CASE STUDY

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REPRESENTATIVE BASIN STUDY - PART 2 ESTIMATION OF GROUNDWATER BALANCE OF GHATAPRABHA REPRESENTATIVE BASIN (UPTO DADDI)

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PREFACE

Representative basin studies are conducted to provide an idea of the hydrological characteristics of the area. The principal objectives are the prediction and quantitative estimation of various components of the hydrological cycle. The results from such type of studies can be used for developing holistic model for similar hydrological systems.

As part of the work programme of Regional Centre, Belgaum, two representative basins, ie. Malaprabha upto Khanapur and Ghataprabha upto Daddi, were selected to represent the Deccan Hard Rock Region of India. In the first part of this study, the concept of representative basin and a detailed account of current status of the two basins were explained.

The present report, prepared by Mr.Chandramohan.T, Scientist B and Mr.Chandra Kumar.S, Research Assistant, deals with the quantification of groundwater potential of Ghataprabha Representative Basin.

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1.0 INTRODUCTION

Over the past few decades, with the increasing demands for irrigation, industrial and domestic purposes, the ground water is gaining added importance in the development of water resources system. Utilisation of this natural resource has two broad aspects, (a) the estimation of total quantity of the resources and (b) the development of suitable methods of harnessing and utilisation to ensure maximum benefit.

Ground water is most widely distributed in the earth's crust and it is a replenishable resource of the nature. Ground water exists wherever water penetrates beneath the surface, the rocks beneath the surface are permeable enough to transmit this water, and the rate of infiltration is sufficient that the rocks are saturated to an appreciable thickness. So the distribution of ground water depends upon the geology of the area, ie. aquifer material, its structure, composition, porosity and permeability. Aquifers are groundwater storage reservoirs. A confined aquifer is overlain and underlain by confining layers and water in the confined aquifer occurs under pressure which is more than the atmospheric pressure. An unconfined aquifer is not overlain by any confining layer but it has a confining layer at its bottom and it is partly saturated with water and the upper surface of saturation is termed as water table which is under atmospheric pressure.

India as a whole can be divided hydrologically into four regions, Hard rock area, Coastal alluvial area, Semi-Arid region and Indo-Gangetic plain.

Hard rocks are those geological formations, the drillability of which is low and the inter-granular porosity is practically absent, such as igneous and metamorphic rocks as well as lime stones, dolomites and cemented sand stones. Unlike sedimentary formation, the hard rock generally represent an isotropic media in which ground water occurs in isolated pockets. 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 major river basins but also for smaller sub basins. In many cases very small tributary basins covering only a few square kilometer area can be demarcated. Since basin boundaries are well defined and inter basins transfers seldom occur, better accuracy can be obtained in hard rock areas in evaluating groundwater resources potential.

Ground water in these hard rock occurs in the weathered and fractured zones. Water levels in the wells vary from about 1.5 m to more than 20m. The annual fluctuation of water level varies from about 2m to 10m. The exploration carried out by the CGWB has indicated that water bearing fractures occur down to 200m at favourable locations. The yield of the wells ranges from 0.5 lps to 15 lps. There are instances when bore wells have given more than 30 lps.

An important aspect of scientific management of ground water resources lies in the provision for better natural and artificial recharge. In the hard rock area natural recharge can be adopted by checking the ground water movement by constructing the under ground water barriers, subsurface dams across the flow direction. Indigenous attempts on such structures in selective catchments in India have been successful. In some advanced countries fracturing of the rocks through non-proliferated underground nuclear detonation or through heavy blasting is planned to create favourable conditions for ground water storage and timely discharge.

For the optimum development of ground water potential of a region, it is imperative that the ground water resource is evaluated as accurately as possible to avoid under utilization or over development. From the point of view of various consideration connected with problems of ground water development, the present study has been oriented to arrive at an evaluation of ground water potential within the representative basin of hard rock region.

2.0 REVIEW

2.1 GROUND WATER SITUATION IN INDIA

India is a vast country having diversified geological characteristics. Variations exhibited by the rock formations ranging in age from the Archaean crystallines to the recent alluvia, are as great as the hydrometeorological conditions. Variations in the land forms are also significant. It varies from sea level at the coasts to the peaks of the Himalayan mountains that attains altitudes of the range of 9,000 metres. These variations have correspondingly given rise to widely varying groundwater situation in different parts of the country.

In the high altitude areas of the Northern and North-Eastern regions and in the Central and South Indian regions, the presence of very steep slope conditions and geologic structures offer extremely high run-off and thus very little scope for rain water to find favourable conditions of storage and circulation as ground water.

The large alluvial tract extending over 2,000 km in length from Punjab in the West, to Assam in the East often referred to as Sindhu-Ganga-Brahmaputra Plain, is the most potential and important region from the view point of groundwater resources.

Almost the entire Central and Southern India is occupied by a variety of hard rocks. Rugged topography, hard and compact nature of rock formations, geologic structures and meteorological conditions have yielded an environment which allows ground water storage in the weathered residium and its circulation. The hard rock terrains, river valleys and abandoned channels, having adequate thickness of porous material, act as potential areas for ground water storage and development.

The coastal and deltaic tracts, particularly of the East Coast are covered with vast and extensive alluvial sediments. Though these tracts are productive in terms of water yield yet the overall groundwater regime in coastal areas suffer from salinity hazards. Groundwater development in coastal areas should be regulated such that contamination of the fresh groundwater body with sea water is avoided.

Salinity in groundwater also exists in inland areas, apart from coastal areas, in parts of Punjab, Haryana, Uttar Pradesh, Rajasthan and Gujarat. This is generally confined to arid and semi-arid regions.

In recent years the source of subsurface water has been put to use on large scale in order to act as a useful source in droughts and also to support water supply schemes and to meet water requirements for high yielding crop varieties.

The groundwater resources were originally estimated based on ad-hoc norms. Though the detailed investigations suggested that these norms can be rationalised, conservative values were adopted during 1976 for reassessment of groundwater resources. Subsequent assessment were made as per norms of the Ground Water Over Exploitation Committee during 1979 and the Ground Water Estimation Committee during 1982.

Since the preparation of the Over Exploitation Committee report in 1979, considerable work has been carried out by various Research Institutes, Central Ground Water Board, State GroundWwater Organisations and Universities in the country, for updating the methodology for groundwater resource evaluation suited to hydrogeological conditions existing in different parts of the country.

3.0 METHODOLOGY

Water balance technique has been extensively used to make quantitative estimates of water resources and the impact of man's activities on the surface water and groundwater regimes. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system. After these studies, modelling can be done for evaluating impact of alternative policies so as to select a safe abstraction policy.

The law of conservation of matter applied to the hydrologic cycle defines the water balance. It states that within a specified period of time, the excess/deficit of inflow into a storage medium like aquifer over the outflow from the aquifer must either go into the storage within its boundaries or be consumed internally. With reference to the groundwater regimes, the inflows include precipitation infiltrating to the water table, natural recharge from streams, channels, lakes and ponds, groundwater inflow through boundaries and artificial recharge from irrigation reservoirs, spreading ponds and injection wells. The element of outflow include evaporation from capillary fringe and areas of shallow water table, transpiration by phreatophytes, natural discharge by seepage and spring flow to streams, lakes and ponds, groundwater outflow through boundaries, and artificial discharge by pumping. Groundwater balance requires that in any interval of time the total inflow does not equal the total outflow and there is no un-accounted amount for consumption, any difference should cause equivalent change in groundwater storage.

The basic concept of water balance is:

inflow to the system - outflow from the system = change in storage of the system, over a period of time.

The general steps involved in the computation of water balance include:

- identification of significant components,
- evaluating and quantifying individual components, and
- presentation in the form of water balance equation as
  Inflow - Outflow = Change in Storage.

3.1 GROUNDWATER BALANCE EQUATION

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

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

where,

R_i = recharge from rainfall
R_c = recharge from canal seepage
R_r = recharge from field irrigation
= R_{rs} + R_{rg}
R_{rs} = recharge from surface water irrigation
R_{rg} = recharge from ground water irrigation
R_t = recharge from reservoirs and tanks
I_g = subsurface inflow to the study area
S_i = influent seepage from rivers
T_p = draft from ground water
E_t = evapotranspiration losses
= E_{tf} + E_{tw}
E_{tf} = evapotranspiration losses from forested area
E_{tw} = evapotranspiration losses from water-logged area
O_g = sub-surface outflow from the study area
S_e = effluent seepage to rivers
ΔS = change in ground water storage, positive for increase and negative for depletion.

In an unconfined ground water regime under exploitation conditions, all the above factors may have to be considered. In a fully confined ground water regime, ground water inflow, outflow and extraction, if any, are the major components of ground water balance that need to be considered. In leaky aquifers, the inflow and outflow components will include leakage into and out of the aquifers. The factors that are inconsequential can be ignored and the ground water balance equation simplified. When the water balance computation is made for a confined aquifer, groundwater balance equation can be simplified considerably.

Proper assessment of the values for the various components of the equation is very much necessary. Either over estimation or under estimation of the components makes the water balance study erroneous.

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

3.1.1 Recharge from Rainfall (R_i)

Theoretically, the optimum amount of groundwater that can be developed in a region is equal to the amount of recharge that takes place to the groundwater body. Hence the determination of the recharge component of the groundwater regime is of prime importance

Part of the rain water that falls on the ground is infiltrated into the soil. This infiltrated water is utilised in filling the soil moisture deficiency and the remaining part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. Rainfall is the most important source of groundwater recharge in the country.

The recharge to groundwater from rainfall can be estimated analytically from available hydrometeorological, soil moisture and water table data. This can be estimated by:

a) water balance approach,
b) vertical variation of soil moisture in the unsaturated zone (zone of accretion),
c) empirical method.

a)In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. The rainfall recharge for monsoon season can be calculated by substituting these estimates in the water balance equation. Recharge coefficient, ie. recharge per unit rainfall is thus estimated. A prerequisite for application of this technique is extensive and reliable data.

b)In this method, the recharge is estimated by studying the one dimensional vertical flow of water in the gravitational water zone. The recharge is the net integrated decrease in the soil moisture obtained by summing the net flux at the top of the gravitational water (percolation) zone. The variation of the soil moisture content with depth can be obtained by solving numerically the governing differential equation with appropriate initial and boundary conditions. This method requires an accurate transient soil moisture history to obtain a realistic estimate of recharge.

Nuclear techniques have been extensively used for the determination of recharge by measuring the travel of moisture through the soil column. The technique is based upon the existence of a linear relation between neutron count rate and moisture content for the range of moisture contents generally occurring in the unsaturated soil zone.

Another method is the gamma ray transmission method and is based upon the attenuation of gamma rays through a medium through which it passes. The extent of attenuation or absorption is closely linked with the moisture content of the soil medium.

The net value of groundwater recharge can also be estimated using soil moisture balance equation considering the unsaturated zone as a lumped subsystem.

c)These equations are generally derived from locally observed data, and thus are not valid for universal application.

Since most of the rainfall occurs in the monsoon season only, it is assumed that in non-monsoon season all the rain water is used by crops and absorbed in the soil moisture zone with no recharge to ground water reservoir. Hence the recharge from rainfall can be taken as zero in the non-monsoon season.

3.1.2 Recharge from Canal Seepage (R_c)

Seepage refers to the process of water movement from a canal into sub-surface strata. Seepage losses from surface water bodies often constitute a significant part of the total recharge to ground water system.

For homogeneous soils, recharge can be calculated using linear and non linear models. Bouwer (1969) assumes a linear relation between flow rate and head difference between channel and aquifer and is essentially based on Dupit assumptions. The coefficient of proportionality generally known as reach transmissibility depends upon the stream bed characteristics and shape of the stream section. Rushton (1979) has suggested a non linear exponential relation.

For estimating the recharge from a channel embedded in non-homogeneous soils, finite difference or finite element methods are normally employed to obtain numerical solution of Laplace equation with appropriate boundary conditions.

To obtain seepage from canal under field situations, the data related to running days in monsoon and non-monsoon seasons are required for the study period. Assuming the seepage factor and knowing wetted area for different irrigation schemes, recharge from canal seepage in monsoon and non-monsoon seasons for different irrigation schemes can be estimated as:

Recharge from Canal Seepage = Seepage Factor x Wetted Area x Running Days

3.1.3 Recharge from Field Irrigation (R_r)

Water requirements of crops is met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated fields for growing crops is lost in consumptive use and the balance infiltrated to recharge the ground water. Infiltration from applied irrigation water, derived both from ground water and surface water sources, constitutes one of the major components of ground water recharge. This recharge depends upon a large number of factors including the pattern of water application, mode of irrigation management, level of cultivators etc.

For a correct assessment of the quantum of recharge by applied irrigation, studies are required to be carried out on experimental plots under different crops in different seasonal conditions. In India, there is no experimental results available to assess recharge. It is generally taken as 30% to 40% of the irrigation water applied in the field.

a) Recharge from Surface Water Irrigation (R_{rs})

Recharge from surface water irrigation has been taken as 35 percent of water delivered for application in the field. Data of irrigated areas and average water depths in monsoon and non-monsoon seasons are required for the study period.

b) Recharge from Ground Water Irrigation (R_{rg})

Recharge from ground water irrigation has been taken as 40 percent of the water delivered (i.e. 30 to 40 percent of the ground water draft).

3.1.4 Recharge from Reservoirs and Tanks (R_t)

The change in storage of surface water stored in depressions at the beginning and at the end of the study period can be estimated from field survey and by taking the evaporation rate for the area into account, recharge to the groundwater reservoir can be estimated. The other approach is to measure ponded infiltration with an infiltrometer and compute the percolation recharge.

Studies have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity. Monthly water level data for tanks are required for the study period. The corresponding water spread areas will be estimated from area-elevation curves available. Then the monthly recharge values are computed by multiplying the seepage factor with the water spread areas.

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

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

$$I_g \text{ or } O_g = T\, I\, \Delta L$$

in which, T is the transmissivity I_g or O_g is the discharge passing through a particular segment, I is the gradient and ΔL is the length of the segment concerned. Thus to get the total discharge passing across the study areas boundaries, the discharge values for each segment are summed up. Thus:

I_g or $O_g = \sum T\ I\ \Delta L$

3.1.6 Effluent and Influent Seepage (S_e and S_i)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent).

For estimation of effluent or influent flows, all rivers coming in the study area are divided into a number of small reaches and computations are made for each segment. For every reach, at least one observation station nearest to the middle of the reach has to be selected. The hydraulic gradient is computed as the ratio of the difference between the river stage at the point where the normal from the observation well meets the river and the water level in the observation well, to the distance between the points under reference. Similarly observation wells are taken on the other side of the river and the hydraulic gradients are computed. Transmissivity of the aquifer is obtained from pump test data. The effluent or influent seepage can be estimated as:

S_e or $S_i = \sum T\ I\ \Delta L$

where, T is transmissivity, I is the hydraulic gradient and ΔL is the length of the reach. By considering sign of the gradient the influent and effluent seepages are estimated over the entire reach for all the rivers coming in the area.

3.1.7 Draft from Ground Water (T_p)

Draft is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal can be made by means of State (Deep) tubewells, Private (Shallow) tubewells, Pumping sets, Open wells and other means. An inventory of wells and sample survey data are prerequisite for computation of ground water draft.

