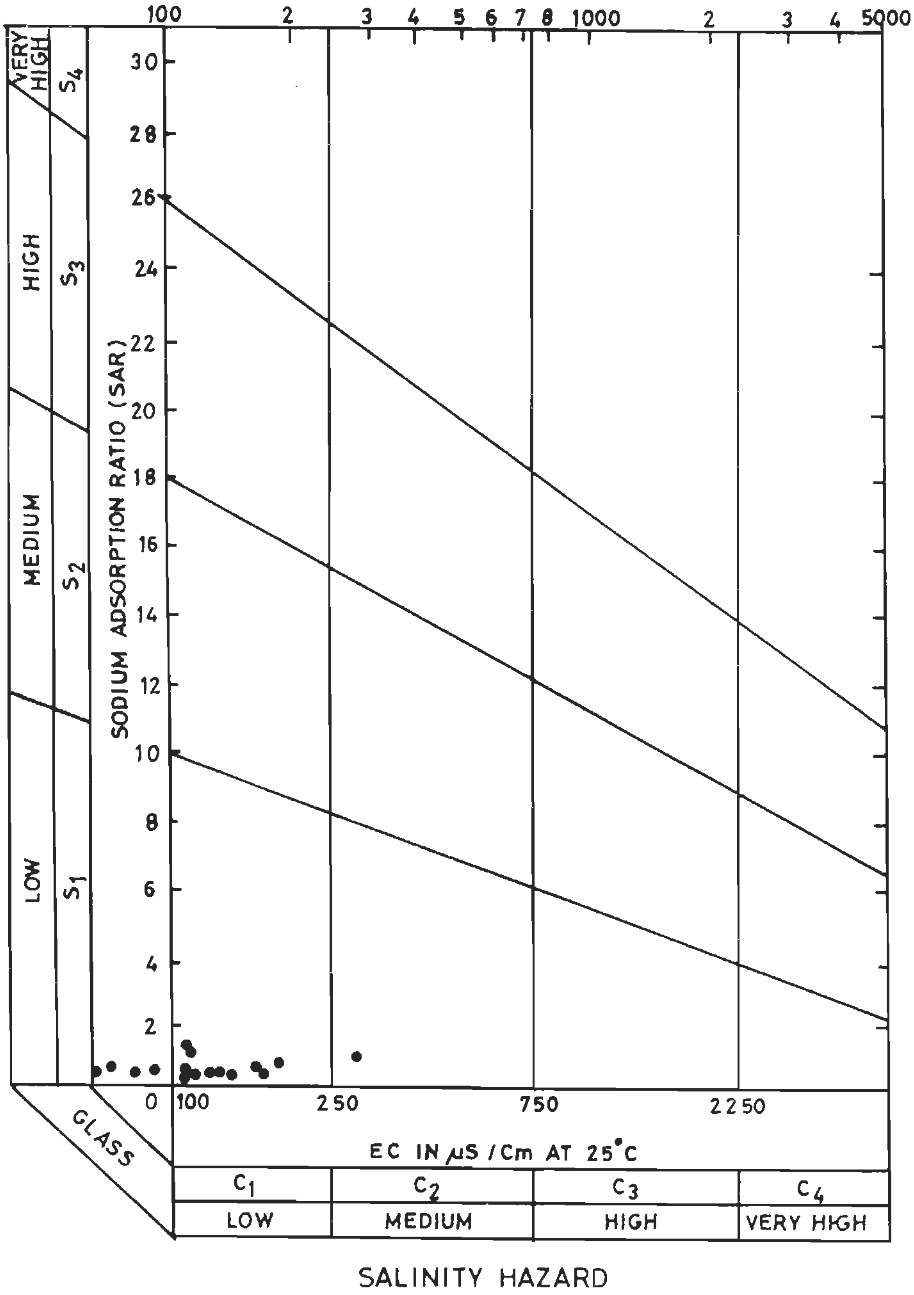


FIG.6·21-PLOT OF S.A.R. Vs E C OF THE RIVER WATER SAMPLES (AFTER US SALINITY LABORATORY)

If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. If the value is between 1.2 and 2.5 epm, the water is of marginal quality, while values less than 1.25 epm indicate that the water is probably safe. Table 6.13 shows the percentage of water samples which lie in various categories.

Table 6.13 shows that 95% of dugwell samples, 83% of borewell samples and all the samples of springs and river fall under the 'safe' category. Only 1% of dugwell water samples and 17% of borewell water samples fall under 'marginal category' while only 4% of dugwell water samples from the lower reaches of the Koyna valley fall under 'unsuitable' category. The lower reaches of the Koyna valley is relatively plain and it has got poor drainage facilities despite over irrigation due to the existing lift-irrigation schemes. Due to these factors alongwith the effect of over use of fertilizers, the shallow groundwater in this area contains high amount of sodium and bicarbonate and carbonate as compared to the alkaline earths and hence the quality deterioration.

A quick comparison of the classification of the individual water samples for their irrigational use by the above three methods of classifications is given in Table 6.14.

The Wilcox diagrams (6.14 to 6.17) and USSL diagram (6.18 to 6.21)[Figures (6.14 to 6.21)] indicate that the dugwell and borewell water in the area have low sodium hazard, but low to medium salinity hazard. In the lower reaches of the Koyna valley where extensive irrigation is practiced, the shallow ground water has high salinity hazard.

Based on the above figures, the water resources, in general, are fit for irrigation. However, for some stretch of land in the lower reaches of the Koyna valley, special management practices for adequate drainage and salinity control are required and plants with good salt tolerance should be chosen in this area for better productivity.

6.6 SUMMARY

With a view to classify the water resources of the Koyna sub-basin and assess their suitability both for drinking and irrigation purposes, 76 samples from dugwells tapping shallow aquifers, 24 from borewells tapping deeper aquifers,29 from cold water springs at higher elevations emerging from different aquifers and 18 from surface water were analysed. Presence of iron in the area was detected with the help of 13 samples from dugwells, 05 samples from borewells, 19 samples from springs and 03 samples from surface water.

The chemical quality of water from aquifers in the basalts indicates that they are rich in Ca^{++}. The concentration of calcium, exceeds that of magnesium. The concentration of Na^{+} is always higher than that of K^{+}. CO_3^{--}, SO_4^{--} and Cl^{-} are very low in concentration. Most of the water samples have simply traces of CO_3^{--} and SO_4^{--}. Spring and river water samples indicate low salinities. The area in general contain high amount of iron. The concentration of iron in spring water is more compared to the other sources. The high iron content in shallow aquifers may be attributed to the laterites at higher elevations, presence of lateritic soils at lower elevations and redbole beds at all elevations.

The Hill-Piper diagram indicate that the waters in general are dominated by alkaline earths (Ca^{++}, Mg^{++}) and weak acids (HCO_3^{-}, CO_3^{--}). The modified Hill-Piper diagram (Romani, 1981) indicate that the waters from shallow aquifers are mostly calcium-bicarbonate type and calcium-magnesium-bicarbonate type. In case of deeper aquifers they are calcium-magnesium-bicarbonate type (29%), sodium-bicarbonate type (24%), calcium-bicarbonate type (19%), calcium-magnesium-sodium-bicarbonate type (19%) and sodium- calcium-bicarbonate type (9%). In the anion triangle in this diagram all the samples plot in bicarbonate field.

Both surface water and groundwater are fit for drinking and domestic purposes as per the criteria prescribed by Bureau of Indian Standards (1983). Based on Wilcox diagram, USSL

Table 6.13 Quality of Water based on RSC

Category	% age of water samples			
	Dugwell	Borewell	Springs	River
Safe	95	83	100	100
Marginal	01	17	0	0
Unsuitable	04	0	0	0

diagram and Residual Sodium Carbonate (RSC), these waters are found fit for irrigation in general, but some deterioration in quality is found especially in the areas in and around Patan in the lower reaches of the Koyna river, due to use of fertilizers and shallow water table (water logging condition). The groundwater in this area shows salinity hazard. For irrigation groundwater from shallow aquifers are more suitable than that of the deeper aquifers.

Table 6.14 Classification of individual water samples for irrigation

Location	EC	Grade	% Sodium	Grade	SAR	Grade	RSC	Grade
Source : Dugwell								
Mahabaleswar	210.0	Good	22.42	Good	0.4	Excellent	-.51	Safe
Old M'Shwar	140.0	Good	9.74	Excellent	0.2	Excellent	-.11	Safe
Taldev	100.0	Good	14.48	Excellent	0.2	Excellent	-.12	Safe
Nayasupane	440.0	Good	24.80	Excellent	0.8	Excellent	-.07	Safe
Manachnagar	120.0	Good	22.93	Good	0.4	Excellent	-.06	Safe
Kadamvadi	60.0	Good	15.30	Excellent	0.2	Excellent	-.08	Safe
Dhankal	80.0	Good	26.82	Excellent	0.4	Excellent	-.02	Safe
Jungti	90.0	Good	19.67	Excellent	0.3	Excellent	-.01	Safe
Ambavne	200.0	Good	15.03	Excellent	0.3	Excellent	-.02	Safe
Sakhre	310.0	Good	14.64	Excellent	0.3	Excellent	0.35	Safe
Mendoshi	250.0	Good	15.89	Excellent	0.4	Excellent	0.02	Safe
Mandure	230.0	Good	26.87	Good	0.5	Excellent	-.05	Safe
Nivkane	170.0	Good	23.30	Good	0.5	Excellent	0.15	Safe
Sasewadi	280.0	Good	14.29	Excellent	0.3	Excellent	-.21	Safe
Mendoshi	320.0	Good	19.29	Excellent	0.5	Excellent	0.03	Safe
Jungti	90.0	Good	15.02	Excellent	0.2	Excellent	-.11	Safe
Ramamala	270.0	Good	21.80	Good	0.4	Excellent	-.06	Safe
Dhansarwadi	200.0	Good	13.57	Excellent	0.3	Excellent	-.87	Safe
Dhansarwadi	280.0	Good	10.92	Excellent	0.3	Excellent	0.01	Safe
Patan	310.0	Good	17.86	Excellent	0.5	Excellent	0.00	Safe
Yerad	240.0	Good	14.69	Excellent	0.3	Excellent	0.08	Safe
Patan	250.0	Good	14.48	Excellent	0.3	Excellent	-.06	Safe
Katavdi	210.0	Good	16.82	Excellent	0.4	Excellent	-.11	Safe
Morgiri	300.0	Good	28.93	Good	0.7	Excellent	-.63	Safe
Bhondri	140.0	Good	19.93	Excellent	0.4	Excellent	0.12	Safe
Bhondri	310.0	Good	20.51	Good	0.5	Excellent	-.10	Safe
Bibi	280.0	Good	19.73	Excellent	0.5	Excellent	0.00	Safe
Kavadevadi	130.0	Good	25.62	Good	0.5	Excellent	0.09	Safe
Yerad	250.0	Good	18.19	Excellent	0.4	Excellent	0.11	Safe
Manevadi	300.0	Good	17.61	Excellent	0.5	Excellent	0.30	Safe

Tamkade	300.0	Good	13.03	Excellent	0.3	Excellent	-.01	Safe
Mendheghar	240.0	Good	14.44	Excellent	0.3	Excellent	-.11	Safe
Kolgevadi	360.0	Good	26.44	Good	0.8	Excellent	0.36	Safe
Mutlavadi	380.0	Good	15.30	Excellent	0.4	Excellent	-.01	Safe
Mhavshi	320.0	Good	13.02	Excellent	0.3	Excellent	0.30	Safe
Adul	280.0	Good	15.27	Excellent	0.4	Excellent	-.09	Safe
Navsare	270.0	Good	18.21	Excellent	0.5	Excellent	-.00	Safe
Marul	110.0	Good	22.18	Good	0.4	Excellent	-.16	Safe
Vadikotavde	230.0	Good	12.68	Excellent	0.3	Excellent	0.12	Safe
Warekarvadi	320.0	Good	16.67	Excellent	0.4	Excellent	0.13	Safe
Pawarvadi	400.0	Good	13.55	Excellent	0.4	Excellent	0.20	Safe
Gokul	320.0	Good	18.68	Excellent	0.5	Excellent	-.18	Safe
Salve	450.0	Good	13.73	Excellent	0.4	Excellent	-.63	Safe
Tamine	100.0	Good	21.76	Good	0.3	Excellent	-.12	Safe
Marli	330.0	Good	42.31	Premissbl	1.2	Excellent	0.78	Safe
Sonavde	270.0	Good	19.75	Excellent	0.5	Excellent	0.34	Safe
Dudusadevadi	335.0	Good	16.10	Excellent	0.5	Excellent	0.18	Safe
Divshi	410.0	Good	22.38	Good	0.7	Excellent	0.59	Safe
Naikba	280.0	Good	15.33	Excellent	0.5	Excellent	-2.00	Safe
Savantvadi	310.0	Good	18.41	Excellent	0.5	Excellent	0.20	Safe
Karle	130.0	Good	24.55	Good	0.4	Excellent	0.02	Safe
Jinti	310.0	Good	18.31	Excellent	0.5	Excellent	0.22	Safe
Dhebevadi	350.0	Good	15.02	Excellent	0.4	Excellent	-.20	Safe
Gudhe	440.0	Good	19.45	Excellent	0.6	Excellent	-.53	Safe
Babuchivadi	320.0	Good	12.96	Excellent	0.3	Excellent	0.10	Safe
Babuchivadi	130.0	Good	25.29	Good	0.4	Excellent	0.12	Safe
Babuchivadi	480.0	Good	20.12	Good	0.7	Excellent	-3.4	Safe
Dhamni	370.0	Good	28.72	Good	0.6	Excellent	-.13	Safe
Kalgaon	480.0	Good	11.86	Excellent	0.4	Excellent	-.46	Safe
Nisre	500.0	Good	32.43	Good	0.0	Excellent	1.75	Safe
Andharwadi	346.0	Good	17.62	Excellent	0.5	Excellent	0.25	Safe
Malharpeth	400.0	Good	24.11	Good	0.8	Excellent	0.22	Safe
Malharpteh	555.0	Good	15.44	Excellent	0.6	Excellent	-.74	Safe
Marul	408.0	Good	20.18	Good	0.6	Excellent	-.03	Safe
Kole	593.0	Good	18.78	Excellent	0.6	Excellent	0.43	Safe
Sidrukvadi	400.0	Good	5.81	Excellent	0.3	Excellent	-8.2	Safe
Sonachivadi	310.0	Good	12.73	Excellent	0.3	Excellent	-.08	Safe
Sonachivadi	300.0	Good	12.98	Excellent	0.3	Excellent	-.13	Safe
Kese	700.0	Good	1.44	Excellent	0.1	Excellent	-.36	Safe

