ANALYSIS OF HIGH FREQUENCY GROUND WATER DATA

A DISSERTATION

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requirements for the award of the degree
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HYDROLOGY

By

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CANDIDATES DECLARATION

I hereby certify that the work which is being presented in the dissertation titled " Analysis of High Frequency Ground Water Data" in partial fulfilment of the requirement for the award of degree of Masters of Technology in Hydrology submitted in the Department of Hydrology of I.I.T., Roorkee, is a record of my own work carried out during the period from July, 2001 to February 2002 under the supervision of Dr. N.K. Goel, Professor, Department of Hydrology, I.I.T., Roorkee.

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

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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SYNOPSIS

In the State of Maharashtra the groundwater levels are monitored at discrete times since 1974. This network has been supplemented with continuous monitoring of groundwater levels by Digital Water Level Recorders (DWLR) through newly constructed piezometers since 1998.

The enormous discrete and continuous data of groundwater levels of Aurangabad district have been used for performing different types of analysis, like adequacy of network design, estimation of level of accuracy of past data and groundwater resources, optimisation of frequency of observation in DWLR and stochastic modelling of hourly groundwater level data. Simpler tools have been developed and used for the conversion of retrieved DWLR data and different analyses.

Network design analysis has been attempted by using coefficient of variation-based technique. The available network of 141 observation wells was found adequate where as the supplemented network was much denser, for 5% error in estimation of average groundwater levels.

The level of accuracy of the past data has been estimated with a meagre error of 6%, showing the reliability of the old system data. Similarly the average error in estimation of groundwater resource is around 7%, which is commensurate with the typical hydrogeological conditions of the study area.

The optimisation of frequency of observation has been attempted by computing the summation error from the smallest feasible interval. The results showed that the present frequency of observation i.e. six hour within district is optimum.

Simulation of hourly groundwater levels of four piezometers by stochastic modelling indicate diurnal periodicity in the data. The periodicities in mean are explained by 8, 6, 2 and 5 significant harmonics for Peerbavada, Dhavalapuri, Waghalgaon and Pimperkheda respectively. The periodicities in standard deviation are explained by 11, 11, 8 and 9 significant harmonics respectively. The dependent stochastic component was explained by AR(2) model for Peerbavada, and AR(1) for all others.

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Introduction

1.1 GENERAL

Groundwater is a significant component of the hydrologic cycle. It is interrelated to other components such as rainfall, runoff, evapotranspiration, base flow etc. Groundwater constitutes a major part of water supply for irrigation, drinking and industrial purposes. Presently more than 55% of irrigation is from groundwater in India. Similarly around 70 to 75% of rural drinking water supply is from groundwater resource only. Rainfall is the primary source of groundwater recharge.

Groundwater being dynamic is always in a continuous state of flux and is reflected into the well in the form of water table or piezometric surface, for shallow and deeper aquifers respectively. Groundwater level fluctuation is a function of various inflows to and outflows from the system. Groundwater recharge (input to the system) exceeding discharge (or outflow from the system) raises the water level and vice versa. Water level being the pulse of groundwater, study of water level fluctuation gives fairly good idea of the system behaviour. A plot of groundwater levels over time results in well hydrograph. This is characteristically different form the flood hydrograph. There is a time lag between rainfall and the rise in water level, as it is a function of hydrological characteristic of the rock formation. However, highly porous formations like karsified limestone and dolomites, sandstones, some Lava flows behave differently. Similarly the response varies from place to place-indifferent geological environments.

A time series is a chronological sequence of observations of a specified variable. The observations may be in continuous time domain or in discrete time domain. In case of groundwater level time series, the depth to water table of an unconfined aquifer or to the piezometric surface of a confined (or artesian) aquifer is measured either continuously or discretely in time (Law, 1974). As the components interacting with groundwater are stochastic in nature, the groundwater level time series is also stochastic in nature. Due to high dependence of groundwater levels to its preceding values, it is a highly time dependent stochastic process.