In the case of State tubewells, information about the number of running hours and discharge measured are used to compute the volume of water pumped in each decision period. Similar information is needed for private tubewells, pumping sets and open wells. In order to determine the draft from these structures, sample surveys have to be conducted regarding their number, discharge and withdrawal in each season or year.

The yearly draft can be computed by multiplying unit draft with the number of devices. Seasonal draft values for monsoon and non-monsoon seasons can be taken as 20% and 80% of the yearly draft values.

3.1.8 Evapotranspiration Losses (E_t)

Evapotranspiration is the amount of water lost by evaporation and transpired through plants from a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface (within 30 cm), the evaporation from the soil and transpiration from the plants will be at the maximum possible rate i.e. at potential rate. Thes potential evaporation will take place in a water-logged tract and potential evapotranspiration takes place from the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such area can be worked out by usual methods of computing evapotranspiration using the known data.

There are several empirical or semi-empirical type of equations for computing potential evapotranspiration utilising one or more climatic measurements. If the study area does not have any forested area, the evapotranspiration losses from forested areas (E_{tf}) can be taken as zero. If the depth to water table below ground level is more than 2.0 m. throughout the study area, the evapotranspiration losses from waterlogged areas (E_{tw}) can also be taken as zero.

Practically no work has been done on the variation of evapotranspiration loss under different depths of water table. Moti Singh (1972) conducted experiments in an aerodynamic tunnel to study the effect of climatological variables and water table depths on evaporation from soil surface under laboratory conditions. It was observed that wind velocity and water table depth affect evaporation from soil surface significantly.

3.1.9 Change in Ground Water Storage (ΔS)

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

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

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

where,

ΔS = change in ground water storage,

Δh = change in water level,

A = area influenced by that well, and

S_y = specific yield.

The value of specific yield can be determined by pump tests, and analysing the data by any of the available methods.

The prerequisite for the quantitative evaluation of ground-water resources is the data on the physical framework of the aquifer system which comprises of topography, geology, geometrical configuration, boundaries, and finally the hydro- geologic characteristics. The hydrogeologic parameters are estimated quantitatively, unlike the others which are only described qualitatively. They appreciably depend upon the initial as well as on the prevalent conditions. The observation techniques and methods of data interpretation also bring in variability. it is, therefore, appropriate to recognise the range of their values.

The data required for carrying out the water balance study can be enumerated as follows;

4.1 Rainfall Data

Monthly rainfall data of sufficient number of stations lying within or around the area should be available. The location of raingauges should be marked on a map. It is desirable to use the data of a number of years. This will enable to determine the recharge of an average year, so that the groundwater potential of the area is known.

4.2 Land Use Data and Cropping Patterns

Land use data are required for estimating the evapotranspiration losses from the water table through forests and orchards. Crop data are necessary for estimating the spatial and temporal distributions of the ground water withdrawals and canal releases, if required Evapotranspiration data should also be available at few locations for estimation of consumptive use requirements of different crops.

4.3 River Data

River data are required for estimating the exchange of flow between the aquifer and hydraulically connected rivers. The data required for these computations are the river gauge data and the river cross sections at a few locations.

4.4 Canal Data

Monthwise releases into the canal and its distributories alongwith running days in each month will be required. To estimate the seepage losses, the seepage loss test data will be required in different canal reaches and distributories.

4.5 Tank Data

Monthly tank gauges and releases should be available. In addition to this, depth vs area and depth vs capacity curves should also be available. These will be required for computing the evaporation and the seepage losses from tanks. Also field test data will be required for computing final infiltration capacity to be used to evaluate the recharge from depression storage.

4.6 Water Table Data

Monthly water table data or at least pre-monsoon and post-monsoon water level data at sufficient number of wells should be available. The well locations should be marked on map. The wells should be adequate in number and distributed within the area, so as to permit reasonably accurate interpolation for contour plotting. The available data should comprise reduced level (R.L) of water table and depth to water table.

4.7 Aquifer parameters

The specific yield and transmissivity data should be available at sufficient number of locations in the area to account for the variation of these parameters within the area.

4.8 Details of Draft from wells

A complete inventory of the wells operating in the area, their running hours each month and discharge are required for estimating groundwater withdrawals. If draft from wells is not known this can be obtained by carrying out sample surveys. For getting the draft in each month, the consumptive use of crops can be adopted for evaluating the same.

5.0 STUDY AREA

Ghataprabha is one of the southern tributaries of river Krishna, originating from the Western Ghats in Sindhudurga District of Maharashtra at an altitude of about 884m, flows eastwards for a length of 283 km before joining Krishna at Kudalisangam about 35 km north-east of Kaladgi at an elevation of 500m. It flows for about 60 km in Sindhudurg, Kolhapur and Ratnagiri districts of Maharashtra before entering Belgaum district of Karnataka. A dam is constructed at Hidkal in Belgaum district to impound 1380 MCM water. Location of Ghataprabha basin is shown in figure 1.

5.1 Representative basin

The representative basin of Ghataprabha upto Daddi is confined by the co-ordinates 15 50' and 16 40' North latitudes and 74 08'and 74 30' East longitudes. The total geographical area is about 1055 Sq.km which lies in Sindhudurg and Kolhapur districts of Maharashtra (about 955 sq.km in Kolhapur and 100 sq.km in Sindhudurg). The study area with its drainage system is shown in figure 2.

5.2 Physiography

Flat to undulating with intermittent hills and valleys is the topographic characteristic of the basin. The representative basin is oval in shape. The altitude ranges between 682 m and 1039 m above the sea level.

5.3 Hydrology

The normal yearly rainfall in the basin is 1960 mm and normal monsoon rainfall is 1780 mm. The average maximum rainfall of 3011 mm is recorded at Chandgad and average minimum rainfall of 885.7 mm is recorded at Daddi. The average maximum temperature in the basin is 34.4 C and average minimum temperature is 18.6 C. The relative humidity is high during the monsoon period and low during the non-monsoon period. Maximum wind velocity of 15.3 km/hr NE is experienced during the month of July. The average discharge recorded at the mouth of the representative basin (Daddi) is 23034.80 cumecs.

5.4 Geology and Soils

Geologically the representative basin is covered by tertiary basalt and lateritic sedimentary rocks especially in the upstream

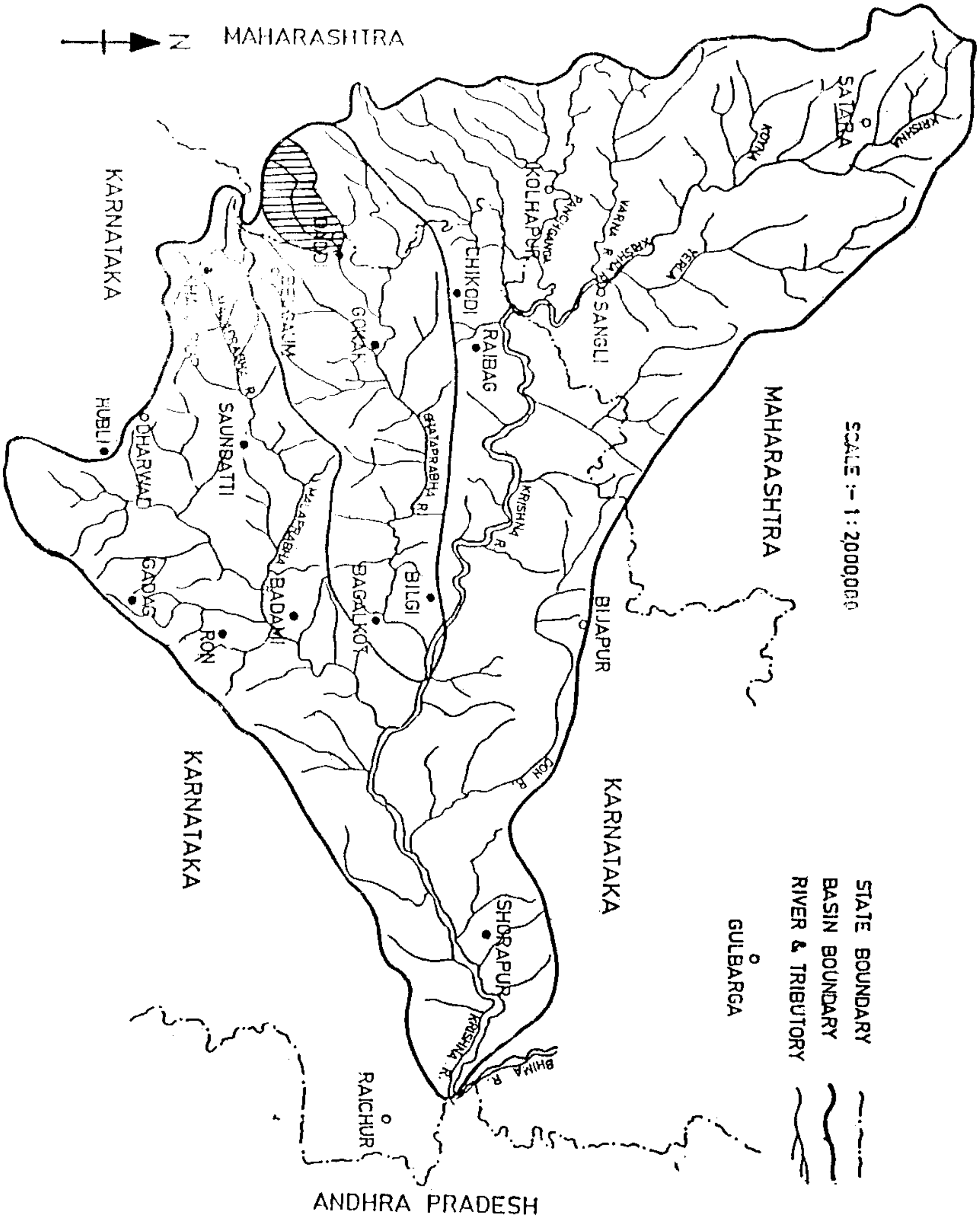

FIG. 1 LOCATION OF STUDY AREA

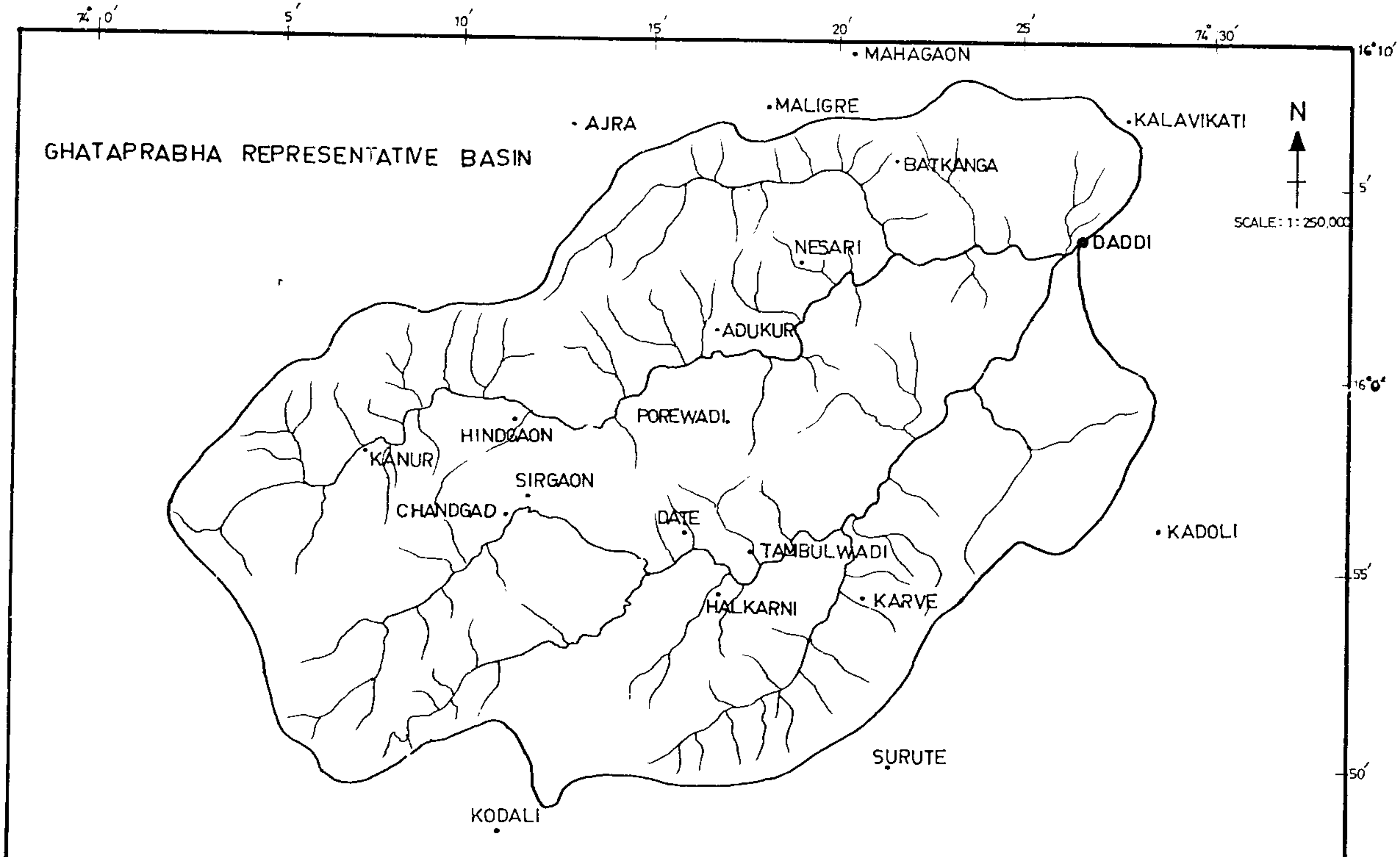

FIG. 2. STUDY AREA

area. There are three prominent types of soils, they are lateritic coarse shallow soil which can be seen in the upstream reaches, lateritic medium deep soil in the middle reaches and coarse shallow black soil in the downstream area.

5.5 Landuse pattern

Landuse and vegetal cover characteristics of an area has a significant influence on the amount of groundwater recharge. About 50% of the representative basin is covered by forest and shrubs and 40% is used for agriculture purpose. The rest of the basin remains as barren or fallow land.

The major crops cultivated in the area are Paddy, Ragi, Cotton, Fodder, Hy.Jowar, Jowar, Hy.Maize, Hy.Bajra and Groundnut in Kharif season, Jowar, Hy.Maize, Wheat, Pulses and Sun flower in Rabi season and Sugarcane as Perennial crop. There is no canal network in the study area. The water requirement for these crops are met by either rain water or groundwater.

5.6 Observation wells

Since the study area is within the catchment, observation wells are not distributed uniformly over the area because of high altitudes and unaccessible regions at upstream reach. For very few wells (5 wells), data is available from 1976 onwards. But for accurate estimation of groundwater balance, adequate number of well data is required, distributed throughout the area. For the present study, a total of 12 observation well data (monthly) is available from 1989 onwards and 15 observation well data is available from 1992 onwards. Monitoring of these wells are conducted by Groundwater Survey and Development Agency (GSDA), Kolhapur. The distribution of observation wells is shown in figure 3. It can be seen that the middle portion of the basin is having a high value of well density while upper and lower reaches are having very low well density.