Sakurdi	410.0	Good	16.97	Excellent	0.5	Excellent	-.01	Safe
Yeravle	690.0	Good	60.98	Doubtful	3.6	Excellent	2.64	Safe
Mundhe	768.0	Permiss	56.59	Permissibl	3.2	Excellent	0.50	Safe
Vijaynagar	680.0	Good	30.71	Good	1.4	Excellent	0.49	Safe
Karad	1120.0	Permiss	53.96	Permissibl	3.7	Excellent	3.97	Safe
Kole	1030.0	Permiss	75.69	Permissibl	6.9	Excellent	3.51	Safe
Ving	970.0	Permiss	26.75	Permissibl	1.1	Excellent	-2.9	Safe

Source : Borewell

Khambilchorge	170.0	Good	21.45	Good	0.4	Excellent	-.10	Safe
Vingle	220.0	Good	13.65	Excellent	0.3	Excellent	0.07	Safe
Jinti	540.0	Good	48.56	Permissibl	2.2	Excellent	1.57	Safe
Sakhre	300.0	Good	27.92	Good	0.7	Excellent	0.17	Safe
Mendoshi	230.0	Good	60.84	Doubtful	2.1	Excellent	1.01	Safe
Yerad	280.0	Good	31.09	Good	0.9	Excellent	0.52	Safe
Gojegaon	290.0	Good	19.87	Excellent	0.5	Excellent	0.22	Safe
Rasati	190.0	Good	13.37	Excellent	0.3	Excellent	0.01	Safe
Keral	280.0	Good	73.56	Doubtful	3.3	Excellent	1.24	Safe
Yerphale	570.0	Good	16.27	Excellent	0.5	Excellent	-.18	Safe
Manevadi	450.0	Good	48.43	Permissibl	2.0	Excellent	1.22	Safe
Sadabaghapur	180.0	Good	18.77	Excellent	0.3	Excellent	-.03	Safe
Mestivadi	260.0	Good	20.12	Good	0.5	Excellent	0.00	Safe
Ludugadevadi	300.0	Good	61.05	Doubtful	2.4	Excellent	1.18	Safe
Sanbur	600.0	Good	12.19	Excellent	0.4	Excellent	0.13	Safe
Sonavde	230.0	Good	23.37	Good	0.5	Excellent	0.06	Safe
Pawarvadi	480.0	Good	24.60	Good	0.8	Excellent	0.59	Safe
Babuchivadi	247.0	Good	42.22	Permissibl	1.2	Excellent	0.56	Safe
Dhamni	930.0	Permiss	31.19	Good	1.5	Excellent	1.41	Safe
Urul	700.0	Good	14.30	Excellent	0.6	Excellent	-2.0	Safe
Mhopre	680.0	Good	32.47	Good	1.5	Excellent	1.68	Safe
Nayasupane	620.0	Good	28.96	Good	1.2	Excellent	1.53	Safe
Kumbhargaon	190.0	Good	72.79	Doubtful	2.7	Excellent	1.06	Safe
Marulhaveli	180.0	Good	17.66	Excellent	0.3	Excellent	0.07	Safe

Source : Spring

Old Mahabaleswar	180.0	Good	61.20	Doubtful	1.8	Excellent	0.60	Safe
Chikhli	170.0	Good	10.37	Excellent	0.2	Excellent	-.14	Safe
Taldev	170.0	Good	13.24	Excellent	0.3	Excellent	0.00	Safe
Aral Nivkane	150.0	Good	14.24	Excellent	0.3	Excellent	-.21	Safe
Dhangarvadi	120.0	Good	1.14	Excellent	0.0	Excellent	-.11	Safe
Virwadi	180.0	Good	17.07	Excellent	0.4	Excellent	0.03	Safe
Ghanbi	110.0	Good	8.87	Excellent	0.1	Excellent	-.13	Safe
Payatyacha	170.0	Good	13.47	Excellent	0.3	Excellent	-.09	Safe
Kusavde	320.0	Good	14.06	Excellent	0.4	Excellent	0.12	Safe
Lendori	160.0	Good	10.45	Excellent	0.2	Excellent	-.20	Safe
Malevadi	150.0	Good	20.35	Good	0.4	Excellent	-.09	Safe
Bhodri	150.0	Good	15.13	Excellent	0.3	Excellent	-.10	Safe
Jhakde	200.0	Good	16.03	Excellent	0.3	Excellent	0.04	Safe
Jaichevadi	140.0	Good	11.87	Excellent	0.2	Excellent	-.19	Safe
Chiteghar	160.0	Good	18.66	Excellent	0.4	Excellent	0.07	Safe
KKatavdewadi	90.0	Good	11.15	Excellent	0.2	Excellent	-.29	Safe
Kalkevadi	190.0	Good	13.92	Excellent	0.2	Excellent	-.15	Safe
Kodal	230.0	Good	15.27	Excellent	0.3	Excellent	0.03	Safe
Natoshi	240.0	Good	16.63	Excellent	0.4	Excellent	0.29	Safe
Amragi	100.0	Good	23.18	Good	0.4	Excellent	0.04	Safe
Gokul	190.0	Good	10.50	Excellent	0.2	Excellent	0.01	Safe
Kusrund	240.0	Good	17.93	Excellent	0.4	Excellent	-.03	Safe
Kokisre	180.0	Good	18.42	Excellent	0.4	Excellent	0.05	Safe
Kolekarvadi	220.0	Good	19.69	Excellent	0.4	Excellent	0.17	Safe
Varpevadi	160.0	Good	20.73	Good	0.4	Excellent	-.07	Safe
Natoshi	140.0	Good	28.36	Good	0.4	Excellent	0.07	Safe
Chugulevadi	210.0	Good	25.36	Good	0.6	Excellent	0.23	Safe
Chugulevadi	260.0	Good	23.53	Good	0.6	Excellent	0.18	Safe
Paneri	70.0	Good	14.65	Excellent	0.2	Excellent	-.07	Safe

Source : River

Tapole	90.0	Good	33.75	Good	0.6	Excellent	0.01	Safe
Koyna Dam	50.0	Good	28.22	Good	0.3	Excellent	-.10	Safe
Koyna Dam	200.0	Good	30.68	Good	0.7	Excellent	-.31	Safe
Koyna Dam	80.0	Good	24.10	Good	0.3	Excellent	-.12	Safe
Koyna Dam	50.0	Good	28.22	Good	0.3	Excellent	-.10	Safe

Koyna Dam	50.0	Good	24.74	Good	0.3	Excellent	-.10	Safe
Koyna Dam	60.0	Good	23.90	Good	0.3	Excellent	-.10	Safe
Vanzole	110.0	Good	27.31	Good	0.5	Excellent	-.01	Safe
Patan	140.0	Good	21.53	Good	0.4	Excellent	-.11	Safe
Sangvad	120.0	Good	19.13	Excellent	0.3	Excellent	-.30	Safe
Malharpeth	300.0	Good	54.21	Good	1.0	Excellent	0.73	Safe
Nisre	110.0	Good	18 99	Excellent	0.3	Excellent	-.03	Safe
Kese	150.0	Good	14.38	Excellent	0.3	Excellent	-.20	Safe
Karad 1	190.0	Good	16.22	Excellent	0.3	Excellent	-.03	Safe
Karad 2	180.0	Good	21.39	Good	0.5	Excellent	-.05	Safe
Karad 3	140.0	Good	18.63	Excellent	0.3	Excellent	-.10	Safe
Karad 4	150.0	Good	14.96	Excellent	0.3	Excellent	-.11	Safe
Karad 5	140.0	Good	16.15	Excellent	0.3	Excellent	0.00	Safe

Chapter 7

Assessment Of Groundwater Resource Potential

7.1 BACKGROUND

Groundwater resource assessment is one of the most important prerequisites for planned development of an area. The optimum amount of groundwater that can be developed in a region should not exceed the amount of recharge that takes place to the groundwater body. Therefore, estimation of the recharge component of the groundwater regime for planning groundwater development programmes forms the cardinal need in any hydrogeological study.

With the construction of Koyna Dam at Koynanagar in the year 1961, the Koyna sub-basin has been divided into two parts - the northern part and the southern part. The hills in continuity along the axis of the dam form water divide for the areas lying upstream in the north and downstream in the south of the Koyna dam respectively (Fig. 4.9). Thus, there is little natural surface water transfer between these two areas due to damming of surface water from upper reaches at Koynanagar. The flow of surface water from the Koyna dam to the downstream areas is monitored artificially by the river-gauging station at Koynanagar. Thus, these two areas form two distinct water-sheds in the Koyna sub-basin. Hereafter, the part of the sub-basin upstream of the Koyna dam in the north is named as Area I and the part downstream of the dam in the south is called Area II (Fig.4.9).

7.1.1 Area - 1

Area I covers the entire catchment area of the Koyna dam and is mostly hilly. It has an areal extent of 954.20 sq.km. Rainfall in this part is of the order of 5300 mm annually. People in this area depend mostly on springs. The spring discharges in this area is estimated to be 8 MCM annually. At many places natural springs have been converted into dugwells by the construction of shallow circular pits around them. Dugwells tapping groundwater are only rarely found. This area has been divided into the following three different zones (Fig. 4.9) :

(i) spring recharge zone of 400.80 sq.km, which consists of flat-topped plateaus and sprawling hills with terraces formed at different elevation,

(ii) dissected plateau of 438.05 sq.km which includes steeper slopes and

(iii) water spread zone of Koyna dam covering an area of 115.35 sq.km.

7.1.2 Area - II

The Area II covers an area of 1081.80 sq.km. downstream of the Koyna dam. It has a broad valley with west-east extension. Area II has also been divided into the following three zones :

(i) Spring recharge zone, covering 321.50 sq. km which consists mostly of flat topped and sprawling hills,

(ii) Steeply sloping zone covering 184.60 sq.km not suitable for groundwater recharge,

(iii) Relatively plain zone, which covers 575.70 sq.km. and exhibits local undulations.

The last zone forms what is known as the central valley. Groundwater development through dugwells and borewells is confined to this zone only. The springs are utilised at higher elevations and foothill zones. Taking into consideration the importance of groundwater in this area, detailed assessment of the groundwater resource potential of only this part of the Koyna sub-basin has been attempted in the following portions.

7.2 ASSESSMENT OF GROUNDWATER RECHARGE

7.2.1 Methods of Assessment

Recharge to the groundwater in the area mainly occurs as vertical percolation of rainwater and return flow of water applied for irrigation. Some recharge also takes place through induced infiltration from surface water tanks. Recharge due to sub-surface inflow from the adjoining sub- basins to the area has been considered negligible.

There are a number of methods for estimation of the groundwater recharge. These include Darcy's equation, analysis of baseflow hydrograph, hydrologic budgeting, tracer techniques, groundwater modelling, analysis of groundwater level fluctuation etc. Choice of any of these methods depends on the field constraints and availability of field data. Most of the parameters involved in the above methods were difficult to obtain accurately in this poorly studied sub-basin. Therefore, a simple method based on water level fluctuation and consumptive use has been followed using the following basic equations.

$$G_r = A_e \times WL_r \times S_y \;...\; (1)$$

where, G_r = Groundwater Recharge

A_e = Effective area for groundwater recharge

WL_r = Average water level rise during the period of

recharge

and S_y = Average regional specific yield

The monsoons in the rainy season forms the major rains in the area and are therefore, the major source of recharge as compared to little winter rains.

The recharge due to return flow of water applied for irrigation and induced infiltration from the surface water tanks have been estimated based on the recommendation given by Groundwater Estimation Committee, Govt. of India (1984).

Various parameters involved for estimating groundwater recharge by water level fluctuation method are the effective area for groundwater recharge, groundwater discharge (both artificial and natural), average regional specific yield and rise in water table during the period of recharge (in this case monsoon only). The effective area for groundwater recharge, after eliminating the area due to steep slopes, has been estimated to be 897.2 sq km for the area under study of the Koyna sub-basin. The average rise in water table has been estimated based on the representative wells distributed throughout the area.

7.2.2 Groundwater Discharge

7.2.2.1 Artificial Groundwater Discharge

Groundwater is withdrawn with the help of large- diameter wells or dug-wells tapping shallow aquifers and borewells tapping relatively deeper aquifers. In the areas adjoining river courses, groundwater in the form of base flow is withdrawn mostly for irrigation purposes. The total artificial groundwater withdrawal for domestic and irrigation use is discussed herewith.

(i) Groundwater for Domestic/Stock Needs

With the help of the census data (1991), the total human and stock population which depend on groundwater in the area is found to be about 2,00,000 and 85,700 respectively. Govt. of India recommends consumption of about 40 litres per day (or 14.6 m^3/year) per person in the rural areas where house service connections are not contemplated and the supply is through borewell/dugwell (CGWB, 1984). Similarly, Dhawan (1975) has recommended consumption of about 50 litres per day (or 18.25 m^3/day) per animal. Thus, total yearly consumption of groundwater in the area becomes 2.92 MCM by human population and 1.56 MCM by stock population bringing to a total consumption of about 4.48 MCM annually.

(ii) Groundwater for Irrigation Use

Groundwater is abstracted for irrigation purposes during the dry seasons from dugwells and by direct pumping of base flow from the river using mobile pump sets. A variety of pump devices are used to abstract water. Diesel driven centrifugal pumps of 5 H.P. are used in the remote areas while in the area having good infrastructure for electricity, 3 H.P. to 5 H.P. electricity driven centrifugal pumps are used. The average discharge of these pump sets has been taken to be 30 m^3/hour in this study area on the basis of well inventory and pumping test data.

(a) Irrigation by Groundwater from Wells

The statistical data regarding the number of irrigation wells, cropping pattern, area under different crops were collected from local authorities. Detailed survey of wells and pumping tests, type of water lifting devices, pumping hours in a day and then in a month and whole year, the rate of pump discharges, etc., was done to assess the amount of ground water withdrawn from the wells for irrigation purposes. Based on these statistics the amount of groundwater used for irrigation is estimated to be 10.40 MCM per year (Table 7.1).A perusal of Tables 7.1 indicates that groundwater is mostly abstracted during winter months (Oct./Nov.
to Feb.). It is of the order 8.40 MCM i.e. more than 80% of the total water used for irrigation through wells.

(b) Use of baseflow for Irrigation

Many farmers whose fields are adjacent to the rivers and tributaries, pump water directly from the river in dry season, mostly from the beginning of November. After October, there is generally no rainfall in the area. Therefore the contribution to the river flow is mostly from the ground water, which represents baseflow. Unauthorised lifting of water from Koyna river is prohibited. Water from this river is extracted only through lift irrigation schemes on co-operative basis.

Except the river Koyna, all other tributaries are ephemeral and dry up by the middle of March. Hence, the base flow from these tributaries sustain only the winter crops (rabi crops). On the basis of data collected, the river water is withdrawn by about 500 pump sets, which run for about 8 hours in a day at an average rate of 30 m^3/hour for about 60 days in a year on an average. Thus, the total yearly consumption of baseflow is estimated to be 7.20 MCM.

(iii) Total Amount of Groundwater in Use

The total amount of groundwater in use for domestic and stock needs, irrigation by wells and by direct pumping of baseflow is given below :

(a) Domestic/stock	4.48 MCM
(b) Irrigation from wells	10.40 MCM
(c) Irrigation from Baseflow	7.20 MCM
Total	22.08 MCM

The above figures indicate that about 70% of the total groundwater in use is through wells mostly the dugwells and the rest 30% is extracted by direct pumping from river during dry season.

7.2.2.2 Natural Groundwater Discharge

The major sources of natural ground water discharges are : (i) Base flow, (ii) Evapotranspirational losses, (iii) Spring discharges, (iv) Sub-surface outflow and (v) Leakage from shallow aquifers to deeper aquifers.

TABLE 7.1 GROUNDWATER DRAFT BY IRRIGATION WELLS

NOTE- The estimate is based on 300 dugwells in the command area of the koyna lift irrigation schemes and 450 dugwells in the non-command areas. The average yield per well has been considered to be 30 m^3/day based on field observations.

Season	Pumping hours per day		Pumping days		Yearly draft (MCM)		Total Yearly draft (MCM)
	Command	Non-command	Command	Non-command	Command	Non-command	
Winter (October/ November to February)	8	5	60	60	4.32	4.05	8.37
Summer (March to May)	5	Nil	45	Nil	2.03	Negligible	2.03

The estimate of discharge in each above case is given as follows :

(i) Estimation of Baseflow

As discussed in Chapter 1, there are two river gauging stations in the area-one situated near the Koyna dam at Koynanagar and another at Warunji before the Koyna meets the river Krishna in the East. While the station at Koynanagar measures the released water from the Koyna dam, the one at Warunji measures the run-off of the area downstream of the Koyna dam (Area II) including the released water from the dam.

As mentioned earlier, upto month of October the Koyna river catchment has some surface run-off. But from November onwards the flow in the river is due to contribution from groundwater and represent baseflow. Here, if the monthly river discharge at Warunji is deducted from that of the Koynanagar, it gives an estimate of the baseflow found in the Koyna river and its tributaries. But there are months in which the discharge at Warunji is less than that of the koynanagar (Tables 7.4 & 7.5). This indicates that water is lost on the way. This is, in fact, due to large scale abstraction of water from the Koyna river for irrigation by the lift irrigation schemes. Therefore, it is felt necessary to estimate the monthly quantum of water being withdrawn from the Koyna river. This has been achieved with the help of the water requirement of crops in the command areas of the lift irrigation schemes (Table 7.2). With the help of Table 7.2, estimate of the monthly water requirements of crops has also been made (Table 7.3). It is found that a quantum of 61 MCM of water in total is extracted from the Koyna river after the month of October. Now, if the monthly abstraction of water is deducted individually from the monthly Koynanagar discharge and the value obtained is deducted again from the Warunji discharge of baseflow found in the river is obtained. In other way, if the monthly discharge of Warunji is deducted from that of the Koynanagar and the value obtained is added to the monthly abstraction of water, it also gives an idea of the baseflow found in the river. The above procedure has got one limitation. After doing all monthly calculation as stated above, in some months it is found that the baseflow gives a negative value, showing loss of water in the river between the two end points. For example, in the year 1992-93 (Table 7.5), the baseflow for the month of March is-1.77, i.e. [111.77-(119.21 - 5.67) MCM = -1.77 MCM], thus indicating that there is a loss of about 2 MCM of water in the river which is very unusual though possible. Such cases in some months may be happening because the total water requirement in a season has been distributed equally among the concerned months depending on the crops and their growing periods. In some months the interval of watering may be two and in some months three, thus bringing a discrepancy of water requirement in a particular month. Due to this complication in some months very high value of baseflow may also be obtained. Therefore, to simplify the procedure and avoid the monthly calculations which sometimes brings erroneous results, the monthly total of the discharges at Koynanagar (A) from the month of November to May has been deducted from the water applied for irrigation or abstracted from Koyna river (C) for these months and the resulting figure is again deducted from the monthly total of discharge at Warunji (B) for the said months (Table 7.4, Table 7.5).

Thus this approach gives a fairly better estimate of baseflow. Using this procedure, the baseflow for the years 1988-89 and 1992-93 in the Koyna river is estimated to be 43 MCM and 37 MCM respectively. Communication with the officials of the Command Area Development Agency, Govt. of Maharasthra at Karad reveal that at least 25% of the water lifted from the Koyna river flows back to the river again through a number small streams. This happens because the farmers generally use flooding method for irrigation and apply as much water as possible in their lands due to easy availability of the surface water. Sometimes the farmers have to wait for longer time for their turn for irrigation. Accordingly, when their turn comes they apply as much water as possible. Many times the lift irrigation schemes run at night also and during this time there is no control as such for irrigation of land. These are all the common practices generally found in the Koyna Command Area. Therefore, it is quite reasonable to consider only 75% of the baseflow estimated earlier on the actual baseflow contributed by the groundwater system. Thus, the estimated baseflow becomes about 32 MCM for the year 1988-89 and 28 MCM for the year 1992-93. This is the amount of baseflow that is unutilised and flow as waste in the Koyna river.

It has been estimated earlier that 7.20 MCM of baseflow is lifted for irrigation from the tributary of the Koyna river. Thus, the total baseflow is estimated to be 39 MCM for the 1988-89 and 35 MCM for the year 1992-93. The average baseflow can, therefore, be taken as

TABLE 7.2 WATER REQUIREMENT OF CROPS IN COMMAND AREA OF THE KOYNA LIFT-IRRIGATION SCHEMES.

Season	Name of Crops	Area Irrigated (ha)	Interval of Irrigation* (days)	No. of watering*	Depth of watering* (cm)	Volume of water required* (hacm)	(MCM)
Kharif (90 days: July to September)	Sugarcane	1091	12	4	7.5	32730	3.27
	Jawar (Sorghum) (1st July-31st Oct.)	6181	30	2	7.5	92715	9.27
Rabi (150 days: October to February)	Sugarcane	1091	12	12	9.0	117828	11.78
	Wheat (Hybrid Variety) (16th Nov -15March)	1854	12	10	7.5	139050	13.90
	Hybrid Jawar (Sorghum) (1st Oct. -28 Feb)	4327	15	10	7.5	324525	32.45
Hot Weather (120 days: March to June)	Sugarcane	1091	10	12	12.0	157104	15.71
Total							86.38

* Data collected from BALMI, Aurangabad, 1989.

TABLE 7.3 MONTHLY WATER REQUIREMENTS OF CROPS DURING RABI AND HOT WEATHER SEASON

Crop	OCt.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May.	June	Total
Sugarcane (Perennial)	2.36	2.36	2.36	2.36	2.36	3.93	3.93	3.93	3.93	27.52
Wheat (hybrid variety (Mid-November to Mid-march)	-	1.74	3.47	3.47	3.47	1.74	-	-	-	13.89
Hybrid Jowar (Sorghum) (Oct-Feb) end	6.49	6.49	6.49	6.49	6.49	-	-	-	-	32.45
Total (MCM)	8.85	10.59	12.32	12.32	12.32	5.67	3.93	3.93	3.93	

The total water requirement from November to March is estimated to be 61.08 or 61 MCM.

TABLE 7.4 ESTIMATION OF BASEFLOW FOR AREA II (1988-89).

Month	River Discharges at Koynagar (A) (MCM)	River Discharges at Warunji (B) (MCM)	Water applied for irrigation(C) (MCM)	Runoff or Baseflow (MCM)
November,	85.80	59.62		B-(A-C)
December	129.31	111.66		= 863.50-(881.07-61.08)
January	163.32	169.67		
February	172.39	171.64	61.08 November to May	= 863.50-819.99
March	172.42	184.06		= 43.51 = 43
April	94.56	91.29		
May	63.27	75.56		Less 25% = 32 MCM
	881.07	863.50	61.08	

TABLE 7.5 ESTIMATION OF BASEFLOW FOR AREA II (1992-93)

Month	River Discharges at Koynanagar (A)	River Discharges at Warunjz (B)	Water applied for irrigation (C)	Run-off or Base flow (MCM)
November	80.20	85.54		B-(A-C)
December	62.18	61.20		= 585.49-(609.67-61.08
January	61.38	57.02	61.08	
February	102.59	98.16	(November to May)	= 585.49-548.59
March	119.21	111.77		= 36.9 or 37
April	84.29	72.89		
May	99.82	98.91		Less 25% = 28 MCM
	609.67	585.49	61.08	

37 MCM annually for the Koyna river and its tributaries downstream of the Koyna dam. Such a high amount of baseflow from such a small area (1082 sq.km) may be attributed to the large quantity of surface water (61 MCM) that is lifted from the Koyna river and applied for irrigation.

(ii) Estimation of Evapotranspiration from Groundwater

Aquifers with water table near ground surface frequently exhibit diurnal fluctuations which can be ascribed to evaporation and/or transpiration. Both processes cause a discharge of groundwater into the atmosphere and have nearly the same diurnal variation as both are related with temperature variations.

Evaporation from groundwater is negligible unless the water table is near the ground surface. Evaporation rates depend upon the position of the capillary zone relative to ground surface. Measurements of groundwater evaporation in tanks filled with soils ranging from clays to loams were made by White (1932) and results are presented in Fig. 7.1, which indicates that evaporation is comparatively high for water tables less than 0.3m bgl. It is low for water tables upto about 1 m bgl and further it decreases and becomes almost negligible for water tables below 3.5 m bgl.