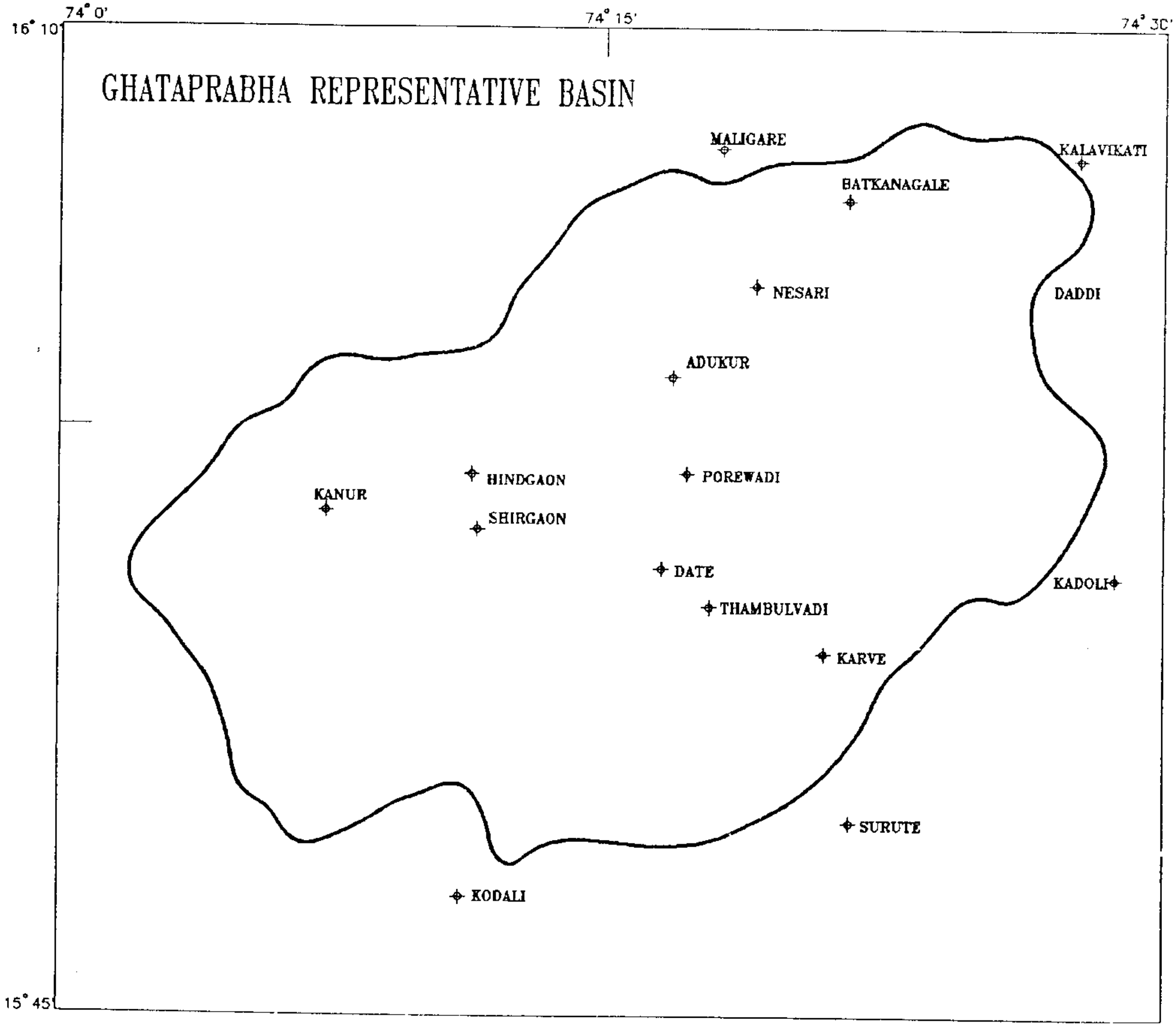

FIG. 3. LOCATION OF OBSERVATION WELLS

6.0 RESULTS AND DISCUSSION

For the assessment of net groundwater balance of the representative basin, Water Table Fluctuation Approach based on recommendations of the Groundwater Estimation Committee, Ministry of Irrigation, Govt. of India, is used.

Using the available monthly groundwater level data, groundwater level contours have been drawn for pre and post monsoon seasons for the period 1989-93. These have been shown in figures 4 to 13. Water table fluctuation between pre-monsoon (April/May) and post-monsoon (September) periods were calculated for each well and for each year (1989-93). These values will only represent the fluctuation in the area surrounding each well. For getting an average value of fluctuation for the study area, suitable weights have been allocated to each well, by drawing Theissen polygon. It is found that the five year average water level fluctuation for the area varies from 5.10 m to 6.78 m.

By analysing the weighted pre-monsoon and post-monsoon groundwater levels for the basin, it can be seen that (fig 14) the general tendency of the groundwater situation in the study area is encouraging, since it is showing an increasing trend. However the pre-monsoon levels show a decreasing trend, the reason for which may be the increase in draft rate in pre-monsoon period over the years (1989-93). Further, groundwater fluctuation also shows an increasing trend (fig 15) which indicates that the long term availability of groundwater resources is increasing.

Analysis for individual wells falling within the basin also shows that (fig 16 to fig 23) the water level increases over the study period, except for Nesari, where it shows a decreasing trends.

For the calculation of average and IMD normal annual rainfall for the study area, 5 raingauge stations were considered in and around the basin and Theissen method have been used for computation. They are Chandgad, Halkarni, Daddi, Ajra, and Nesari. Rainfall data for these stations have been given in table 1.