It is observed from the water level data of the hydrograph stations established by GSDA and CGWB in the Koyna sub-basin that the average water level during the period November to June is generally below 3.5 mbgl and as such during this period the evapotranspiration from the groundwater is negligible. However, during the monsoon period (July to October) when the water table is high evapotranspiration from the groundwater occurs. Based on the average water level during a particular month, the approximate rate of evapotranspiration from groundwater was taken from Fig. 7.1 and from the values of Pan evaporation for that particular month (recorded at Koynanagar by CWC), the actual evapotranspiration from groundwater during that month was estimated and given in Table 7.6. It indicates that the ground water evapotranspiration takes place in the study area only during monsoon period when water table is high and during the rest of the period groundwater evapotranspiration is negligible. The evapotranspiration is estimated to be 2.54 MCM for 1988, 4.49 for 1991, 4.05 MCM for 1992. It, thus, averages around 3.69 MCM.

(iii) Estimation of Annual Discharges by Natural Springs

It has already been estimated earlier (Chapter 4) that 14 MCM is the total annual discharge of the springs in the koyna sub-basin.

Generally, spring discharges are proportional to the recharge areas and thus the discharges could be separated for Area I, upstream of Koyna dam and Area II, downstream of Koyna dam. Area I has a spring recharge area of 400 sq km while Area II has a recharge area of 322 sq km. Thus, the 14 MCM spring water is divided in proportion in both the areas, Spring discharges for Area 1 is found to be 8 MCM while for Area II, it is 6 M CM. Since the evaluation of groundwater resources is done for Area II only, the approximate season wise distribution of spring discharges in this area is as follows :

Rainy season	-	3 MCM
Winter season	-	2 MCM
Summer season	-	1 MCM

It may be stated here that the above estimation of discharges do not include the combined spring discharges of a chain of springs which eventually form a stream and contribute to the river flow. If the combined discharge of such cluster of springs is measured, they form 3rd to 4th magnitude of springs as per Meinzer's scale (Spring No. 24) and contribution of such springs are more towards baseflow, which has already been estimated, as compared to smaller springs. The discharges of most of the smaller springs are used for irrigation/drinking or lost on the way while the water flows downstream on the slope.

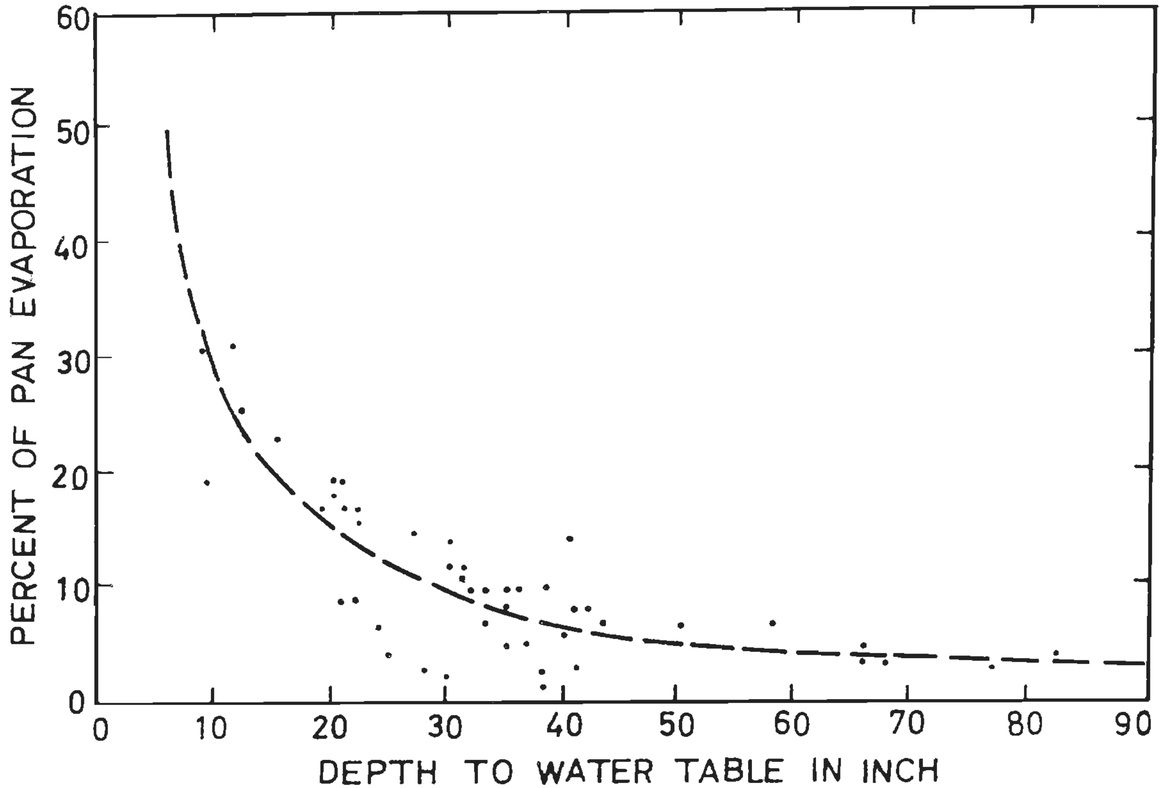


FIG: 7.1 — RELATION OF EVAPORATION RATE AND DEPTH TO WATER TABLE.
(AFTER WHITE, 1932)

TABLE 7.6 MONTHLY ACTUAL EVAPOTRANSPIRATION VALUES FROM GROUNDWATER

MONTH	Pan Evaporation X 0.7 (mm)	Average-Water Level during the month (mbgl) 1988	1991	1992	Groundwater Evapotranspiration as % of Pan Evaporation 1988	1991	1992	Groundwater Evapotranspiration (MCM) 1988	1991	1992
January	61.32	4.60	3.81	2.83	N	N	N	N	N	N
February	69.86	4.92	4.61	3.38	N	N	N	N	N	N
March	102.41	5.35	5.00	4.01	N	N	N	N	N	N
April	111.58	5.24	5.12	4.68	N	N	N	N	N	N
May	110.11	6.83	5.46	4.99	N	N	N	N	N	N
June	50.16	4.14	2.46	3.32	N	3.0	0.50	N	0.86	0.14
July	23.03	1.64	1.29	2.14	4.0	5.50	3.50	0.52	0.75	0.46
August	13.16	2.23	1.64	1.55	3.50	4.0	4.0	0.29	0.29	0.29
September	35.28	1.81	1.77	1.57	4.0	4.0	4.0	0.86	0.86	0.86
October	47.18	2.71	2.10	1.85	2.50	3.50	4.0	0.98	1.15	1.15
November	45.08	3.64	3.05	2.35	N	1.50	3.0	N	0.58	0.86
December	50.96	3.19	3.55	3.18	1.0	N	1.0	0.29	N	0.29
							Total	2.54	4.49	4.05

N-negligible

7.2.3 Evaluation of Regional Specific Yield

Specific yield is defined as the volume of water (expressed as either per cent or fraction of the total volume of the aquifer) that an aquifer (unconfined) releases from or takes into storage per unit area of aquifer per unit change in the component of head. This can be determined either from pumping tests on shallow wells tapping the unconfined aquifer or from soil moisture measurements or from groundwater budgeting and water level fluctuations. Detailed soil moisture measurements could not be carried out in the present studies and hence the other two methods were employed for the specific yield determination.

7.2.3.1 Pumping Test Method

As discussed in Chapter 5, the storage coefficient of the basaltic aquifers in the Koyna sub-station is found to be of the order of 0.01. This value does not match well with those of other workers who have assigned high values for different water bearing horizons in basalts (Table 7.7). However, the values obtained by pumping test methods are spot values and may not represent the area as a whole. Thus, it was felt necessary to evaluate the regional specific yield with the help of groundwater budgeting and water level fluctuations.

7.2.3.2 Method of Groundwater Budgeting and Water Level Fluctuations

The regional specific yield of the shallow aquifer zone in a basin can be estimated by counting all the parameters of discharge from the aquifer during the recession period and relating the same with the decline in the water table during the same period. This regional specific field can be worked out by the following equation :

$$S_y = \frac{D_w + RO_{bf} - RF_w}{WL_d \times A_e} \qquad \text{.......(2)}$$

where, S_y = Regional specific yield

RO_{bf} = Baseflow

RF_w = Winter rainfall

WL_d = Average water level decline

A_e = Effective area for ground water recharge

There should not be any additional recharge during the period taken into consideration for specific yield determination. But in case of Koyna sub-basin, there is continual recharge due to lift irrigation schemes throughout the year and hence the additional recharge due to applied irrigation has been deducted from the groundwater draft and baseflow to get accurate result of the specific yield determination. The spring discharges also have been added to the total quantum of discharge due to draft and baseflow. Thus, in view of this, the formula is modified to the following form :

$$S_y = \frac{(D_w + RO_{bf} + S_d) - (RF_w + I_{Ig})}{WL_d \times A_e} \qquad \text{......(3)}$$

where, S_d = Spring discharge

I_{Ig} = Recharge due to return flow of water applied for irrigation

(Other variables defined earlier)

The recession period from November to May is chosen because of the following reasons:

(i) There will be better control over the measurement of baseflow during this period.

(ii) there will be no recharge due to rainfall as this being the dry period of season for the sub-basin.,

(iii) The evapotranspiration from groundwater becomes less and less as the water table declines and can be neglected.

Table 7.7 Specific Yield as determined by several workers in Basaltic Terrain by Pumping Test Method

Name of worker	Area	Specific Yield
Davis et al (1959) & Johnson (1967)	Several parts in USA	1 to 5%
Walton and Stewart (1961)	Snake River Basalt, Idaho, USA	2 to 6%
Rao (1975)	Pune and Ahmednagar districts, Maharashtra India	3 to 7%
	Weathered Basalts :	2 to 7%
	Fractured and jointed basalts :	0.5 to 10%
	Vesicular basalts:	1 to 3%
GSDA (1976)	Weathered basalts in Pune, Sangli, Kolhapur, Bhir and Dhule Districts Maharashtra, India	2 to 6%
Venugopal (1979)	Karanja Basin, Karnataka, India	1.18to 2.55%
Deolankar (1980)	Same area as above	
	Weathered basalts :	Maximum 7%
	Vesicular Basalts :	4%
	Fractured and Jointed basalts :	1%
CGWB, (1984)	Upper Betwa Basin, Central India	0.01 to 12%
CGWB (1984)	Nion Sub-basin, Central India	0.5%

The groundwater draft includes (i) groundwater used for domestic and stock needs, (ii) groundwater used for irrigation by wells and (iii) baseflow directly pumped from the river channel for irrigational uses. The average water level fluctuation between November to May has been determined based on the water level data of the representative wells established throughout the area.

Since the groundwater levels in the Command area of the Koyna lift irrigation schemes do not represent true water levels due to periodic but continuous recharge on account of applied irrigation, only the wells established in non- command areas have been considered. The effective area has been worked out by deducting the area of the sub-basin from where there are no chances of groundwater recharge to take place. The area includes the spring recharge areas.

The parameters thus obtained are as follows :

(i) Groundwater draft from November to May : 20.21 MCM
(2.61 MCM for domestic/stock needs +10.40MCM for irrigation from wells +7.20 MCM for irrigation through baseflow).

(ii) Baseflow from November to May : 32 MCM (1988-89)
(unutilised) 28 MCM (1991-92)

(iii) Spring discharges from November to May : 3 MCM

(iv) Recharge due to winter rainfall : negligible

(v) Recharge due to applied irrigation in the Koyna L.I.S. command area : 21.35 MCM (taken as 35% of the applied irrigation as per recommendation of the Ground water estimation Committee, C.G.W.B., 1984)

(vi) Average water level decline : 2.82 m (1988-89)
(November to May next year) 3.18 m (1992-93)

(vi) Effective area for groundwater recharge : 897.2 sq.km or 897.2×10^6 m^2

Thus, by putting the above parameters in Formula (3), the specific yield for the years 1988-89 and 1991-92 is found to be 1.34% and 1.04% respectively.

If the additional recharge due to applied irrigation (i.e. 21.35 MCM) is neglected, the specific yields for the years 1988-89 and 1991-92 are found to be 2.18% and 1.79% respectively. Here, the average specific yield is determined to be 1.99 or 2% which gives a relatively high value. It may be mentioned that the high amount of baseflow found in the catchment is mainly attributed to the additional recharge due to applied irrigation which causes shallower water table and small fluctuation of water levels. Moreover, these fluctuations do not actually represent the general decline of water levels in the area. There are cases when the water level in May is shallower than that of the November as discussed earlier in the section on "water level fluctuations". Thus, it is justified to subtract the additional recharge due to applied irrigation for the period from November to May from the groundwater discharges (i.e. groundwater draft, baseflow and spring discharges) to get a reasonable estimate of the regional specific yield.

The regional specific yield of 0.012 or 1.2% as estimated above not only compares well with that of pumping test method, but also with the regional specific yield determined by various workers (CGWB, 1984, Sahoo, 1989, Angadi, 1986)in the basaltic terrain. C.G.W.B. (1984) has assigned a specific yield of 1% for the Upper Betwa Basin, Central India. Sahoo (1989) has found a specific yield of 1.32 % for the Yeshoda sub-basin, Maharashtra. Angadi (1986) has determined a specific yield value of 1.5% for the watersheds lying in basalts in Ghataprabha basin, Karnataka. Therefore, the regional specific yield value of 1.2% is quite reasonable in the study area.

7.2.4 Groundwater Recharge

7.2.4.1 Groundwater Recharge due to Rainfall (Monsoon)

After the estimation of average specific yield, the annual groundwater recharge has been estimated with the help of equation (1), which is stated again as follows :

$$G_r = (A_e \text{ x } WL_r \text{ x } S_y + RO_{bf} + S_d + ET + D_{wd} + R_{DP.Aq} \ldots (4)$$

where, G_r = Total Groundwater recharge due to monsoon rainfall

ET = Evapotranspiration during the monsoon period

D_{wd} = Groundwater draft due to domestic and stock needs

$R_{DP.Aq}$ = Leakage to deeper aquifers

(Other variables defined earlier)

Normally, in the area recharge occurs during the monsoon period only when about 90% of the annual rainfall occurs. Recharge due to winter or summer rainfall is quite negligible and has not been considered.

The estimation of baseflow during the monsoon months cannot be considered very reliable due to the reasons mentioned in the section on "estimation of baseflow" (7.3.2.1). Similarly it is also not possible to estimate the spring discharges and the actual evapotranspiration during the monsoon months with accuracy. In any case as these three factors, i.e. baseflow as part of the total run-off, spring discharges which later join the stream flow and evapotranspiration during the monsoon period, when no water is required for irrigation, will be lost during the same period and will not be of much importance from the use point of view. It is also difficult to estimate the exact amount of leakage to deeper aquifers. As such these factors have not been taken into account while estimating the groundwater recharge.

Generally a well hydrograph follows a definite trend like stream hydrograph with a peak followed by a recession limb. The recession limb in a post-recharge period is characterised by two distinct slopes - one a steep one (from August to October/November) and another a gentler one (from October/November to May end or beginning of June). The steeper limb signifies the quick dissipation of a major part of recharge during the later part of recharge period itself. This recession of water table is very sluggish in alluvial areas compared to hard rock areas wherein a substantial recession occurs within one or one and half months after the peak water level is achieved. Due to low demand and adequate soil moisture in later half of recharge period and under prevailing agricultural practice in India the fast receding limb of hydrograph is not considered for computation of utilisble recharge. The utilisable recharge is estimated based on pre-recharge (premonsoon, i.e., May) to post recharge (post- monsoon, i.e. November) water level fluctuation for areas receiving South-West monsoon. This is the amount of recharge which the aquifer actually retains at the beginning of the recession period.

The average rise in water-levels in the representative wells in the non-command areas (water levels in Command areas not considered due to their poor representation) between May to November (i.e. due to rainfall) is found to be 2.72 for the year 1988 and 2.96 for the year 1992. Thus, the annual groundwater recharge due to monsoon for the year 1988 is 32.70 MCM while for the year 1992 is found to be 27.62 MCM. In average, the total minimum replenishable ground water recharge is estimated to be 30 MCM annually for the area downstream of the Koyna dam.

7.2.4.2 Recharge due to Induced Infiltration

(i) Recharge due to Surface Water Tanks

As stated earlier (Chapter 1), the 9 percolation tanks, 1 minor-irrigation tank and many other small tanks have a gross storage of 6.26 MCM in the area. Groundwater Estimation Committee, Govt. of India (1984) recommends assumption of 50% of the gross storage from such structures as recharge to the groundwater regime. Thus recharge due to these structures is estimated to be 3.13 MCM annually.

(ii) Recharge due to Return Flow of Water applied for Irrigation

The water applied for irrigation has been estimated to be 61 MCM annually from the Koyna river, 7.20 MCM from other tributaries and 10.40 MCM from dugwells. Groundwater Estimation Committee, Govt. of India (1984) has recommended 35% of the return seepage from the surface-water irrigation and 30% from groundwater irrigation as recharge to the ground water regime. Thus recharge due to the return seepage from water applied for irrigation is estimated to be 26.63 MCM.

7.2.4.3 Total Annual Recharge

The total amount of annual recharge received by Area II in the Koyna sub-basin is given below :

(i)	Recharge due to monsoon rainfall	=	30 MCM (average)
(ii)	Recharge due to surface water tanks	=	3.13 MCM
(iii)	Recharge due to return flow of water applied for irrigation	=	26.63 MCM
	Total	=	59.76 MCM
			≈ 60 MCM

Out of this 60 MCM of groundwater recharge, 50% is due to induced infiltration, mainly from the return flow of water applied for irrigation. Such a high amount of return flow is attributed to the continual lifting of water from the Koyna river by the lift-irrigation schemes for irrigation of about 73 sq km of land beside the river, which forms the Command area of the lift irrigation schemes, known as Koyna Command area.

7.3 GROUNDWATER BALANCE

In terms of hydrologic cycle for a particular groundwater basin, a balance must exist between the quantity of water supplied to the basin (inputs) and the amount leaving the basin (outputs) and the change in groundwater storage.

Normally in the study area, rain starts in the early or middle of June and the recession period after the monsoon extends till the beginning or middle of next June. Therefore, the hydrological year has been taken from end of May to end of May of next year for working out the groundwater balance of the area.

The groundwater balance of the top shallow zone only is attempted and discussed in this section. The basic equation for the groundwater balance of the shallow groundwater reservoir of the sub-basin during a hydrological year can be written as :

Groundwater Inflow (Inputs)

= Groundwater Outflow (Outputs)

$\pm$ Change in Groundwater Storage (ΔS_G)

The groundwater inflow or inputs to the groundwater reservoir consist of :

(i) recharge by infiltration of precipitation (I_p)

(ii) sub-surface inflow (GW_I)

(iii) recharge by seepage from canals, surface-water reservoirs/tanks, (I_{CT})and

(iv) recharge due to return flow of water applied for irrigation (I_{Ig})

The outputs from the shallow groundwater reservoir consists of

(i) groundwater draft by wells and direct pumping from river (D_W),

(ii) baseflow (RO_{bf})

(iii) spring discharges (S_d)

(iv) Groundwater evapotranspiration (ET_g)

(v) Sub-surface outflow (GW_o), and

(vi) recharge to deep aquifers below shallow zone ($R_{DP.Aq.}$)

Therefore, the detailed equation for the groundwater balance of the shallow groundwater reservoir during a hydrological year can be written as

$$I_p + GW_I + I_{CT} + I_{Ig} = D_w + RO_{bf} + S_d + ET_g + GW_o + R_{DP.Aq} \pm \Delta S_G \quad \dots (5)$$

7.3.1 Groundwater Inflows or Inputs

Recharge due to rainfall (I_p) has already been estimated and is found to be 32.70 MCM for the year 1988-89 and 27.62 MCM for 1992-93.

As the water level rises during the monsoon, simultaneous loss of ground water from the reservoir takes place in the form of base- flow, spring discharges, evapotranspiration and withdrawal due to domestic needs during the same period, which also have to be added to get the total amount of infiltration from precipitation. However, these factors have also to be accounted under the outputs. Therefore, instead of double accounting in both inputs and outputs, they have been eliminated from both inputs and outputs.

It has already been stated earlier that no sub-surface ground water inflow into the sub-basin from the adjacent areas is taking place and therefore, GW_I is taken as nil. There does not exist any canal in the sub-basin. The contribution from the surface water reservoirs/tanks (i.e. I_{CT}) and water applied for irrigation (I_{Ig}) have been estimated to be 3.13 MCM and 26.63 MCM respectively annually.

Thus, the total inputs for the years 1988-89 and 1992-93 are estimated to be 62.46 MCM and 57.38 MCM respectively.

7.3.2 Groundwater Outflows or Outputs

Groundwater draft (D_w) by wells for domestic/stock needs and for Irrigation has been estimated to be 20.21 MCM for the period from November to May. The baseflow for this period has been estimated to be 32 MCM for 1988-89 and 28 MCM for 1992-93. The evapotranspiration has been found to be 0.29 MCM during this period.

No sub-surface outflow of groundwater takes place from the area into the adjoining sub-basin and therefore GW_O is taken as nil.

The change in groundwater storage (ΔS_G) has been estimated by taking the difference in the average water level recorded at the beginning and end of the hydrological year, i.e. end of May to the end of May of the next year, and multiplying the value with the average specific yield and the effective area. There is decline of 0.21 m of water table between May, 88 and May, 89. Similarly, there is a decline of 0.22 m of water-table between May, 92 and May, 93. Thus, the change in groundwater storage (S_G) is found to be 2.52 MCM for 1988-89 and 2.05 MCM for 1992-93.

Recharge to the deep aquifers ($R_{DP.Aq}$) below the depth of 25 m has been taken as the amount to balance both sides of the equation as all other items of the equation, except this, are estimated.

7.3.3 The Balance

The details of the groundwater balance is given in Table 7.8. It indicates that the recharge to the deep aquifers below the shallow zone, comes out to be 4.44 MCM during 1988-89 and 3.83 MCM during 1992-93. This accounts to be only 7% of the total inputs during these two years. However, this estimate is only for the period from November to May and during monsoon period higher quantity of recharge is expected. The low permeability of the weathered and fractured zone, available only for a very shallow zone, reduces the downward leakage of groundwater and increases interflow. But, the downward leakages of groundwater to deeper aquifers cannot be overruled though the exact amount is uncertain. The lineaments may be extending to deeper levels as indicated by a comparison between the borewell yields and the existing lineaments.

7.4 ESTIMATION OF STATIC GROUNDWATER RESERVE

Groundwater available below the zone of natural water level fluctuation (dynamic reserve) is called static groundwater reserve. An estimate of such a reserve is essential for an optimum utilisation and future planning of groundwater resources of an area. It can be calculated using the following formula :

$$G_{rs} = B \times A_e \times S_y \qquad \ldots \qquad (6)$$

where, G_{rs} = Static Groundwater reserve

B = Saturated thickness of aquifer below the deepest level of water in premonsoon period

(A_e and S_y defined earlier)

The total thickness of the weathered and jointed zone below land surface upto the first massive basalt has been estimated with the help of the well inventory, borewell data and other hydrogeological investigation. While in the non-command areas, which mostly lie in the dissected plateaus, the dugwells are fully penetrating and the water levels nearly touch the depth of the wells, in the Koyna Command areas, there lies a thick weathered and fractured zone below the summer water level. The well inventory reveal that the thickness of the shallow aquifer (water bearing horizon) below the zone of dynamic water level fluctuation varies between 0.10 to 18.20 m and 7.17 m in average. Thus the static groundwater reserve is estimated to be 77.20 MCM or 77 MCM.

Such a high amount of reserve mostly occurs in the Koyna command area where farmers depend more on surface water than on groundwater. Groundwater is poorly extracted and consumptive use is not practiced. Thus in such areas consumptive use of surface water and groundwater is highly recommended to have an optimum utilisation of the groundwater resources. While in the command areas, groundwater is readily available, in other parts, the static reserve can be exploited by deepening of the existing wells and with the help of the horizontal or vertical bores.

7.5 ESTIMATION OF SAFE YIELD OF THE GROUNDWATER SYSTEM

The Safe Yield of the groundwater system is that amount of groundwater that can be exploited continuously without detrimental effects on the groundwater reservoir. It includes all exploitable groundwater originating within the catchment and consists of (i) utilisable or

Table 7.8 Groundwater Balance Estimate (all figures in MCM)

1988-89		1992-93	
Inputs	Outputs	Inputs	Outputs
I_p = 32.70	D_w = 20.21	I_p = 27.62	D_w = 20.21
GW_I = 0	RO_{bf} = 32.0	GW_I = 0	RO_{bf} = 28.0
I_{CT} = 3.13	ET_g = 0.29	I_{CT} = 3.13	ET_g = 0.29
I_{Ig} = 26.63	S_d = 3.0	I_{Ig} = 26.63	S_d = 3.0
	GW_o = 0		GW_o = 0
	ΔS_G = 2.52		ΔS_G = 2.05
	$R_{DP.Aq}$ = 4.44		$R_{DP.Aq}$ = 3.83
62.46	62.46	57.38	57.38

exploitable dynamic groundwater, (ii) amount of water used for domestic and stock needs in monsoon periods and (iii) Return flow of water applied for irrigation.

7.5.1 Exploitable Dynamic Groundwater Reserve

Generally upto the end of October, the soil will be saturated with soil moisture and no additional groundwater for irrigation will be required. From the beginning of November, water requirements for irrigation will start. Nearly 70% of groundwater in the area is used for irrigational needs and it is felt that the estimated exploitable dynamic groundwater reserve will be of great significance from groundwater development point of view. It can be calculated using the following formula, i.e.

$$G_{re} = WL_d \times A_e \times S_y \ldots (7)$$

where, G_{re} = Exploitable/utilisable groundwater reserve and

WL_d = Average water level decline between November to May next year

(A_e and S_y defined earlier)

The average water level fluctuation between November to May next year is found to be 2.82 m and 3.18 m for the years 1988-89 and 1992-93 respectively. Thus, the exploitable/utilisable groundwater reserves for these two years are estimated to be 33.90 MCM or 34 MCM and 29.67 MCM or 30 MCM respectively. In average it is estimated to be 32 MCM for the whole catchment downstream of the Koyna dam (Area II).