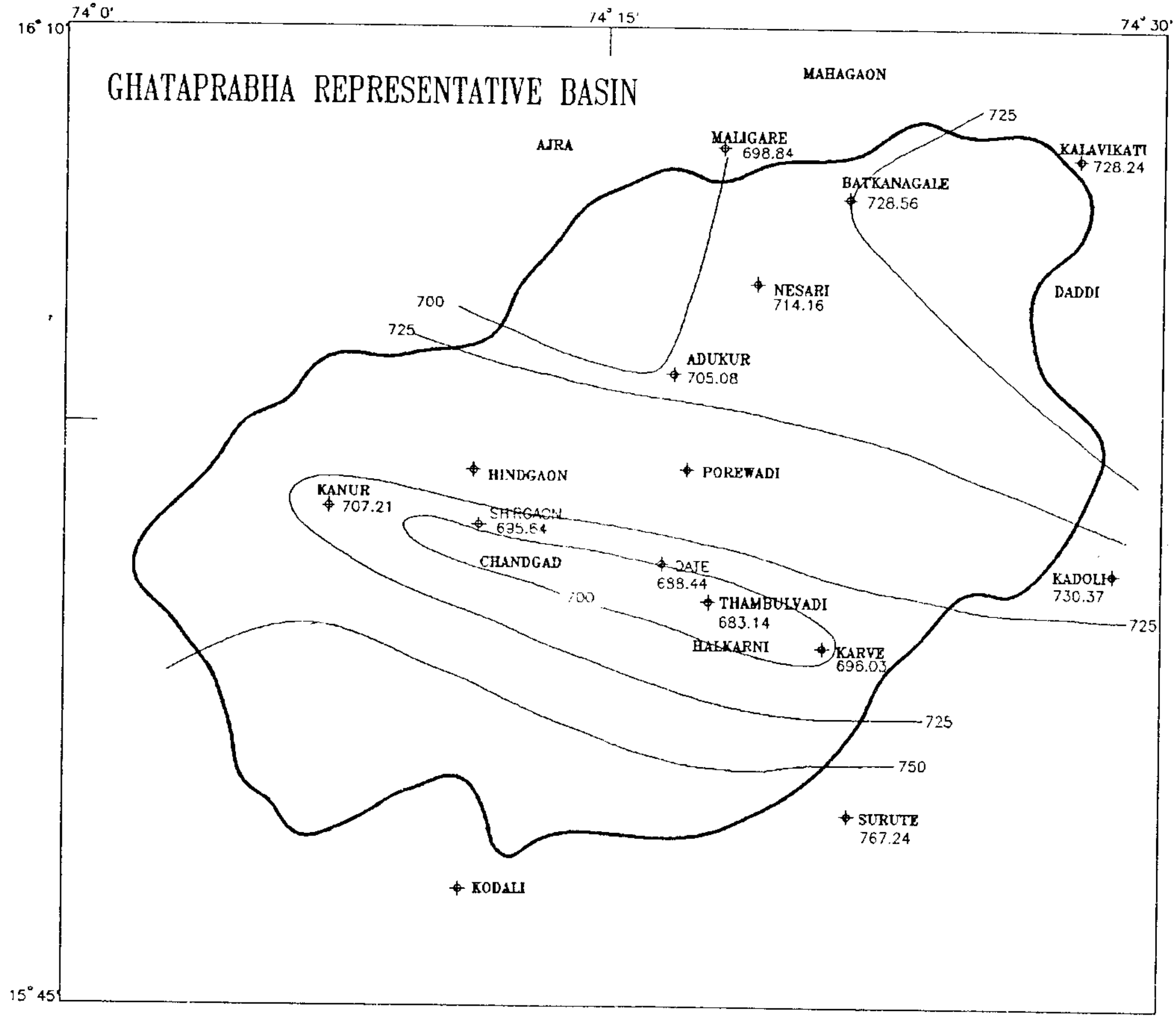

FIG. 4. GROUNDWATER LEVEL CONTOUR - 1989 PRE-MONSOON

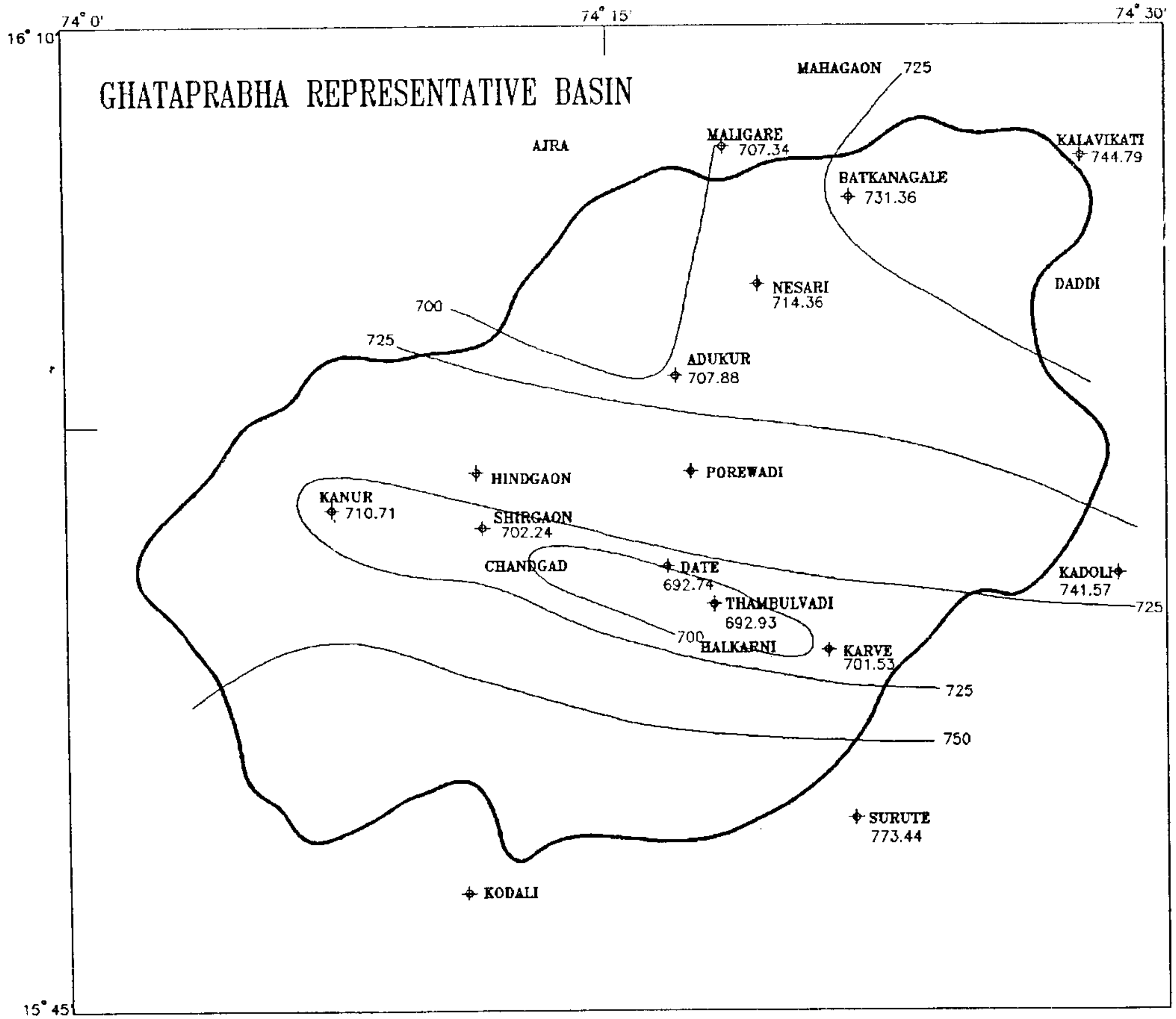

FIG. 5. GROUNDWATER LEVEL CONTOUR - 1989 POST-MONSOON

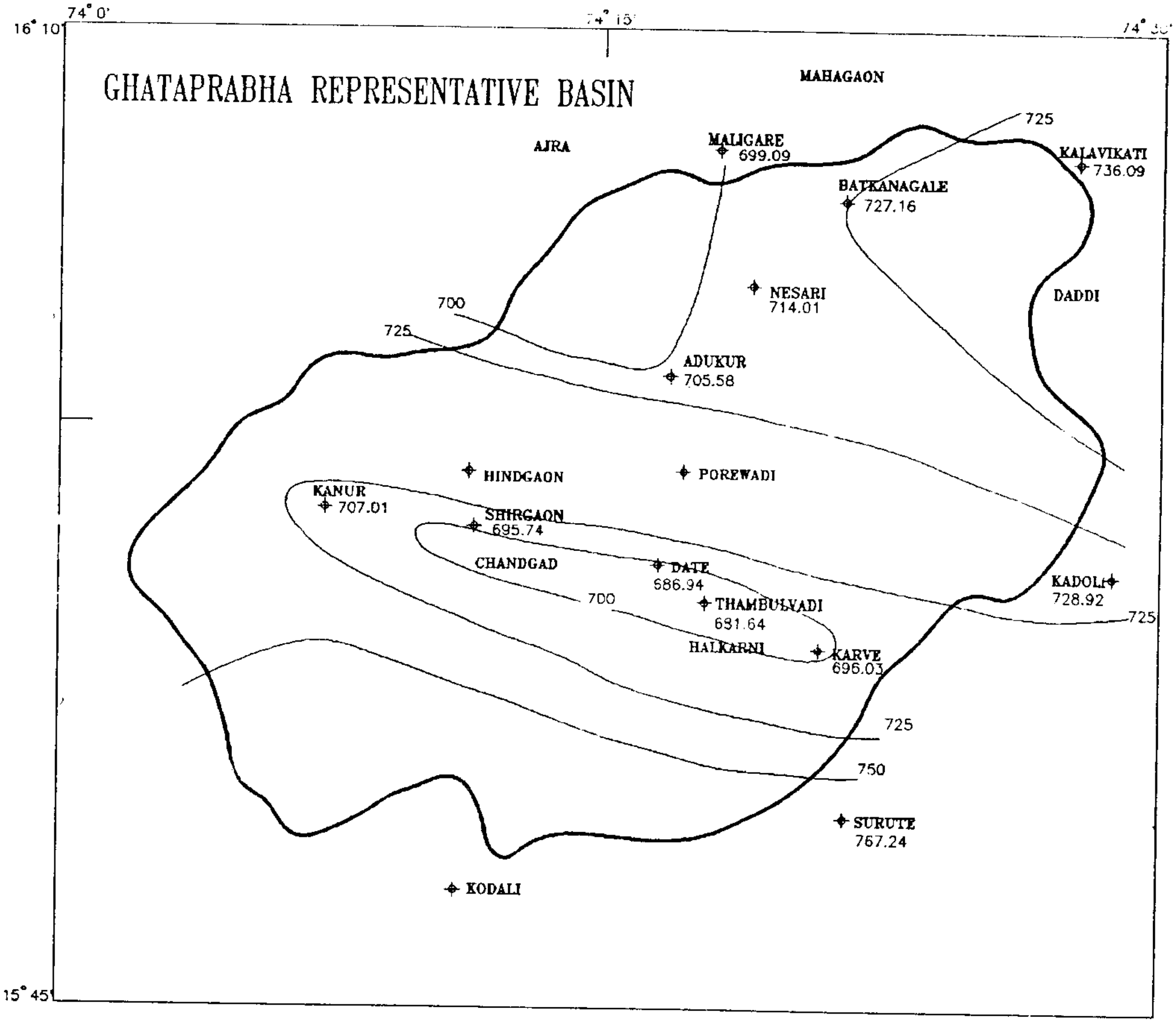

FIG. 6. GROUNDWATER LEVEL CONTOUR - 1990 PRE-MONSOON

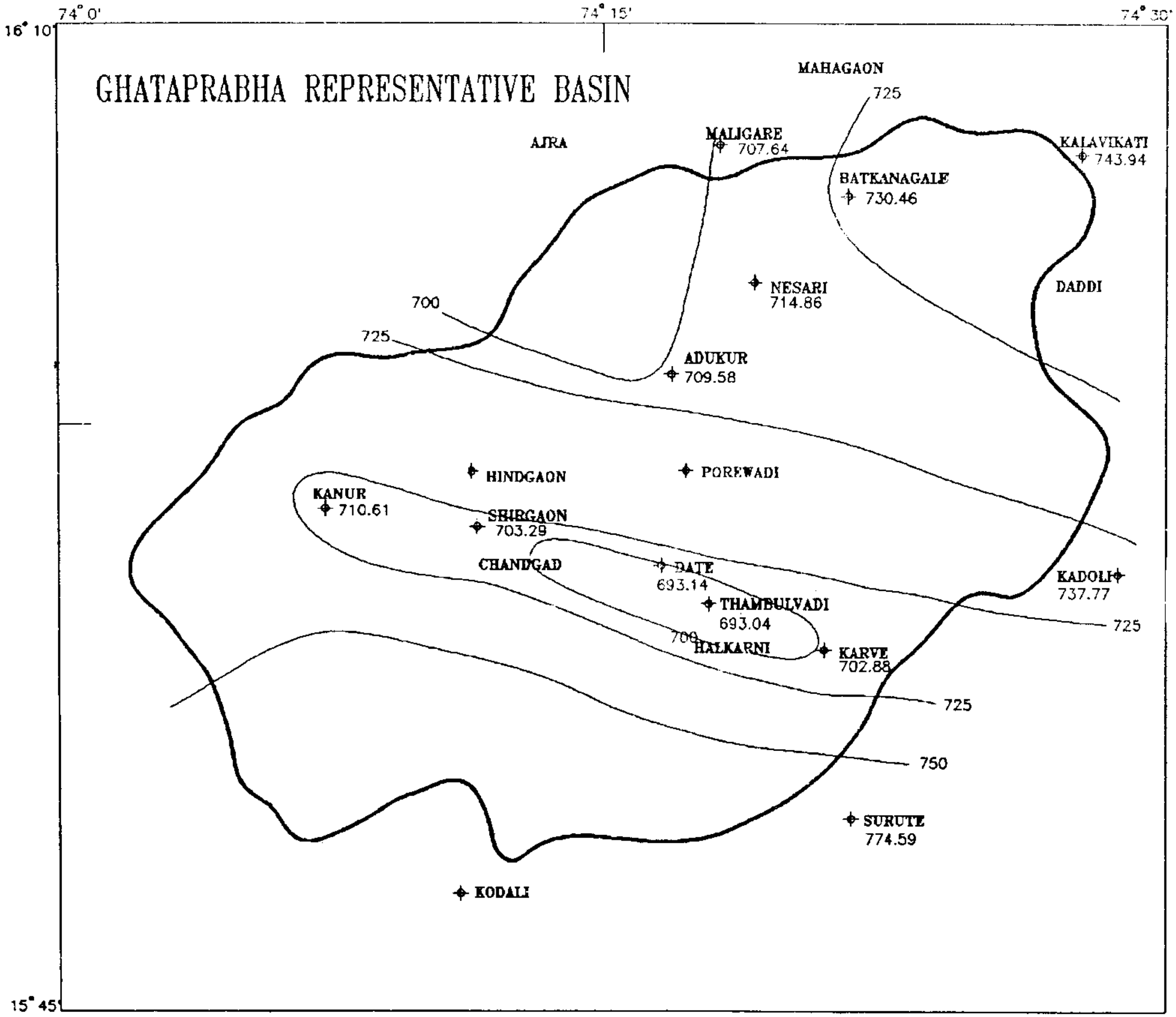

FIG. 7. GROUNDWATER LEVEL CONTOUR – 1990 POST-MONSOON

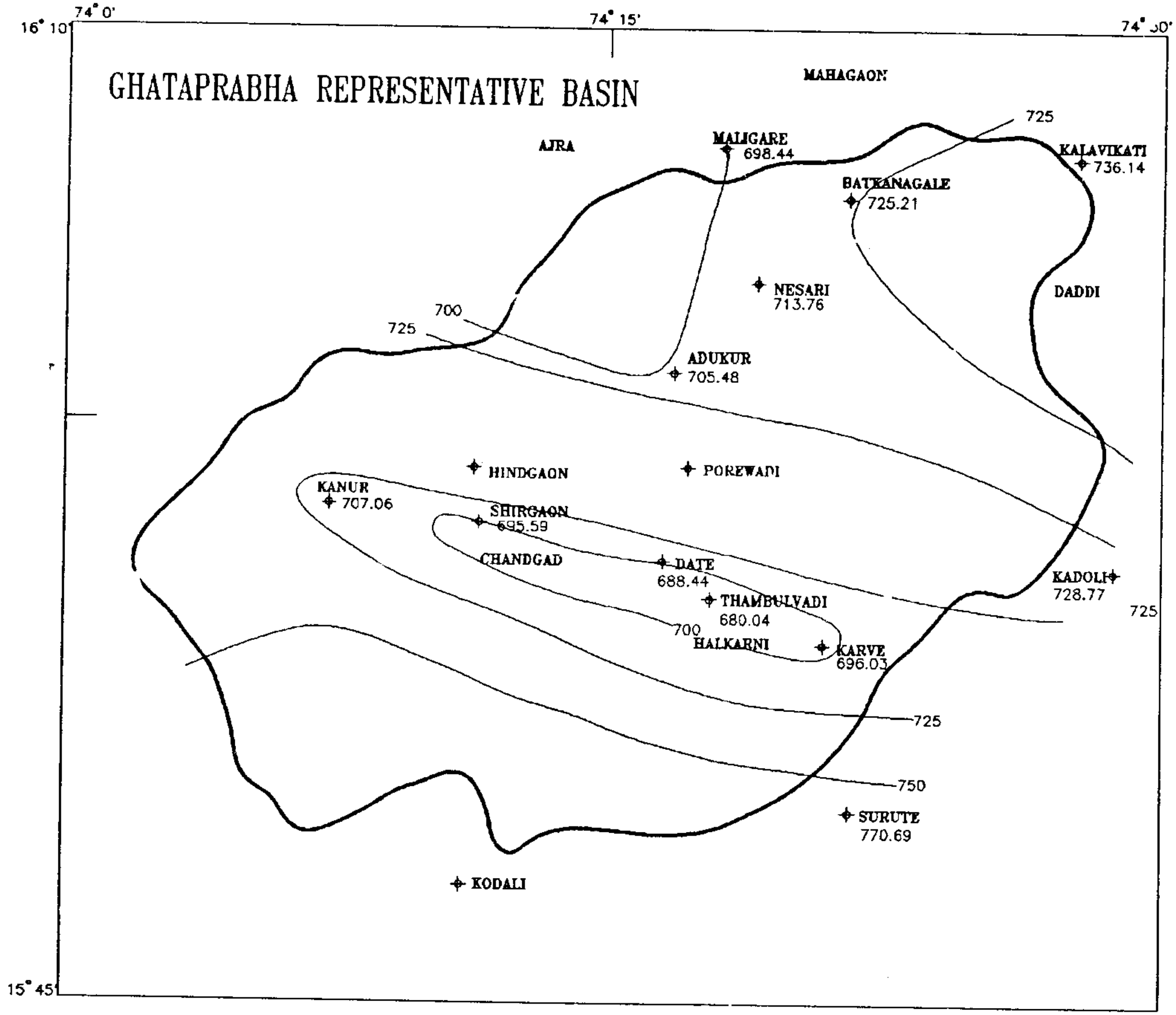

FIG. 8. GROUNDWATER LEVEL CONTOUR - 1991 PRE-MONSOON

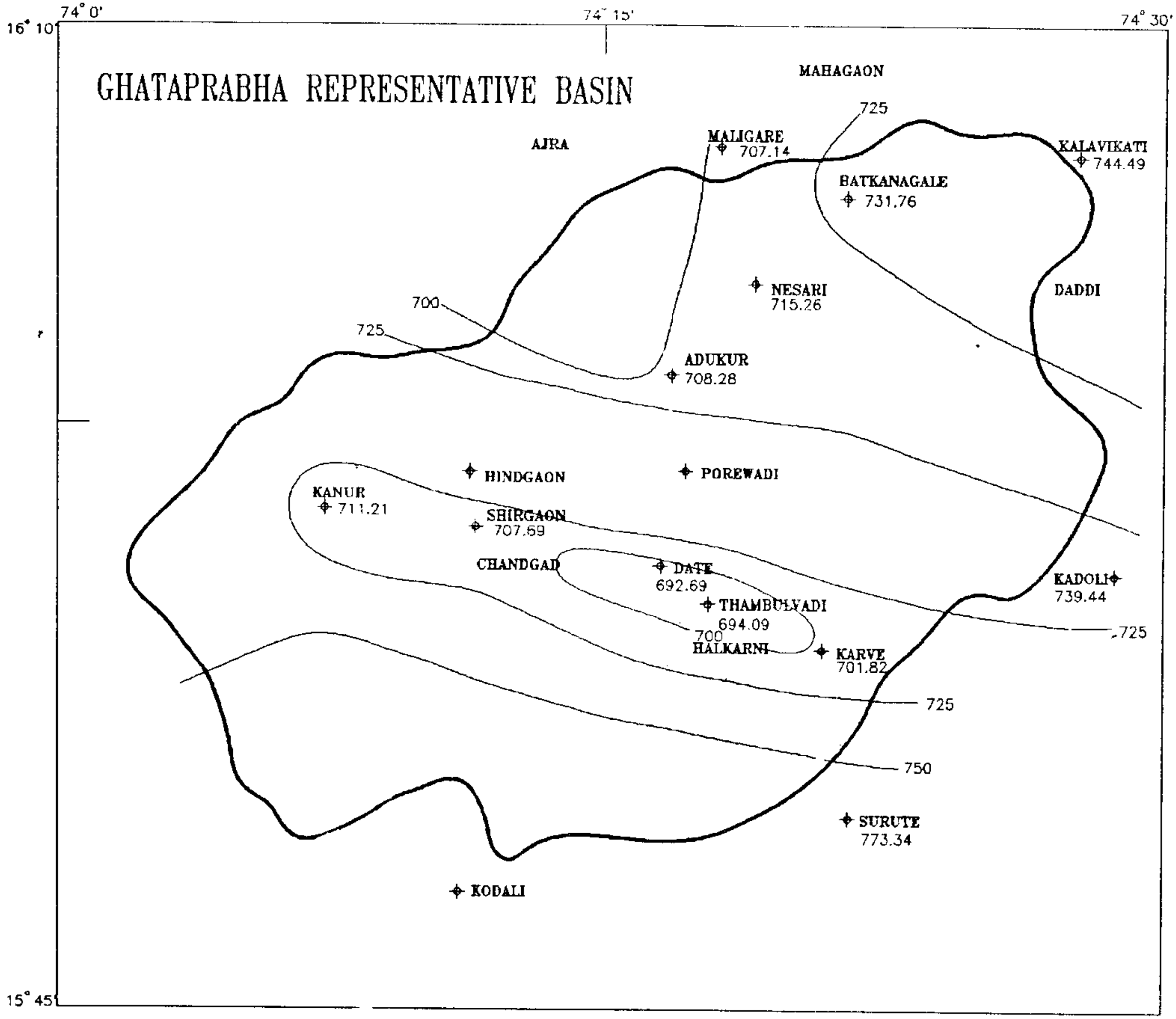

FIG. 9. GROUNDWATER LEVEL CONTOUR - 1991 POST-MONSOON

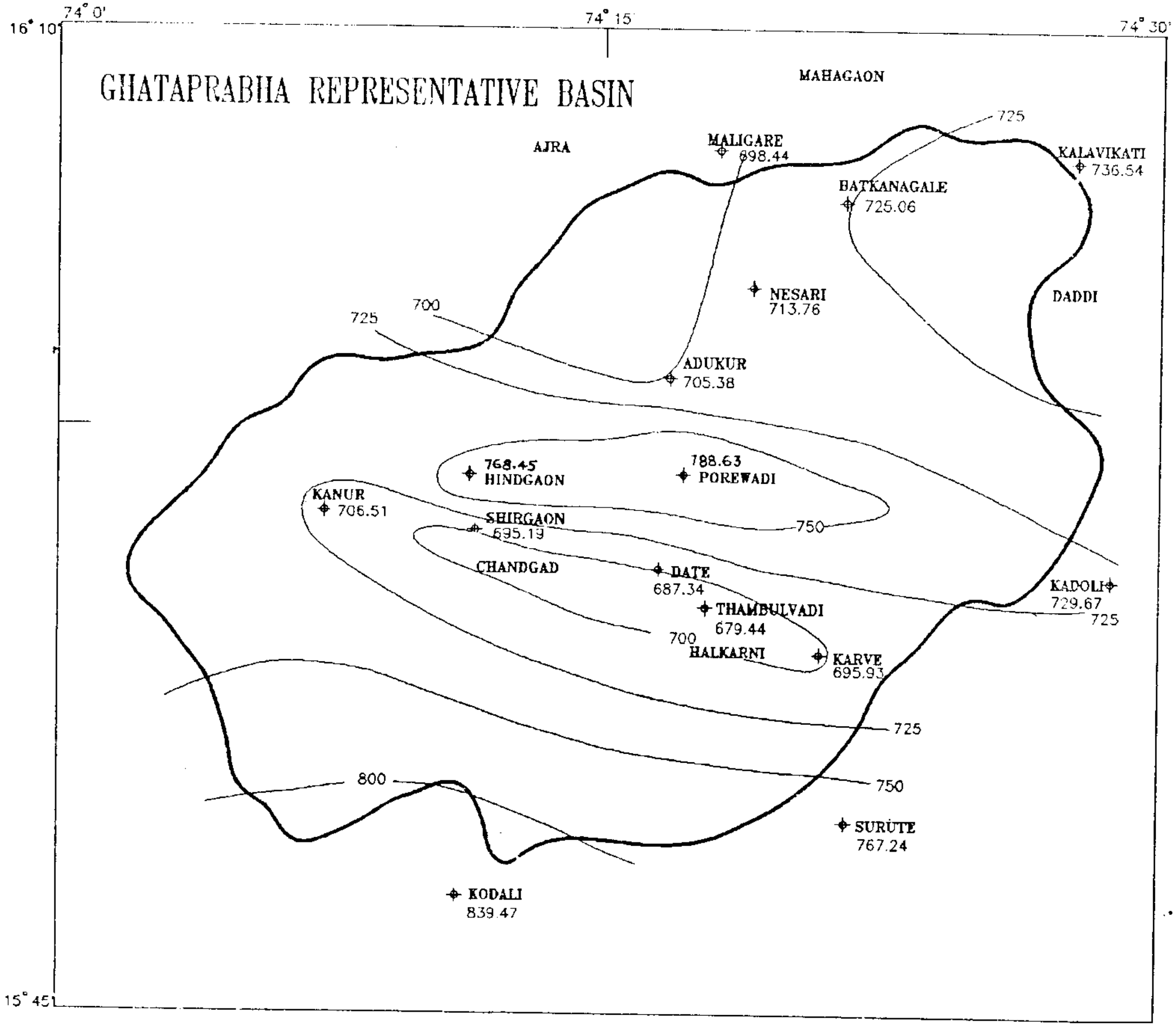

FIG. 10 GROUNDWATER LEVEL CONTOUR - 1992 PRE-MONSOON

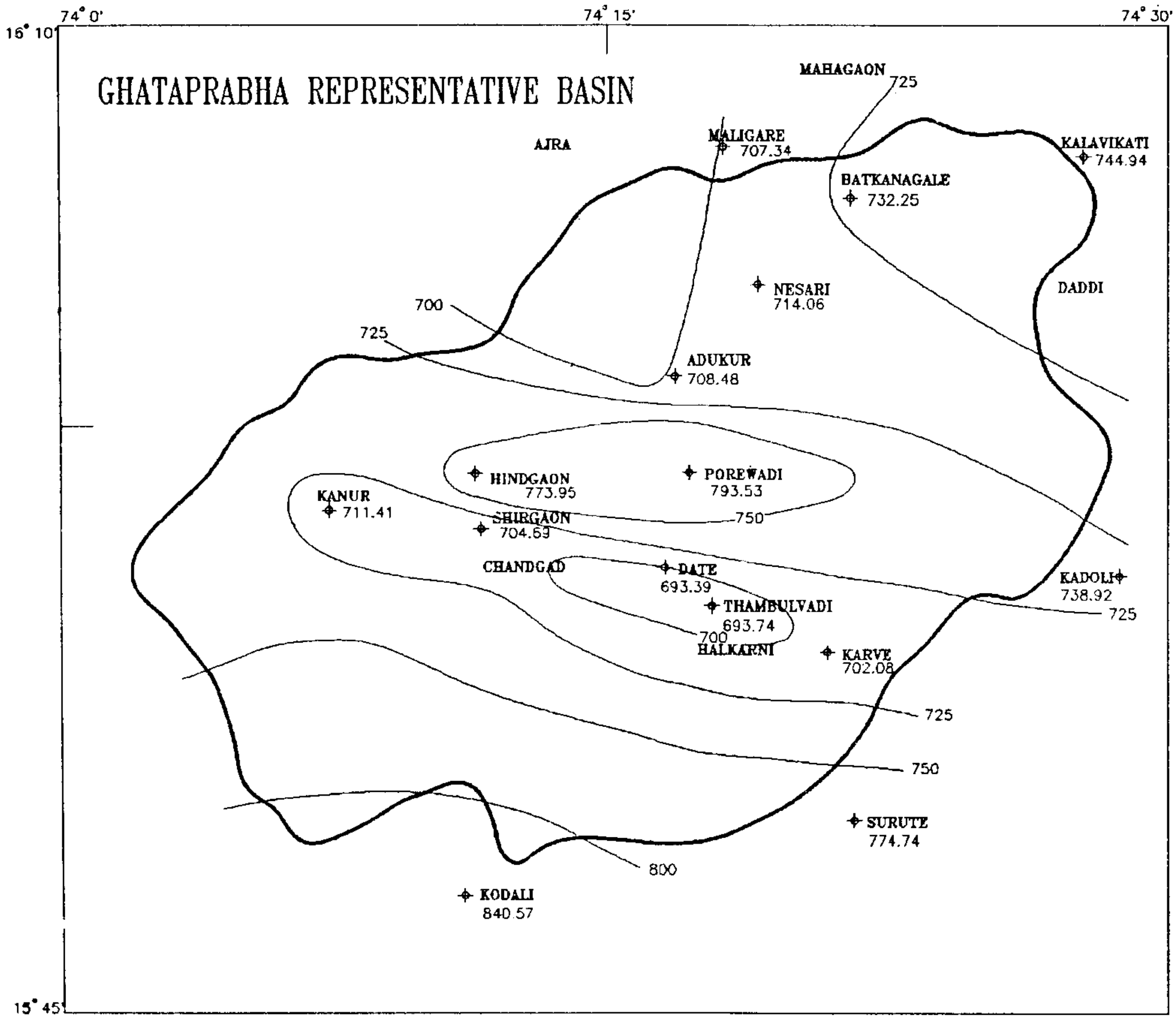

FIG. 11. GROUNDWATER LEVEL CONTOUR - 1992 POST-MONSOON

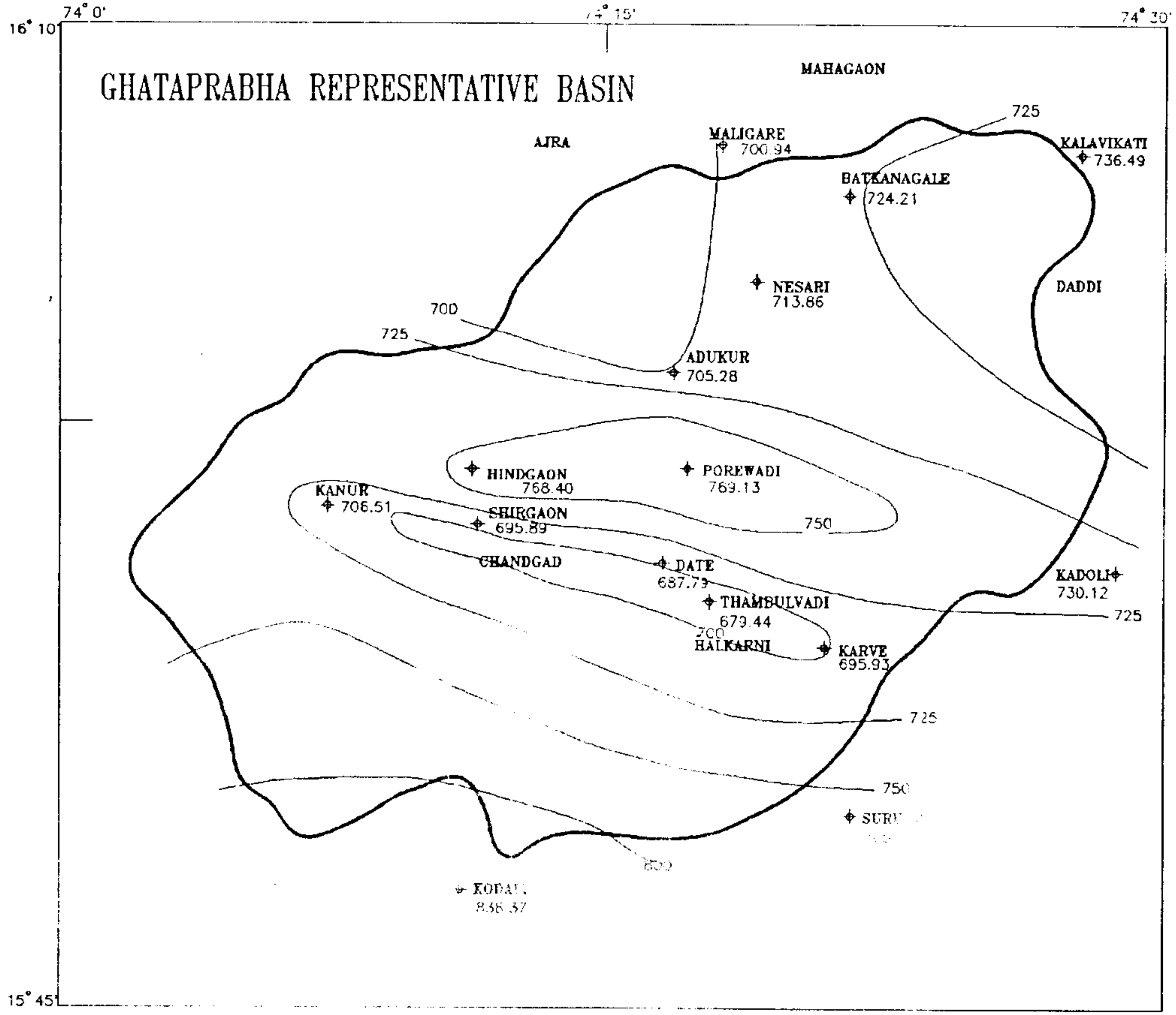

FIG. 12. LEVEL CONTOUR - 1995 PRE-MONSOON

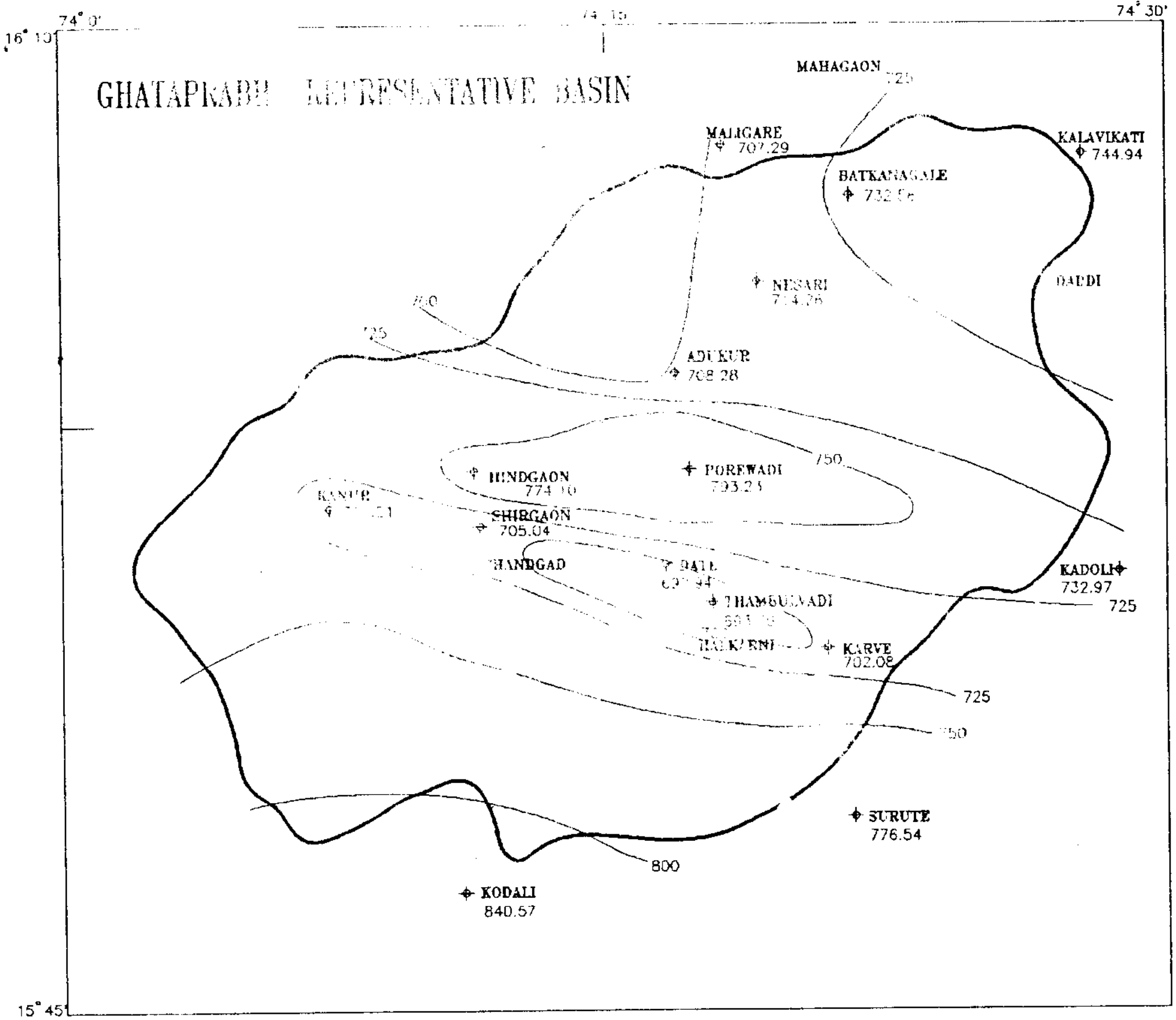

FIG. 13. GROUNDWATER LEVEL CONTOUR – 1993 POST-MONSOON

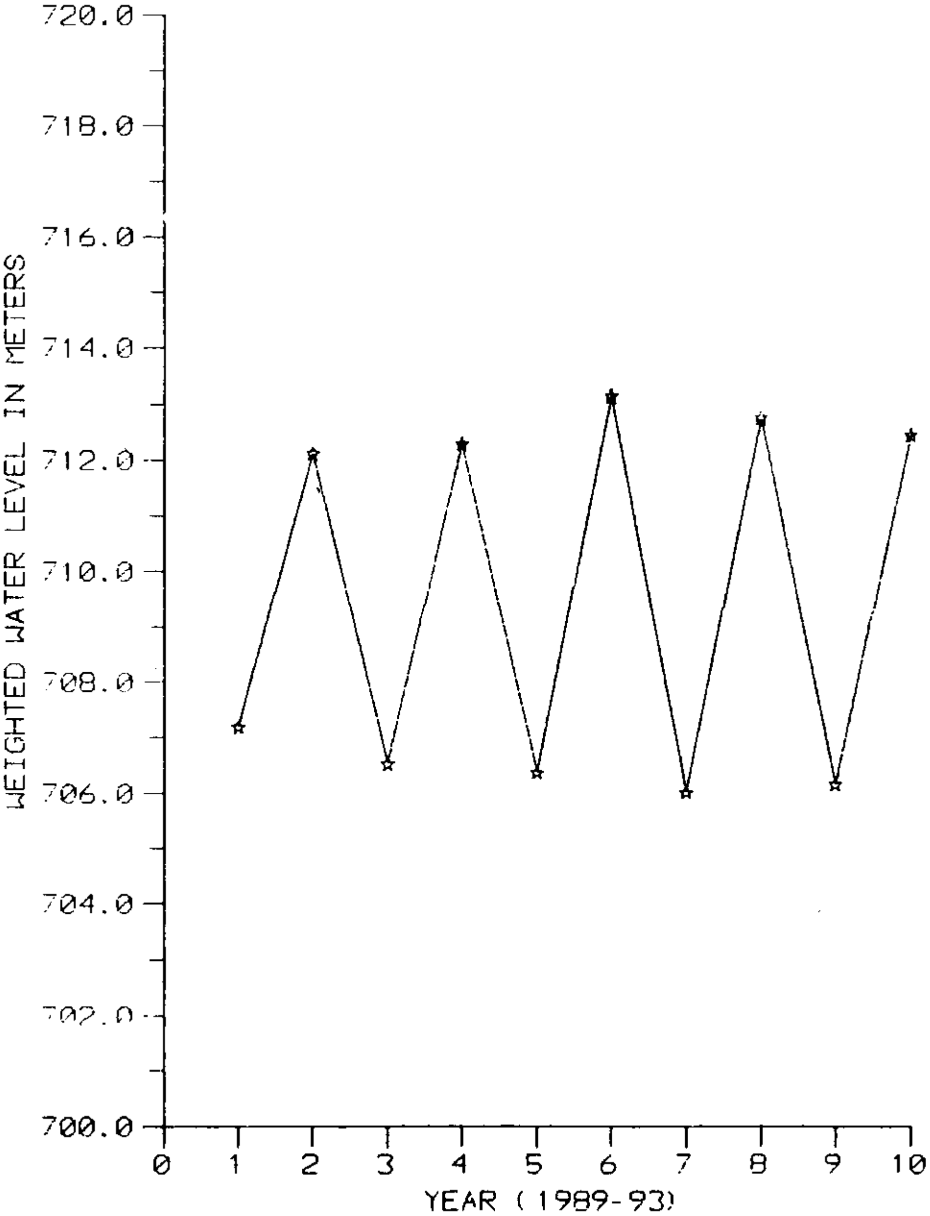

FIG 14: WEIGHTED PRE AND POST MONSOON G.W LEVELS OF THE BASIN

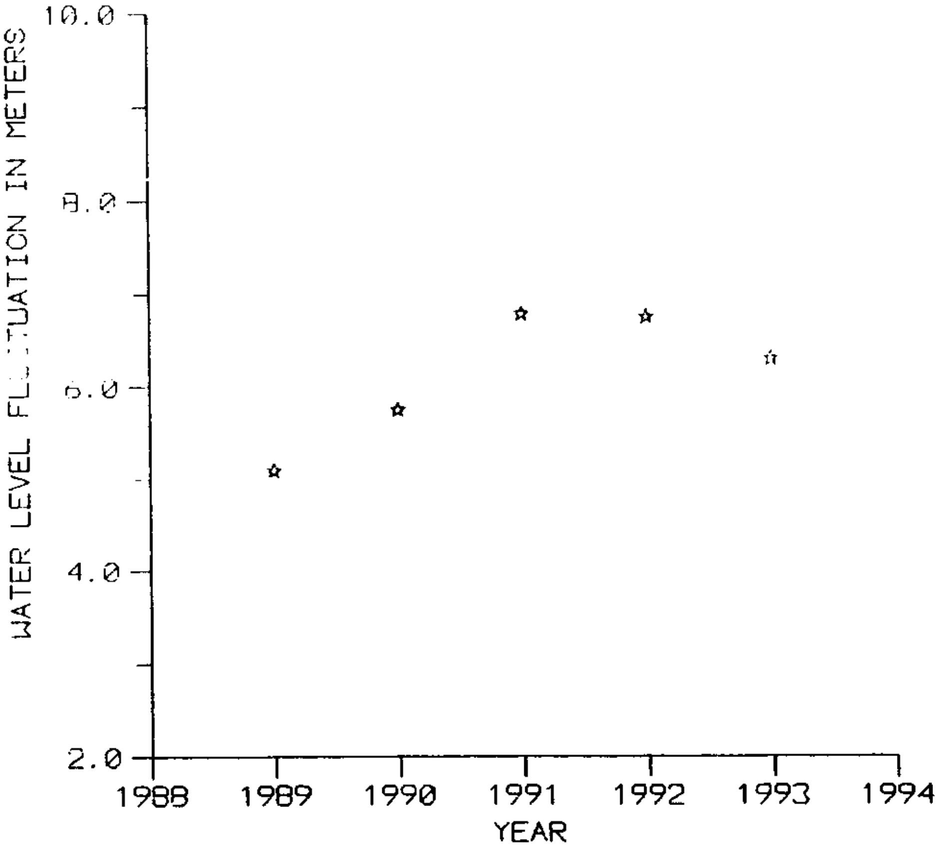

FIG 15: G.W LEVEL FLUCTUATION FOR THE BASIN

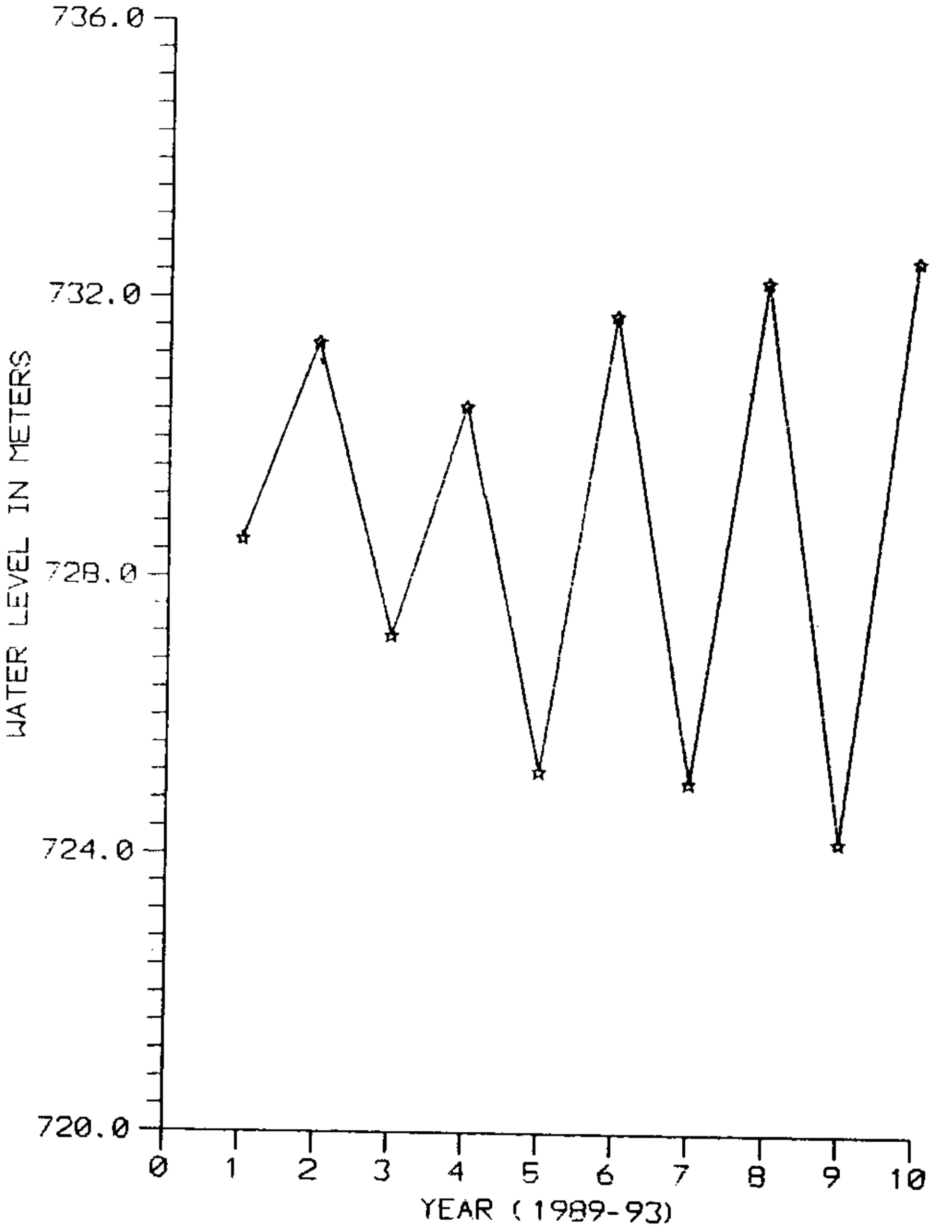

FIG 16: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT BATKANGALE

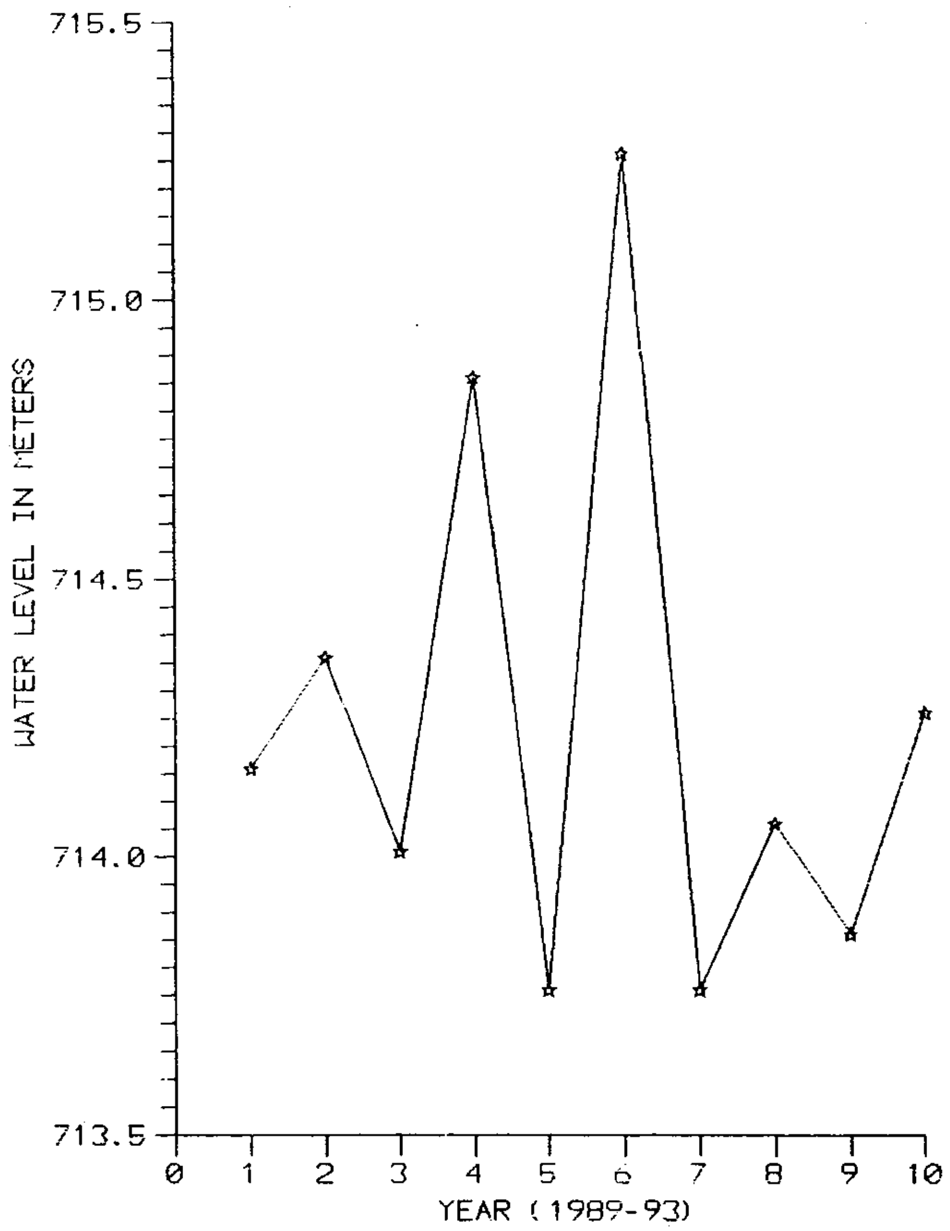

FIG 17: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT NESARI

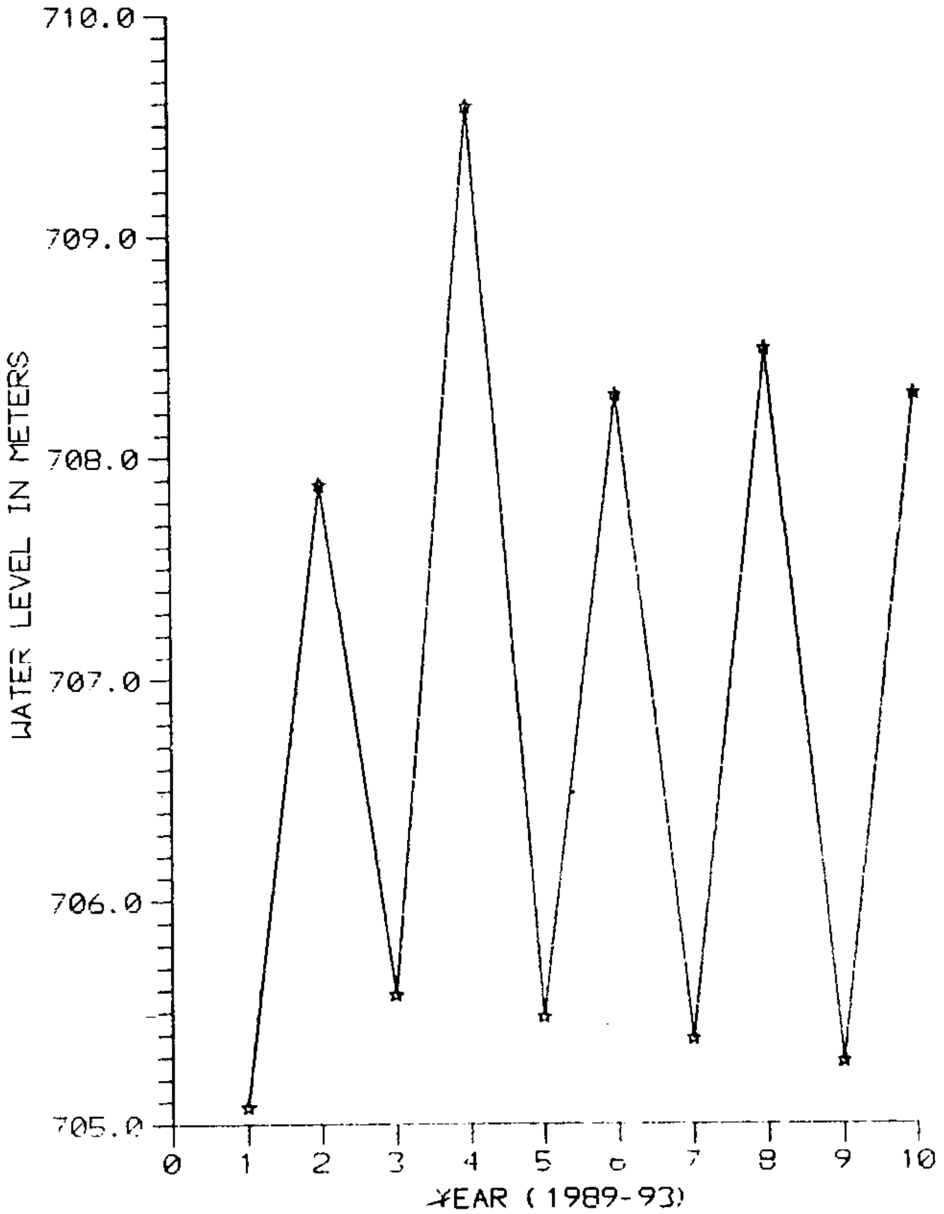

FIG 18: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT ADUKUR

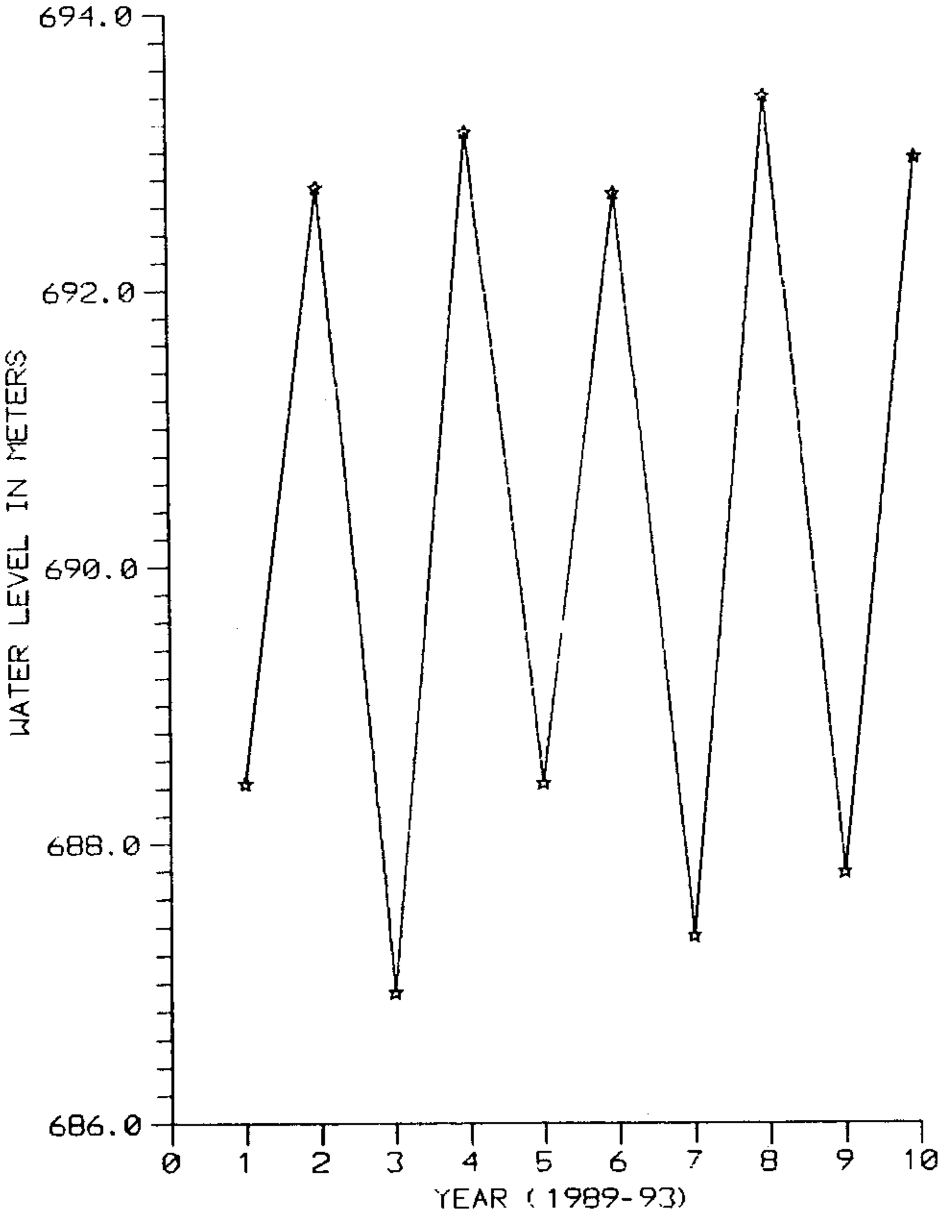

FIG 19: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT TAMBULWADI

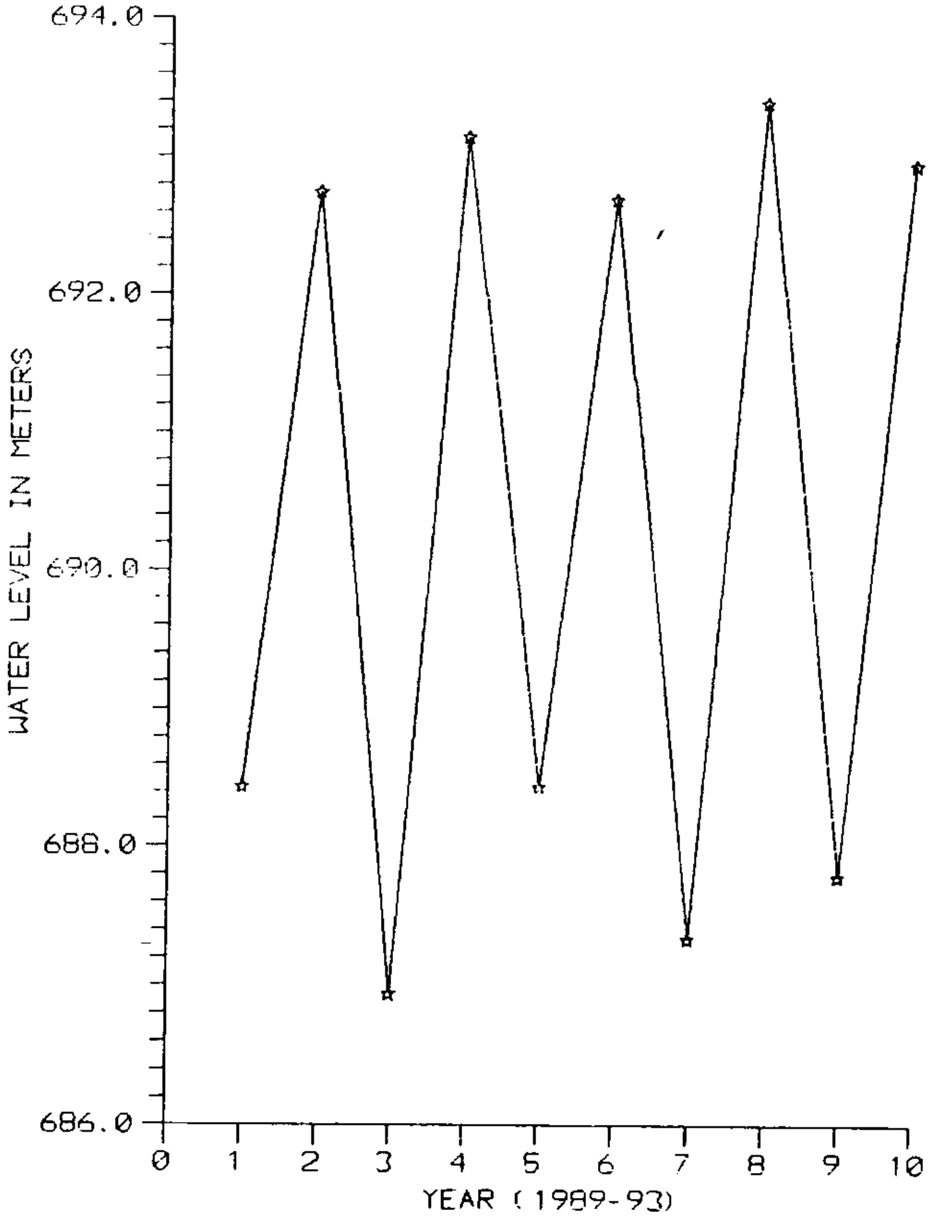

FIG 20: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT DATE

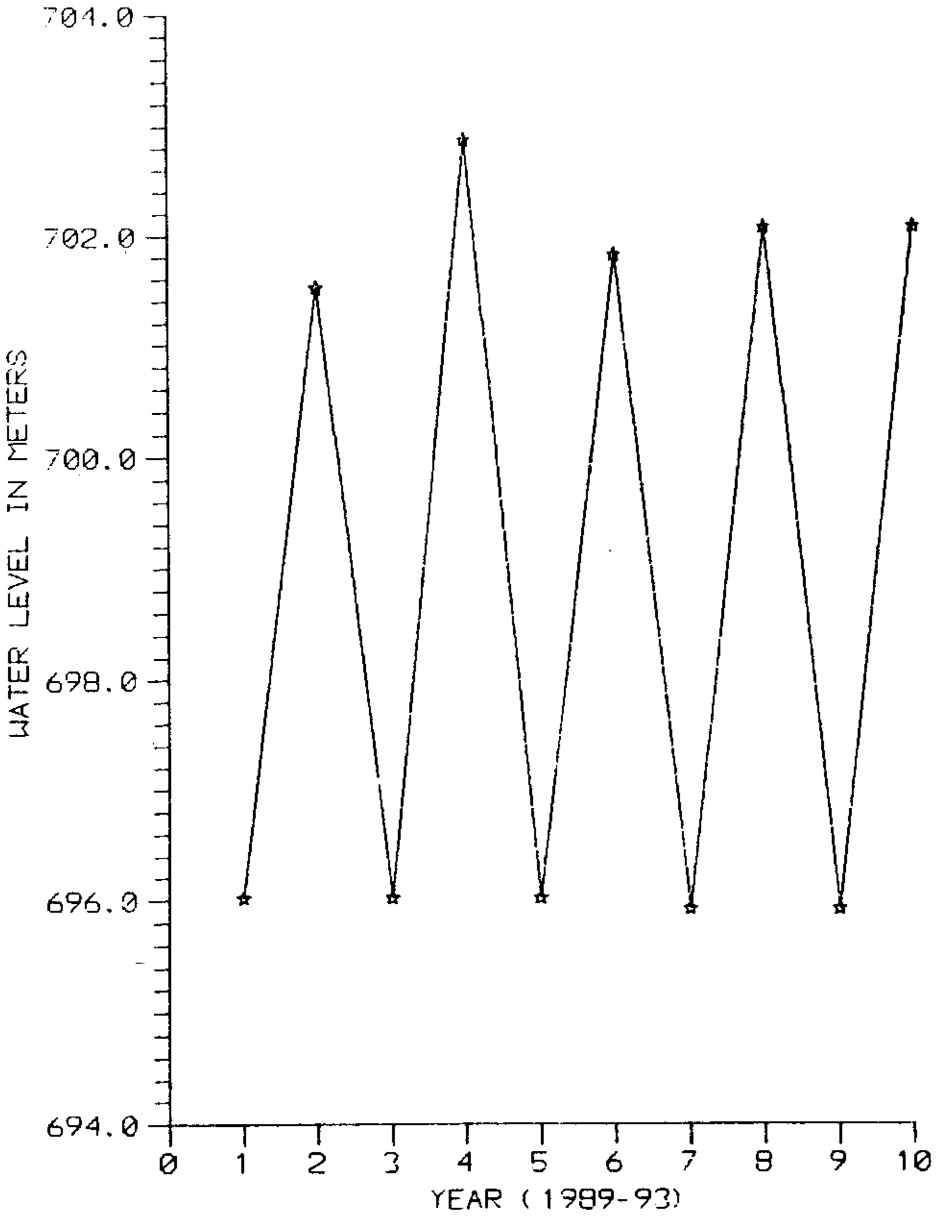

FIG 21: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT KARVE

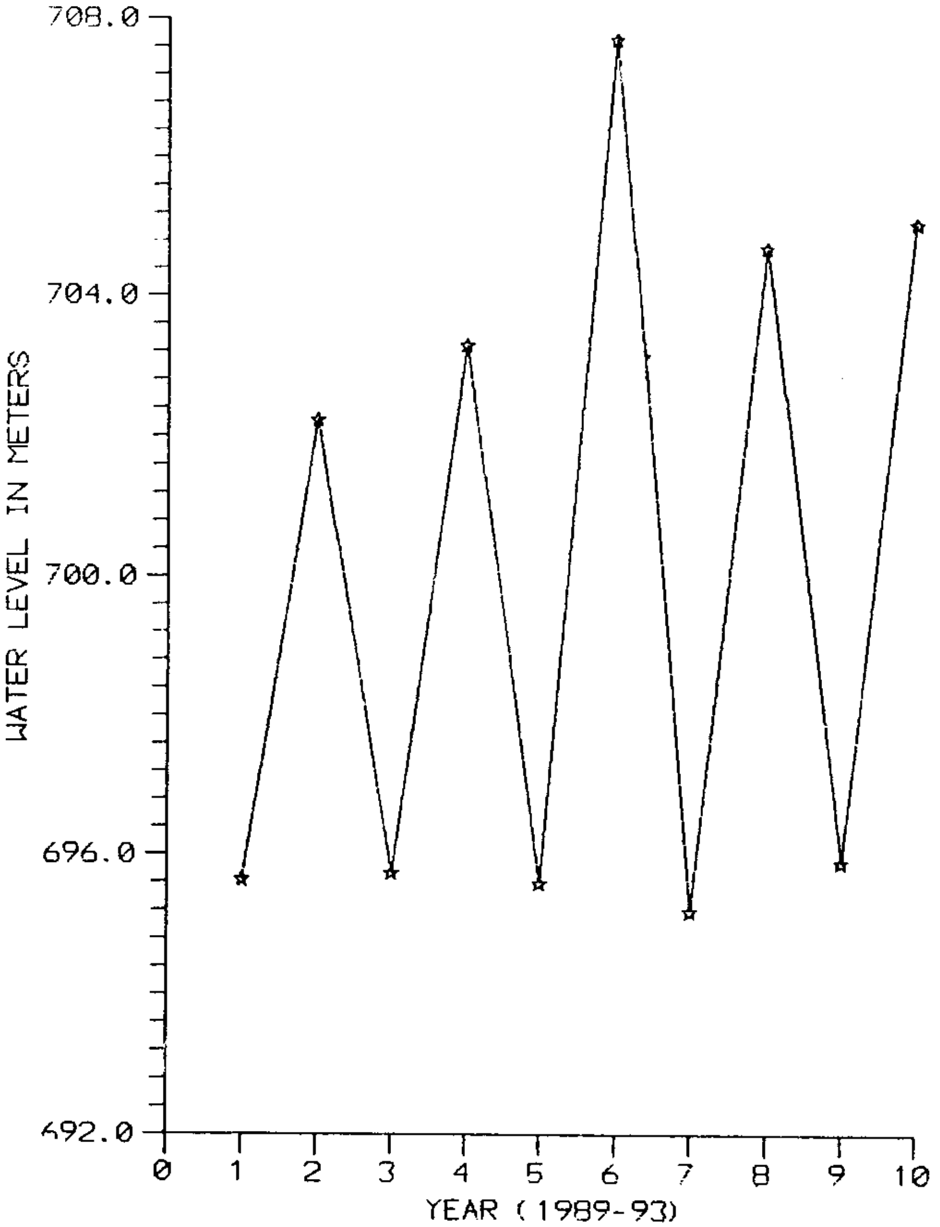

FIG 22: PRE AND POST MONSOON G.W LEVEL
FOR THE WELL AT SHIRGAON

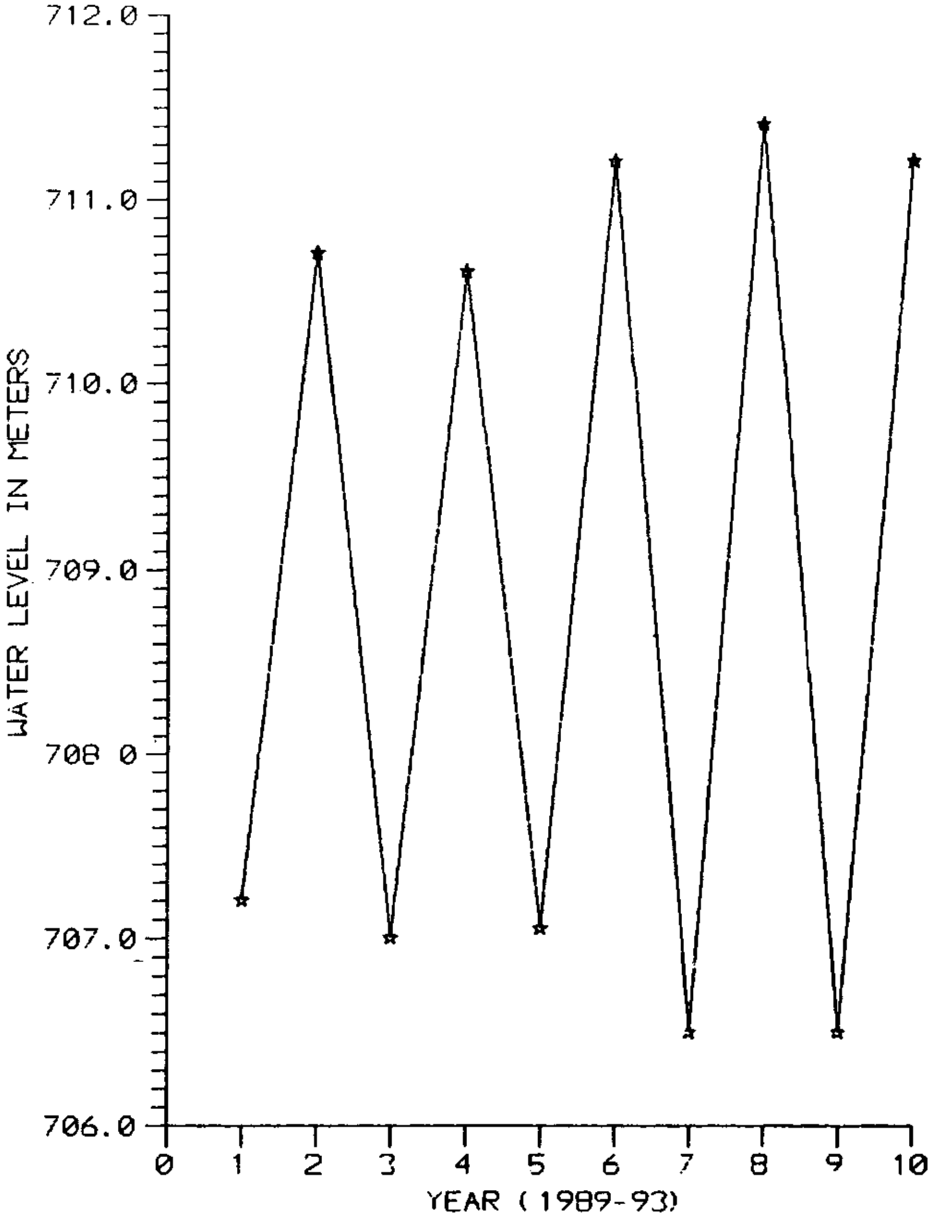

FIG 23: PRE AND POST MONSOON G.W LEVEL FOR THE WELL AT KANUR