7.5.2 Amount of Groundwater used for Domestic and Stock needs in Monsoon Period

Amount of groundwater used for domestic and stock needs has been estimated for the whole year as 4.48 MCM. So for the period from June to October it works out to be 1.87 MCM.

7.5.3 Return flow of water applied for irrigation

This amount has been estimated to be 26.63 MCM for area under consideration.

7.5.4 Total Exploitable Groundwater Reserve (Safe Yield)

The total exploitable groundwater reserve or safe yield of the Area II, as detailed below works out to be 60 MCM per year in average.

(i)	Exploitable/utilisable Dynamic groundwater reserve	32 MCM
(ii)	Groundwater used for domestic and stock needs during monsoon	1.87 MCM
(iii)	Return flow of water applied for irrigation	26.63 MCM
	Safe yield	60.50 MCM or 60.00 MCM

It may be noted here that this amount of safe yield (60 MCM) or exploitable groundwater reserve includes the present groundwater draft by wells for domestic, stock and irrigational needs which is estimated as 14.88 or 15 MCM per year and the natural losses from the groundwater reservoir which are mostly baseflow and spring discharges amounting to 40 MCM (37 MCM baseflow + 3 MCM spring flow) per year, out of which 7 MCM is already being directly pumped from the tributaries of the koyna river for irrigational needs. Thus, there remains a balance of only 5 MCM for further groundwater development without modification of the present hydrogeological set up.

During the initial months after monsoon rainfall, it will be difficult to intercept the baseflow. There will be little demand for water at that time as well. But during the dry span of the year, the unutilised baseflow can be tapped by effective scientific methods such as by constructing additional dugwells, dug-cum-borewells or horizontal trenches or deepening of the existing wells etc. It is thus assumed that at least 25% of the unutilised baseflow can be brought to fruitful use. This amounts to about 8 MCM annually.

Thus about 13 MCM of groundwater could be used at the existing hydrogeological set-up through wells only. At the existing set up and pumping rates in different areas, the unit draft per well per year works out to be 0.021 MCM in the command areas and 0.01 MCM in the non-command areas. Taking into consideration the declining trend of groundwater table in the non-command areas, it is recommended that the 13 MCM of available groundwater be used in the command areas only so as to minimize the rising trend of groundwater table in these areas. Thus about 620 additional dugwells could be constructed in the command areas alone to make the best utilisation of the available groundwater resources.

Similarly about 25% of the unutilised spring flow, i.e. about 1 MCM out of 3 MCM can at least be tapped through pipe-lines not only for drinking water supply to the small hamlets in the hilly tracts, but also for irrigation and horticulture. It may be mentioned here that the hill slopes of the Western Ghats are generally barren or are having only small shrubs. These slopes essentially need afforestation. Thus, spring discharges can be used for the afforestation programmes in the area for which Government is taking serious steps.

7.6 SUMMARY

For assessment of the groundwater resource potential of the Koyna sub-basin, it has been divided into two parts, such as Area I (954.20 sq.km.) covering the entire catchment area of the Koyna dam and Area II (1081.80 sq.km) downstream of the Koyna dam. These two divisions have defined basin boundaries and have been treated as two separate watersheds. Area I is mostly hilly and the inhabitants mostly depend on spring water while Area II forms relatively plain valley in recharge areas. Groundwater development through dugwells and borewells is mostly confined to Area II only and hence the present assessment of the groundwater resources is made for this part of the Koyna sub-basin only.

Water level fluctuation method has been adopted for estimation of the groundwater recharge.

The groundwater discharges through wells and lift system have been estimated to be 22.08 MCM, out of which 4.48 MCM is used for the domestic/stock needs, 10.40 MCM is used for irrigation from wells and the rest 7.20 MCM for irrigation from baseflow. Natural groundwater discharges include baseflow, evapotranspiration from groundwater, spring discharges and subsurface outflow. Baseflow from the month of November to May is estimated to be about 30 MCM. The total annual loss of groundwater due to evapotranspiration is found to be 3.70 MCM. Out of 14 MCM of spring discharges estimated for the whole Koyna sub-basin, this area accounts for only 6 MCM of the total quantum of discharge. While the sub-surface outflow from the area is considered to be negligible, the leakage from the shallow aquifers to the deeper aquifer system amounts to about 4 MCM during the postmonsoon period (November to May).

The average regional specific yield has been estimated to be 1.20%. The annual groundwater recharge has been estimated to be 60 MCM, out of which 30 MCM is due to monsoon rainfall and the rest 30 MCM is due to induced recharge from the surface water tanks (3 MCM) and water applied for irrigation (27 MCM). The high amount of groundwater recharge (45%) due to return flow from water applied for irrigation is attributed mainly to the extensive use of surface water through lift irrigation schemes along the Koyna river.

The static groundwater reserve and exploitable groundwater reserve have been estimated to be 77 MCM and 32 MCM respectively. The safe-yield has been estimated to be 60 MCM. Out of this 60 MCM, 22 MCM is already being used for domestic/stock and irrigational needs, 30 MCM is unutilised baseflow and 3 MCM is spring flow. Thus, there remains a balance of only 5 MCM for further groundwater development. Assuming that at least 25% of the unutilised baseflow (i.e. 8 MCM) can be brought to fruitful use, the total amount of groundwater available for further development amounts to 13 MCM. Taking a unit draft of 0.021 MCM per well per year at the existing hydrogeological set-up, about 620 dugwells can be constructed in the command area alone. Similarly, at least 25% of the spring flow (i.e bout 1 MCM) can be tapped through pipe-lines for drinking, irrigation and afforestation.

Chapter 8

Summary And Conclusions

The western margin of the Indian Peninsula is characterised by hilly terrain, known as Western Ghats (hills). The Koyna sub-basin (a part of Krishna River basin) is located east of the main ridge, locally called the 'Sahyadri Hill Range'. Trending north-south in general, this sub-basin with Koyna river and its tributaries covers an area of 2036 sq. km in the Deccan Terrain of the district of Satara, Maharashtra State, India.

This sub-basin drew attention of geo-scientists after the Koyna earthquake (magnitude 7) of 1967. Since then, detailed geological, tectonic and seismic investigations of the sub-basin have been carried out by several workers to work out the causative factors which triggered the earthquake. Despite these investigations, very little studies have been done on the hydrogeological aspects of this sub-basin. The present work, therefore, is an attempt in this direction to evaluate the hydrogeological framework of the sub-basin and assess its groundwater potential.

The Koyna sub-basin experiences sub-tropical monsoon type of climate. There is a wide variation in the distribution of rainfall in the area due to orographic influence of the Western Ghats. The annual normal rainfall due mainly to monsoon decreases steadily from the western (6024mm) to the eastern parts (745mm). In the southern parts there is a marked declining trend of rainfall since the year 1974.

The sub-basin has an elevation range of 550 to 1460m above MSL and represents a typical physiographic set-up characteristic of the Deccan Basaltic Plateau. It is drained by trunk stream Koyna and its tributaries. The overall drainage pattern of the sub-basin is sub-dendritic. Morphometric analysis puts Koyna as a 6th order stream. After a southerly flow for about 65 kms, the Koyna river is dammed by the Koyna dam forming the Shiv Sagar Reservoir (popularly known as Koyna Reservoir). After the worst earthquake of 1967, which caused considerable leakages in the dam structure, water is released periodically (twice in a month) from the dam. The released water has given rise to a number of lift irrigation schemes in the central valley portion of the Koyna sub-basin.

Geologically, the Koyna sub-basin occupies a terrain characterised conspicuously by flat topped hills which are commonly known as 'Deccan Trap'. These traps are formed by the basaltic flows. At times these traps are covered by laterites at higher elevations. In the lower reaches of the river valleys alluvium is found.

Each basaltic flow consists of mainly two trap units, viz. (i) massive unit and (ii) vesicular unit, the former occupying the lower portion and the later the upper part of the flow. The consecutive lava flows are commonly separated by redbole bed.

The soils of the area belong mainly to two types,viz.(i) lateritic soil and (ii) black cotton soil.

Four hydrogeomorphic units, viz. (i) plateau (flat), (ii) dissected plateau, (iii) shallow buried pediment and (iv) deep buried pediment have been identified on the basis of thematic mapper data. The deep buried pediment forms the most potential zone for groundwater occurrence in shallow aquifers.

The major structural features found in the area are joints, lineaments and major faults. Sub- vertical to vertical dipping joints are common. Horizontal to sub-horizontal joints commonly known as sheet joints, are also found at places towards the top of individual flows. The lineaments indicate prominent trends as NE-SW, N-S and NW-SE. The drainage network is mostly controlled by lineaments. The Koyna river flows along a north-south trending lineament in the upper reaches. It trends east-west along several lineaments in the middle and lower reaches. The bifurcation ratio of the order of 5.08 also indicates structural control of the drainage network. The longitudinal profile and the assymmetrical transverse profile indicate structural control of the Koyna river.

Unpaired river terraces, river piracy with distinct nick points causing interbasinal transfer of surface water etc. indicate slow but continuous rejuvenation in the Koyna sub-basin. An analysis of the structural and tectonic features indicate that the Koyna sub-basin and for that matter the Deccan Plateau is no more a stable land as conceived earlier by several workers but have evidences of deep crustal movements and neotectonic activities taking place in the region.

On the basis of 240 dugwells and the data collected from 305 borewells, the occurrence of groundwater in various types of aquifers was studied. The aquifers are found to be associated with basalts, laterites, alluvium and talus deposits. In the exposed section of the sub-basin, 27 basaltic flows have been identified. The thickness of the basaltic flows vary in thickness from 10 m to more than 60 m. The upper vesicular unit of the basaltic flows, unlike the lower massive part, exhibits primary porosity and permeability and is weathered in most parts even at depth. However, at many places, the non-vesicular (massive) unit has developed secondary porosity due to fracturing, jointing and weathering. The laterites and talus deposits are highly porous and permeable, but have very low specific retention of groundwater. The water-bearing properties of the clay- rich alluvium are largely controlled by sand/clay ratio. The lateritic soils have better potential than that of black cotton soils.

Based on the analysis of 545 wells, the shallow aquifers are found upto a maximum depth of 25 m. The laterites, alluvium, soil, talus deposits and the weathered uppermost basalts form shallow aquifers in the area. The deeper aquifers are found below the zone of weathering in basalt, due mainly to fracturing and are tapped only by borewells. 88% of the dugwells in the area tap shallow basaltic aquifers as against 12% of the wells in laterites, alluvium, soil and talus deposits. Thus, laterites, alluvium, soils and talus deposits form shallow aquifers of secondary importance as compared to basaltic aquifers. The basaltic lava flows in their present-day weathered zone consists of 4 typical water-bearing horizons,such as (i) black cotton soil with yellow or reddish clay (0.50-8 m), (ii) highly weathered and highly jointed basalt (3 - 10 m), (iii) poorly weathered and highly jointed basalt (1 - 2 m) and (iv) poorly weathered and poorly jointed basalt, which overlies the hard massive basalt (1 - 2 m). Depending on location all or part of these four horizons are tapped by the dugwells.

The groundwater in deeper aquifers occurs at the contact between the basaltic flows, within the vesicular and amygdaloidal section at the lava flow top or within the fractured and jointed section. It occurs under semi-confined condition when the productive horizon is separated by fractured and or jointed basalt. Confined aquifer conditions are found when the water-bearing horizon lies at the contact of two lava flows - the upper one occurring as massive basalt and the lower one as vesicular or fractured basalt. At many places shallow aquifers are connected to deeper aquifers through fractures.

Well yields of groundwater are found to be related with the lineaments and the geomorphic features. While the lineaments have a better control over the yields of the borewells tapping deeper aquifers, the geomorphic features have greater control over the shallow aquifer system. Deep buried pediments and the NE-SW trending lineaments are highly potential areas for dugwells and borewells respectively. Borewells in deep buried pediments with NE-SW lineaments have yields as high as 39,000 lph.

The depth to water levels (DTW) in the shallow aquifers were recorded in 42 representative wells in 1988 and 47 representative wells in 1992 during premonsoon and postmonsoon periods. The depth to water levels (DTW) in the premonsoon period in most of these representative wells (31% in 1988 and 32% in 1992) range from 2 to 4 mbgl. The water levels generally do not exceed 8-10 m in more than 90% of the wells. In the postmonsoon period, the DTW is O to 2 mgbl in most of the wells (60% in 1988 and 56% in 1992). The DTW in more than 95% of the wells does not exceed 4-6 mgbl in the postmonsoon period.

The seasonal fluctuations of water levels at the 48 well distributed representative wells were worked out for premonsoon and postmonsoon periods at the individual stations for the years 1988 and 1992. During 1988, 62% of the wells show a fluctuation less than 2m, while 19% of them show a range of 2 to 4m and an equal number show a fluctuation greater than 4m. Similarly, during 1992, 53% of these wells show fluctuation range of less than 2m while 24% and 21% of the wells show fluctuation of 2 to 4m and greater than 4m respectively. Thus the water level fluctuation from premonsoon to postmonsoon period is less than 2m in most of the wells. In the command area of the Koyna lift irrigation schemes, the seasonal fluctuation of about 1m or less is observed.