TABLE 1: Rainfall Data (mm)

Station: Chandgad

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	00.0	00.0	00.0	00.0	00.0	934.3	930.2	890.8	100.5	18.4	12.3	3.0
1981	00.0	00.0	00.0	00.0	00.0	452.3	910.0	1133.6	168.9	25.2	9.0	00.0
1982	00.0	00.0	00.0	00.0	00.0	352.0	1201.0	1072.5	68.5	125.5	16.0	00.0
1983	00.0	00.0	00.0	00.0	00.0	1139.0	849.0	895.0	177.1	58.6	00.0	00.0
1984	00.0	00.0	00.0	00.0	00.0	495.0	1067.4	337.5	133.9	91.0	00.0	00.0
1985	00.0	00.0	00.0	00.0	00.0	578.9	597.4	705.8	89.3	241.2	00.0	00.0
1986	00.0	00.0	00.0	00.0	00.0	767.0	705.6	674.3	55.4	41.6	52.0	00.0
1987	00.0	00.0	00.0	00.0	00.0	244.6	704.1	439.6	264.8	59.1	00.0	00.0
1988	00.0	00.0	00.0	00.0	00.0	385.5	1646.3	732.4	484.6	21.2	00.0	00.0
1989	00.0	00.0	00.0	00.0	00.0	769.4	1022.9	463.9	201.9	00.0	00.0	00.0
1990	00.0	00.0	00.0	00.0	00.0	457.0	1987.0	903.2	117.4	120.4	00.0	00.0
1991	00.0	00.0	00.0	00.0	38.2	552.6	1196.0	715.6	67.0	00.0	00.0	00.0
1992	00.0	00.0	00.0	00.0	00.0	539.4	878.5	922.9	139.0	96.6	00.0	00.0
1993	00.0	00.0	00.0	00.0	00.0	460.4	1078.2	757.4	191.7			

Station: Ajra

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	00.0	00.0	00.0	00.0	00.0	515.0	657.0	681.0	108.0	12.0	15.3	00.0
1981	00.0	00.0	00.0	00.0	00.0	306.0	712.0	666.0	202.0	2.0	00.0	00.0
1982	00.0	00.0	00.0	00.0	00.0	244.0	795.0	578.0	44.0	140.0	53.0	00.0
1983	00.0	00.0	00.0	00.0	00.0	891.0	653.0	531.0	149.0	104.0	00.0	00.0
1984	00.0	00.0	00.0	00.0	00.0	399.0	711.0	378.0	83.0	76.0	00.0	00.0
1985	00.0	00.0	00.0	00.0	00.0	517.0	410.0	496.0	49.0	182.0	00.0	00.0
1986	00.0	00.0	00.0	00.0	00.0	669.0	268.0	453.0	107.0	36.0	61.0	00.0
1987	00.0	00.0	00.0	00.0	00.0	193.0	436.0	215.0	119.0	48.0	30.0	00.0
1988	00.0	00.0	00.0	00.0	00.0	254.0	887.0	379.0	200.0	16.0	00.0	00.0
1989	00.0	00.0	00.0	00.0	00.0	516.0	684.0	263.0	143.0	8.0	00.0	00.0
1990	00.0	00.0	00.0	00.0	00.0	252.0	648.0	520.0	62.0	67.0	00.0	00.0
1991	00.0	00.0	00.0	00.0	29.0	354.0	413.0	960.0	373.0	132.0	00.0	00.0
1992	00.0	00.0	00.0	00.0	00.0	324.0	551.0	225.0	195.0	116.0	00.0	00.0