In the Command area of the lift irrigation schemes, groundwater is poorly extracted due to easy availability of surface-water for irrigation. Because of continual recharge due to irrigation, the water levels in this area are rising steadily. Thus, this is leading to near water-logging condition in the lower reaches of the sub-basin. The non-command area, on the other hand, indicates a gradual decline of water levels due to overdraft for irrigation. The decline in water level is more pronounced in the southern parts away from the Command area, due not only to overdraft but also to the general declining trends of rainfall since 1974. In fact, drought occurs in this area once in every four years. This part of the sub-basin, therefore, calls for artificial recharge of the aquifers to augment the existing groundwater regime.

The hilly region of the Koyna sub-basin is dotted by many cold-water springs. The high rate of precipitation and the terrace-like topographic features found in the hills facilitate recharge of the aquifers through weathered/ fractured/ jointed rocks. These aquifers, whenever are dissected by fractures, joints and exposed to hill face, are drained in the form of springs. Based on the examination of 121 springs, it is found that they generally emerge through fractures or the contact between (i) laterite and lithomargic clay or poorly lateritised basalt. (ii) vesicular basalt and massive basalt, (iii) highly weathered massive basalt and moderately or poorly weathered massive basalt or redbole, (iv) talus deposits and hard massive basalt or laterite or poorly lateritised basaltic flow.

The springs are distributed at an elevation range of 600 to 1350 m above MSL with maximum concentration (47%) in between 900 to 1000 m elevation. A distinctive break in slope and an extensive hill terrace especially in the south and central part is found above 900 m contour. The springs have a recharge area of 722 sq.km and frequency of occurrence of one spring per square kilometre.

The mean discharge of the individual springs in winter is about 46 m^3 /day (range 2.06 to 432 m^3 /day) as against the mean discharge of 28 m^3 /day in summer (range 0.94 to 216 m^3 /day). Maximum number of high yielding springs ($>$ 72 m^3 /day)are located above the altitude of 1300 m. The annual discharge of springs for the Koyna sub-basin as a whole is estimated to be 14 MCM, out of which 8 MCM accounts for the rainy season, 4 MCM for the winter season and 2 MCM for the summer season. As per Meinzer's classification (1923), mostly the springs of magnitude fifth and sixth are present in the area.

Based on the nature of their emergence, the springs could be classified as contact springs (89%) and fracture springs (11%). However, since the emergence of groundwater in the form of springs is largely controlled by the water-bearing properties of the formations in the study area, these springs can also be classified on the basis of their source-aquifers. Thus, a simple classification has been proposed which classifies these springs into five different types such as (i) laterite springs (9%), (ii) talus springs (23%),(iii)vesicular basalt springs (20%), (iv) weathered non-vesicular basalt springs (37%) besides fracture springs (11%) associated with any type of aquifer. The first four types comes under the category of "contact springs".

The springs are used both for drinking and irrigation purposes in the hilly tracts. Generally villagers combine the water of two or more springs and bring it to one channel, which is unlined. While flowing in such open channels down the slope, a major part of water is lost due to seepage on the way. Taking into consideration the terrain conditions and need of the inhabitants, several measures have been suggested for effective harnessing of the spring water in the Koyna sub-basin.

Among the various hydraulic parameters, Transmissivity (T) and Storage Coefficient (S) have been estimated for the shallow aquifers of the study area with the help of 8 pumping tests conducted in large-diameter wells (dugwells) through the help and courtesy of the private well owners. The methods suggested by Papadopulos-Cooper (1967), Boulton and Streltsova (1976), Mishra and Chachadi (1985) and Singh and Gupta (1986, 1991) have been used in the present study for estimating these two most important hydraulic parameters. The transmissivity values derived from all the four methods for individual test sites lie in comparable range and therefore for each test site the average value of T is considered. Accordingly, the transmissivity of the shallow aquifers in the area in general varies between 28 to 135 m^2/day. It is found to be of the order of 128 m^2/day for talus deposits, 64 to 135 m^2/day for the highly weathered and jointed basalt, 57 m^2/day for the poorly weathered and poorly jointed massive basalts. The Storage Coefficient (S) derived by these methods, is assessed to be of the order of 0.01 for the shallow basaltic aquifers of the area.

The yields of the dugwells were tested with the help of their specific capacity, unit area specific capacity and specific capacity index values. The methods suggested by Slichter (1906) for estimation of specific capacity, by Narasimhan (1965) for unit area specific capacity, by Singhal (1973) and Walton (1962) for specific capacity index values were used in the present study. The unit area specific capacity is found to be better parameter as compared to others for assessment of the productivities of the dugwells. For the dugwells tapping talus deposits, black cotton soils, alluvium and basalts, the unit area specific capacity values are found to be of the order of 1.2, 0.7 to 1.3, 1.4 and 0.3 to 6.7 (exceptional 25.2) lpm/m/m^2 respectively. In the dugwells tapping basalts alone, it is found to be of the order of 0.3 to 1.3 lpm/m/m^2 for the poorly weathered and poorly jointed basalts, 0.7 to 1.2 lpm/m/m^2 for the poorly weathered and highly jointed basalts and 0.9 to 6.7 (exceptional 25.2) lpm/m/m^2 for the highly weathered and jointed basalts. With the help of unit area specific capacity, the aquifers could be arranged in terms of their decreasing production capacity as highly weathered and jointed basalts, alluvium, talus deposits, soils, poorly weathered and highly jointed basalts and poorly weathered poorly jointed basalts. The production capacity of the dugwells largely depend on their location with respect to hydrogeomorphic units and water-bearing properties of the horizons tapped. The unit area specific capacity is found to be of the order of 1.2 lpm/m/m^2 for the plateau (flat), 0.7 to 0.9 lpm/m/m^2 for the dissected plateau (exceptional 6.7 lpm/m/m^2), 0.8 lpm/m/m^2 for the shallow buried pediments and 1.3 to 2.8 lpm/m/m^2 (exceptional 25.2 lpm/m/m^2) for the deep buried pediments.

With a view to classify the water resources of the Koyna sub-basin and assess their suitability both for drinking and irrigation purposes, 76 water samples from dugwells tapping shallow aquifers, 24 from borewells tapping deeper aquifers, 29 from cold water springs at higher elevations emerging from different aquifers and 18 from surface water were analysed. Chemical quality of water from aquifers in the basalts indicate that they are rich in Ca^{++} and in almost all the samples, Ca/Mg ratio is greater than one. The concentration of Na^{+} is always higher than that of K^+ . CO_3 , SO_4 and Cl^- are very low in concentration. Most of the water samples have simply traces of CO_3^{--} and SO_4^{--} . Spring and river water samples indicate low salinities. The area, in general, contain high amount of iron (maximum upto 2 ppm) The high iron content in shallow aquifers may be attributed to the laterites at higher elevations, presence of lateritic soils at lower elevations and the commonly occurring redbole beds.

The Hill-Piper diagram indicate that the waters in general are dominated by alkaline earths (Ca^{++}, Mg^{++}) and weak acids (HCO_3^-, CO_3^{--}). On the basis of the modified Hill-Piper diagram (Romani, 1981) the waters from shallow aquifers can be classified as calcium-bicarbonate type (53%) and calcium-magnesium-bicarbonate type (27%). In case of deeper aquifers they are calcium-magnesium- bicarbonate type (29%), sodium-bicarbonate type (24%), calcium- bicarbonate type (19%), calcium-magnesium-sodium- bicarbonate type (19%) and sodium-calcium-bicarbonate type (9%). In terms of anions, all the samples plot in bicarbonate field.

Both surface water and groundwater are fit for drinking and domestic purposes as per the criteria prescribed by Bureau of Indian Standards (1983). Based on Wilcox diagram, USSL diagram and Residual Sodium Carbonate (RSC), these waters are found fit for irrigation in general, but some deterioration in quality is found especially in the lower reaches of the Koyna river due to use of fertilizers and shallow water table (water logging condition). The groundwater in this area shows signs of salinity hazard. For irrigation, groundwater from shallow aquifers are more suitable than that of the deeper aquifers.

With the erection of Koyna dam, the Koyna sub-basin, stands divided into two parts;Area I (954.20 sq.km.) to the north of the Koyna dam which covers the entire catchment area of the dam and the Area II (1081.80 sq.km) downstream of the Koyna dam. These two divisions have defined basin boundaries and have been treated as two separate watersheds. Area I is mostly hilly and the inhabitants mostly depend on spring water while Area II forms relatively plain valley. Groundwater development through dugwells and borewells is mostly confined to Area II and hence the assessment of the groundwater resources was made for this part of the Koyna sub-basin only.

Water level fluctuation method has been adopted for estimation of the groundwater recharge.

The artificial groundwater discharges have been estimated to be 22.08 MCM, out of which 4.48 MCM is used for the domestic/stock needs, 10.40 MCM is used for irrigation from wells and the rest 7.20 MCM for irrigation from baseflow. Natural groundwater discharges include baseflow, evapotranspiration from groundwater, spring discharges and subsurface outflow. Baseflow from the month of November to May is estimated to be about 30 MCM. The total annual loss of groundwater due to evapotranspiration is assessed to be 3.70 MCM. Out of 14 MCM of spring discharges estimated for the whole Koyna sub-basin, this area accounts for only 6 MCM of the total quantum of discharge. While the sub-surface outflow from the area is considered to be negligible, the leakage from the shallow aquifers to the deeper aquifer system amounts to about 4 MCM during the postmonsoon period (November to May).

The average regional specific yield has been estimated to be 1.20%. The annual groundwater recharge has been estimated to be 60 MCM, out of which 30 MCM is due to monsoon rainfall and the rest 30 MCM is due to induced recharge from the surface water tanks (3 MCM) and water applied for irrigation (27 MCM). The high amount of groundwater recharge (45%) due to return flow from water applied for irrigation is attributed mainly to the extensive use of surface water through lift irrigation schemes along the Koyna river.

The static groundwater reserve and exploitable groundwater reserve have been estimated to be 77 MCM and 32 MCM respectively. The safe-yield has been estimated to be 60 MCM. Out of this 60 MCM, 22 MCM is already being used for domestic /stock and irrigational needs, 30 MCM is unutilised baseflow and 3 MCM is spring flow. Thus, there remains a balance of only 5 MCM for further groundwater development. Assuming that at least 25% of the unutilised baseflow (i.e. 8 MCM) can be brought to fruitful use, the total amount of groundwater available for further development amounts to 13 MCM. Taking a unit draft of 0.021 MCM per well per year at the existing hydrogeological set-up, about 620 wells can be constructed in the Command area alone. Similarly, at least 25% of the spring flow (i.e bout 1 MCM) can be tapped through pipe-lines for drinking, irrigation and afforestation.

The Koyna sub-basin is characterised by both scarcity and abundance of water-scarcity in the dissected plateau which calls for artificial recharge of the aquifers, and abundance in the Command area of the Koyna lift-irrigation schemes which calls for consumptive use of the water resources. For optimal development of the available groundwater resources it is but imperative to practice both these vital aspects. The areas having NE-SW trending lineaments should be looked for greater success of the borewells, whereas more number of dugwells may be constructed in deep buried pediments due to their high groundwater potential. The Command area of the lift-irrigation schemes may be expanded further to the adjoining scarcity areas for effective development of the available surface water potential. The springs form very important source of water which could be harnessed effectively in the hilly tracts without disturbing the existing natural system.