1993	00.0	00.0	00.0	00.0	00.0	525.0	748.0	471.0	73.0			

Station: Gaddi

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC
1980	00.0	00.0	00.0	144.6	39.5	191.4	303.8	257.0	136.2	12.2	41.7	7.2
1981	4.2	00.0	12.8	4.0	99.0	161.4	308.1	266.2	163.6	38.4	5.6	00.0
1982	21.0	6.0	105.8	16.2	5.6	139.4	326.4	95.2	87.0	92.8	00.0	00.0
1983	00.0	00.0	00.0	00.0	4.0	635.2	168.9	313.8	88.0	50.4	3.0	10.8
1984	00.0	00.0	00.0	11.8	180.2	71.6	229.4	243.4	56.7	66.6	54.6	00.0
1985	21.0	00.0	27.6	[illegible]	75.8	141.2	260.0	203.5	10.2	92.3	00 0	00.0
1986	00.0	00.0	00.0	00.0	24.8	212.0	107.5	111.6	130.5	76.4	62.0	3.8
1987	00.0	1.0	2.5	9.8	29.0	78.0	99.7	35.1	131.9	28.7	15.3	2.1
1988	00.0	00.0	00.0	28.0	24.5	94.4	319.1	175.6	115.7	2.5	00.0	00.0
1989	00.0	00 0	3.3	34.2	42.7	182.8	332.3	96.9	225.3	18.8	16.0	0.6
1990	6.2	00.0	00.0	00.0	40.1	78.7	240.7	289.5	28.1	92.5	39.7	00.0
1991	00.0	00.0	00.0	110.1	179.0	296.6	354.8	174.3	115.3	40.0	00.0	00.0
1992	00.0	00.0	00.0	14.4	72.4	207.0	163.9	200.9	129.9	126.9	26.5	00.0

Station: Halkarni

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	00.0	00.0	00.0	00.0	27.0	721.0	674.0	245.0	200.6	31.0	06.2	00.2
1990	00.0	00.0	00.0	00.4	69.7	324.5	653.8	486.8	90.0	117.7	02.9	00.0
1991	00.0	00.0	00.0	47.7	75.1	343.5	770.0	425.1	97.8	64.9	20.9	00.0
1992	00.0	00.0	00.0	11.7	78.0	366.5	679.1	539.0	92.8	132.4	48.2	00.0
1993	00.0	00.0	15.6	30.3	38.1	491.5	769.6	454.3	137.6	190.0	85.9	15.5

Station: Nesari

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	182.8	13.1	00.0
1991	00.0	00.0	00.0	00.0	00.0	160.2	347.1	452.7	181.0	85.5	00.0	00.0
1992	00.0	00.0	00.0	00.0	156.6	291.4	270.5	292.5	130.6	142.6	00.0	00.0
1993	00.0	00.0	00.0	00.0	113.0	244.0	469.2	296.7	61.8			

Recharge Components:

Recharge to the groundwater reservoir occurs mainly through rainfall infiltration and to a small extent from existing tanks, canals and return flow from irrigation. Within the basin, which is having a total geographical area of 1055 sq.km., upstream reaches are not suitable for recharge because of its steep terrain and its characteristics. For the computation of groundwater recharge, an effective area of 865 sq. km is considered. From the results of pumping test, conducted by GSDA, Kolhapur, it is found that the specific yield for the area varies between 0.01 to 0.05. An average value of 0.03 is considered as specific yield for calculations. Transmissivity for the aquifer is calculated from pump test data as 14 sq.m/day.

Since the study area is not covered by a canal network, the recharge component from canal seepage is nill. A total area of 3850 ha is under surface and lift irrigation in which 480 ha is used for kharif crops, 400 ha for rabi crops and 2970 ha for perennial crops. By considering a seepage factor of 0.35 for surface water irrigation, an average of 810 ham. water is recharging in monsoon season and 1875 ham. in non-monsoon season. Monsoon recharge from groundwater irrigation is found to be 330 ham.

One percolation tank is situated in Bukkihal village in Chandgad taluka which is having a total storage capacity of 70 ham. A seepage factor of 50% is taken for the percolation tank as per the Groundwater Estimation Committee. Subsurface inflow / outflow is governed by the hydraulic gradient of the water table (I) and transmissivity of the aquifer (T). For the estimation of subsurface inflow/outflow, groundwater level contours have been drawn for pre-monsoon and post-monsoon seasons. Basin boundary is divided into inflow/outflow segments by examining the pattern of the contours. Direction of subsurface flow and hydraulic gradient were decided by considering the groundwater levels of each observation wells in each segment, one inside and one outside the boundary of the study area. Net subsurface inflow has been calculated for each year (monsoon and non-monsoon) by using the formula Q=TIL, where L denotes the length of each segment.

Discharge Components:

A total of 4800 dugwells are used in the area for tapping groundwater. Unit draft for these wells varies from 0.05 to 0.95 ham/year. Average draft from these wells are found to be 1100 ham. in monsoon season and 2555 ham. in non-monsoon season. Since the water levels in all observation wells are always below 2 m mark for the study area, (except for observation well at Nesari), evaporation from groundwater basin has been neglected. Forest area covers about 17% of the catchment and therefore evapotranspiration component has been taken into consideration for the calculation of groundwater balance. Average monsoon and non-monsoon evaporation values for the area are 0.0144 m and 0.0217 m respectively. For the calculation of ET component, a coefficient of 0.7 has been taken. Net subsurface outflow has been calculated for each year (monsoon and non-monsoon) by using the same method as that used for the estimation of subsurface inflow.

Change in groundwater storage:

The change in storage of groundwater in an aquifer is an indicator of the long term availability of groundwater. It is reflected by change in groundwater level or groundwater level fluctuation. It was estimated by multiplying the effective area available for recharge, the specific yield for the area and the average groundwater level fluctuation.

Groundwater Balance:

Each of the above components has been estimated separately from year 1989 to 1993. Groundwater balance has been estimated by substituting these components in groundwater balance equation. The groundwater available for future development has been estimated by deducting the draft from the groundwater balance. The results are as given in table 2 and figure 24. It can be seen that the groundwater situation of the area is steady except for the last year in which there is a marked increase. Recharge coefficient is found to vary between 10.60% to 13.50%.

TABLE 2 YEARLY GROUNDWATER BALANCE

YEAR	G.W.BALANCE (MCM)	G.W.AVAILABLE FOR FUTURE DEVELOPMENT (MCM)
1989	140.51	114.96
1990	141.49	115.94
1991	144.06	118.51
1992	144.06	118.50
1993	153.79	128.24

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