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APPENDIX : BRIEF DETAILS OF SPRINGS INVESTIGATED

Sl. No.	Village Name with Toposheet & Quadrant No.	Spring Location	Discharge during Winter (m^3/day) and Meinzer's Magnitude	Discharge - during Summer (m^3/day) and Meinzer's Magnitude	Elevation (m above MSL)	Origin (at the contact between)	Use
1.	Old Mahabaleswar (47G/9 1B)	Panchganga Temple	16.2/sixth	16.2/sixth	1340	-	Not used
2.	-do-	About 1/2 km SE of Punchaganga Temple	37.01/sixth (2 springs)	37.0/sixth	1300	Talus/HMB	Not used
3.	-do-	Near Arthur's peat	2.06/seventh	2.06/seventh	1320	WMB/HMB	-do-
4.	Tandulnil (47 G/9 1C)	1 km N of Duck Point	111.10/fifth	105.60/fifth	1300	Talus/ Moderately WMB	Gravity water supply
5.	Tandulnil (47 G/9 1C)	1 km N of Duck Point	112.80/fifth	107.16/fifth	1300	Talus/HMB	Irrigation through open channel.
6.	Mahabaleshwar/ (47 G/9 1B)	SW of Mahabaleshwar about. 300 m E of Falkland point.	17.28/sixth	17.28/sixth	1240	WMB/Red-bole	Gravity water supply
7.	Magar (47 G/9 2B)	South of main village	22.22/sixth (3 small springs)	16.66/sixth	1100	WMB/ moderately WMB	Irrigation
8.	-do-	NE of main village	-	-	1100	-do-	Drinking (open channel)
9.	Chikhli	50 m W of village	6.17/sixth	0.94/eighth	1140	WMB/Red-bole	Gravity water supply
10.	-do-	100 m NEE of village	42.02/sixth	21.02/sixth	1080	-do-	Irrigation
11.	-do-	1 km NW of village	-	-	1080	-do-	Gravity water supply
12.	-do-	1/2 km west of village	3 9/sixth	1.92/sixth	1200	WMB/HMB	Irrigation (15 areas of rabi crops)

13.	Jhalachi Khind (47G/9 2C)	East of villate	23.52/sixth	7.2/sixth	1110	-	Gravity water supply (infective)
14.	Taldev (47G/9 3C)	1 km N of village	12.96/sixth	6.48/sixth	1010	VB/HMB	Developed into a dugwell
15.	-do-	NW of main village	21.60/sixth (2 springs)	8.64/sixth	1060	-do-	Driking & irrigation (waters)
16.	Taldev (47G/9 3C)	40 m away from spring No.15	-/sixth	-/sixth	1060	VB/NMB	Irrigation
17.	Khambil Charge (47G/9 3C)	N of village beside the road	-	-	680	Horizontal fractures	Drinking
18.	Vingle (47G/9 3C)	Gl fo village	-	-	660	-do-	Developed into a dugwell
19.	Tetali (47G/13 3A)	NW of village in the hills	54/fifth	27/sixth	980	-	Gravity water supply (ineffective)
20.	Savri (47G/14 1A)	SW of village	-	-	670	Fractures in HMB (horizontal)	Drinking
21.	Gharbi (47G/15 1A)	NNE of village	288/fifth (3 springs)	288/fifth	980	Talus/ poorly lateritised	Irrigation
22.	-do-	NW of village	105.19/fifth	105.19/fifth	990	Laterite/ lithomarge	-do- (10 areas)
23.	-do-	on the way to Karvat	-	-	980	Laterite/ poorly lateritised flow	No use
24.	Vatole (47G/15 1A)	N of village	>3110.40/third (a number of springs)	>3110.40/third	940-960	Talus/ poorly lateritsed flow	irrigation (>75 areas)
25.	Marathwadi (47G/15 1B)	About 1 km of village	432/fifth	216/fifth	1020	-	Drinking/irrigation (open channels)
26.	Dhangarwadi (47G/15 1B)	500 m of village	36/sixth	36/sixth	950	Laterite/ HMB	Not use

27.	-do-	-do-	-	-	930	Vesicular basalt/ moderately HMB	-do-
28.	-do-	20 m W of Amba Phursai Temple	4.8/seventh	4.8/seventh	1020	-	Drinking
29.	Aral Nivkane (47G/15 1B)	NE of village on hill top	31.8/sixth	31.8/sixth	1000	-	Gravity water supply
30.	Phursai (47G/15 1B)	SSE of village	129.60/fifth	-	950	WMB/HMB	Not use
31.	-do-	-do-	129.60/fifth	-	950	VB/HMB	-do-
32.	-do-	-do-	129.60/fifth	-	950	VB/HMB (hor. fractured)	-do-
33.	Malevadi (47G/15 1B)	1/2 km SE of village	-	-	975	Talus/WMB	Gravity water supply (ineffective)
34.	Malevadi (47G/15 1B)	1/2 km SE of village	5.4/sixth	-	970	WMB/ Redbole	Not use
35.	-do- (No. 29)	50 m E of above spring	5.4/sixth	-	970	-do-	Drinking (open channel)
36.	Borgevadi (47G/15 1B)	1/2 km NW of village	15.89/sixth	-	970	-do-	-do-
37.	-do-	40 m E of spring No.30	25.92/sixth	-	960	-do-	Not use
38.	Malevadi (47G/15 1B)	1/2 km SE of village	36.12/sixth	27.10/sixth	955	WMB/HMB	Gravity water supply
39.	-do-	-do-	-/sixth	-/sixth	955	-do-	Not use
40.	Mandure (47G/15 1B)	NE of village in the hills	25.92/sixth	6.45/sixth	900	-	Gravity water supply (wrag spring tapped)
41.	Khatavderodi (47G/15 1B)	NE of village in hill top	24.31/sixth	-	1080	Laterite/ Lithomarge	Gravity water supply
42.	Ambavone (47G/15 1B)	NW of village near Dhanparwadi	22.08/sixth	5.52/sixth	960	WMB/ Moderately WMB	-do-
43.	-do-	West of village	44.16/sixth	22.08/sixth	800	VB/HMB	-do-

44.	-do-	-do- (A chain of springs)	-	-	800	-do-	Not use
45.	Natachi Pag (47G/15 1B)	N of village	32.40/sixth	16.20/sixth	820	VB/ Moderatley WMB	Water supply & irrigation (partly wasted)
46.	Jaichevadi (47G/15 1B)	NW of village	52.99/sixth	39.74/sixth	980	Laterite/ Redbole	Gravity water supply (ineffectvie)
47.	Chapoli (47G/15 1B)	1/2 km NW of village	6.62/sixth	6.62/sixth	700	Talus/HMB	-do-
48.	Dhoroshi (47G/15 1C)	SSW of village	4.8/seventh	4.8/seventh	750	WMB/HMB	Not used
49.	Pabalwadi (Vajhroshi) (47G/15 1C)	300 m Sw of village and 150m of of a temple	432/fifth (chain of springs)	-	950- 850	-	Drinking & Irrigation (open channels)
50.	Bhandvadwadi (Vajhroshi) (47G/15 1C)	SW of village and South of Tarkeshwar temple	216/fifth	-	1000	VB/WMB	Not used
51.	-do-	100 m SSE of village and 300 m SE of Bhairavnath temple	54/fifth	-	1010	-	-do-
52.	-do-	15 m E of spring No.47	30.84/sixth	-	1010	-	-do-
53.	Sadabaghapur	1/2 km E of vilalge	51.84/sixth	25.92/sixth	1080	Laterite/ Lithomarge	irrigation
54.	Sadabaghapur (47G/15 1C)	500 m NW of village	21.6/sixth	-	1060	Talus/poorly laterite flow	Not used
55.	Joglevadi (47G/15 2C)	1 km W of village	-/sixth	-/sixth	860	WMB/ moderately WMB	Not used
56.	Pagatyachawadi (47G/15 2A)	N of village	9.6/sixth	-	900	-	Gravity water supply
57.	Thirambe (47G/15 2A)	500 SE of village	-	Dry	610	Talus/HMB	-do-

58.	Taliye (47G/15 2A)	SE of west Taliye	216/fifth	-	600	VB/ Moderately WMB	-do-
59.	Lendori (47G/15 2A)	SE of village	17.28/sixth	12/96/sixth	980	-	Gravity water supply
60.	Kusavde (47G/15 2A)	-do-	36.72/sixth	23.52/sixth	720	-	-do-
61.	-do-	-do-	34.56/sixth	25.92/sixth	700	-	-do-
62.	Pimplashi (47G/15 2B)	500 m NW of village	23/16/sixth	-	660	Talus/HMB	-do-
63.	-do-	-do-	15.43/sixth	-	660	-do-	-do-
64.	Kavadvadi (47G/15 2B)	1/2 km NE of village	-	-	630	Fractures in HMB (N50°E-S50W, N60E-S60W)	Not used
65.	Brondri (47G/15 2B)	NW of village	11/35/sixth	8.50/sixth	1000	Laterite/ HMB	Gravity water supply (ineffective)
66.	-do-	W of village	-	-	660	Talus/HMB	Irrigation
67.	-do-	-do-	-	-	700	-	Developed into a dugwell
68.	-do-	1 km SW of village	11.23/sixth	5.26/sixth	940	WMB/HMB	Not used
69.	Chiteghar (47G/15 2B)	-do-	13.58/sixth	6.70/sixth	700	WMB/HMB	Gravity water supply
70.	Jhakate (47G/15 2B)	3oo m W of village	13.08/sixth	-	620	Talus/HMB	Not used
71.	-do-	300 m S of village	-	-	660	Talus/HMB	-do-
72.	Kalkevadi (47G/15 2C)	300 m S40E of village	13.80/sixth	13.80/sixth	860	Fractures in massive basalt	Drinking (open channels)
73.	Dadoli (47G/15 2C)	South of village	43.2/sixth	21.6/sixth	900	VB/HMB	Not used

74.	Digewadi (47G/15 2C)	NNE of village	-/sixth	-/sixth	1050	-	Gravity water supply
75.	Kodal (47G/15 3A)	SW of village	30.86/sixth	-	670	VB/HMB	Not used
76.	-do-	S of village	43.20/sixth	-	700	-	-do-
77.	KoKisre (47G/15 3B)	W of village	123.43/fifth	61.73/fifth	925	-	Gravity water supply irrigation
78.	Amrag (47G/15 3B)	510 m SE of village	86.40/fifth	43.20/sixth	910	-	Not used
79.	-do-	-do-	108/fifth	27/fifth	890	-	-do-
80.	Gokul (47G/15 3B)	560 E of village	13.08/sixth	3.26/sixth	790	-	-do-
81.	Varpewadi (47G/15 3B)	SE of village	-	-	860	VB/ moderately WMB	-do-
82.	-do-	SSE of village	18/sixth	-	880	-	-do-
83.	-do-	-do-	21.6/sixth	-	900	VB/ moderately WMB	-do-
84.	-do-	S of village	13.54/sixth	-	920	-do-	-do-
85.	-do-	-do-	-	-	950	WMB/Redbole	-do-
86.	Takkawadi (47G/15 3B)	200 m SE of village	-	-	940	VB/ Moderately WMB	-do-
87.	Natoshi (47G/15 3B)	S40W of village	86.40/fifth	-	900	WMB/Redbole	-do-
88.	-do-	S30W of village	43.20/sixth	-	900	-do-	-do-
89.	-do-	S25W of village	12.36/sixth	-	900	-do-	-do-
90.	-do-	-do-	21.60/sixth	-	900	-do-	-do-

91.	-do-	-do-	8.64/sixth	-	900	-do-	-do-
92.	-do-	S15W of village	7.20/sixth		900	-do-	-do-
93.	Natoshi (47G/15 3B)	S10°W of village	10.8/sixth	-	900	-	Not used
94.	-do-	S30°E of village and S40°W of Kadamvadi	10.8/sixth	-	900	-	-do-
95.	Kubrund (47G/15 3B)	S35W of Pawarvadi	21.60/sixth	10.80/sixth	900	-	Gravity water supply
96.	-do-	-do-	21.60/sixth	10/80/sixth	900	-	-do-
97	-do-	S of Kuorund	144/fifth	72/fifth	900	-	-do-
98.	-do- (Kotekarwadi)	SSW of Kotekarwadi	12/sixth	6/sixth	900	-	-do-
99.	Dhadamvadi (47G/15 3B)	W of main village in between two wadis	-	-	860	Fractures of HMB	Drinking
100.	-do-	W of village	-	-	900	VB/ moderately WMB	Castle use
101.	Tamine (47G/15 3B)	E of village (3 springs)	144/fifth	-	90	Laterite/ HMB	Not used
102.	-do-	S of village	9.6/sixth	-	950	-	Gravity water supply
103.	Changulewadi (47G/15 3C)	300 m S50E of villsge	7.2/sixth	Dry	760	-	-do-
104.	-do-	S25E of village	21.6/sixth	10.8/sixth	840	-	Not used
105.	Bhalekarvadi (47G/15 3C)	500 m E of village	-/sixth	-/sixth	940	-	-do-
106.	Julewadi (47G/15 3C)	SW of village	-	-	930	-	Developed into a dugwell
107.	-do-	-do-	-	-	930	Laterite/ HMB	Not used

108.	Asolevadi (47G/15 3C)	250 m NW of village	-	-	920	-	-do-
109.	Divshi (47G/15 3C)	SSW of village	-	-	780	Fracture in ves. basalt (vesicular not interconnected)	-do-
110.	Naikba (47G/15 3C)	200 m SW of village	-	-	760	WMB/HMB	Washing
111.	Paneri (47G/16 1A)	150 m S of village	-	-	900	Talus/HMB	Not used
112.	-do-	-do-	18.62/sixth	-	900	Talus/HMB	Gravity water supply
113.	-do-	300 m SW of village	-	-	950	Talus/HMB	Not used
114.	Dhaudvadi (47G/16 1A)	E of village	86.40	-	960	-	-do-
115.	Dhangarvodi (47G/16 1A)	100 m NW of village	-	-	980	Talus/ poorly Lateritised flow	-do-
116.	Karle	N of village	-	-	950	-	Irrigation (30 areas)
117.	Nijade (47G/16 1B)	SE of village	86.40	-	770	Fractures in HMB	Not used
118.	Khale (47G/16 1C)	NE of village	-/sixth	Dry	600	-	-do-
119.	Achrevadi (47G/16 2C)	SSw of village	-	-	900	-	Cattle use
120.	Sidrukvadi (47K/3 3A)	1 km NE of Koderi	-	-	840	Talus/HMB	-do-
121.	Joglevadi (47G/11 2C)	About 1 km West of village	-/sixth	-/sixth	860	WMB moderate WMB	Not used

Index
Talus = Talus deposits
VB = Vesicular basalts
WMB = Weathered massive basalt
HMB = Hard massive basalt, may be poorly weathered and poorly jointed.