The groundwater level time series manifests in itself all the characters of influencing factors i.e. natural or man made. Different types of variations like trends, jumps, and periodicities are introduced in the time series by natural processes such as recurrence of drought, earthquakes, rainfall patterns etc. The hydrograph represents the resultant effect of a number of phenomenon many of which may be periodic (i.e. self repeating). Each periodic phenomenon imparts a periodicity to the time series. However, due to their superposition, all these periodicities may not always be visible in the time series. Well-defined nature of rainfall in Indian sub continent introduces seasonality in the time series by recharges and by stream-aquifer interactions. Influence of man's activities like groundwater overdraft, artificial recharge, surface water and groundwater irrigation etc, on groundwater is very large and significant. All these activities are very well reflected into the continuous hydrograph obtained from automatic water level recorders. Thus hydrograph obtained from DWLR (Digital Water Level Recorders) may comprise apart from an annual cycle, many cycles of shorter duration like seasonal, barometric, daily tidal etc.

Stochastic analysis and modelling of groundwater level helps in quantifying and separating the influences of the above mentioned factors on groundwater regime. It provides information about future state of the system. The optimal monitoring frequency of groundwater levels and synthetic data generation based on stochastic analysis can be used to check the robustness of the system under study. Forecasting of groundwater levels may be used by planners for calculation of available resources for any lead period in future.

1.2 EARLIER STUDIES

Very few studies pertaining to stochastic analysis of groundwater level time series have been made on international level. On national level the continuous data was almost non-existent till the commencement of Hydrology project. Since 1998 the data for continuous water levels are available at high frequency. Prior to this discrete data of limited period is available. The time series analysis of water level data is not routinely done because the data at necessary frequency are usually not available.

However, with available record good amount of works have been done to establish the trend in groundwater level (falling or rising) in time domain. Groundwater level time series have been studied by some workers to establish various transfer function models. Many of these transfer function models are linear in nature, establishing relationships between groundwater levels and other influencing factors viz, rainfall, draft, stream, aquifer interaction.

Law (1974) analysed time series of 84 wells of Western United States. In his study he modelled stochastic nature of residuals by autoregressive models. Adamowski and Hamory (1983) studied linear stochastic transfer function model to establish relationship between groundwater levels and stream runoff. Houston (1983) used structural analysis of the time series for establishing relationship between groundwater levels and rainfall. Vishwanathan (1983) established groundwater recharge from rainfall taking into consideration antecedent precipitation. Gehrels et al (1994) used linear transfer function model for separating artificial components from natural groundwater level time series. Mayer et. al (1994) established the relationship between the hourly groundwater level and river flow.

Studies of groundwater fluctuations in time domain are carried out as a part of groundwater regime monitoring. Generally, statistical regression models Linear, quadratic or polynomial, are fitted to the data to establish rising or falling trends over the time periods and attribute them to some physical reasons. Generally in a natural process, groundwater levels do not show any significant trend. Central Groundwater Board (CGWB, 1992) studied the water levels of hard rock aquifers at Aurangabad district, Maharashtra, India. They attributed no specific reasons. Faust and Lyons (1989) studied water levels of alluvial aquifers at Lousivelle, Kentucky, USA. They worked out the reasons behind the decline of water levels as below normal precipitation. Groundwater Surveys and Development Agency (GSDA, 1998) studied the water levels of Tapi-Purna alluvium, Maharashtra, India. They worked out the reasons behind decline of water levels as over pumping of groundwater for cash crops. Patterson and Zaporozee (1987) studied short term and long-term fluctuations of groundwater levels in Wisconism, USA. The study was conducted to investigate presence of long-term trends in the data. Kovalevcky (1982) used long-term trend analysis for forecasting of groundwater levels.

Groundwater Surreys and Development Agency, Maharashtra state, a state Groundwater Organization, maintains water level records at 5056 hydrograph stations within the state. The hourly groundwater level data at three such stations within Aurangabad district of the state, of different periods, have been used to study the stochastic nature of groundwater.

1.3 OBJECTIVES OF PRESENT STUDY

There is no standard methodology for the analysis of high frequency groundwater level data i.e. DWLR data. The present study was undertaken with following objectives:

- Determination of adequacy of piezometers in the district.
- Determination of level of accuracy of past data of dug wells.
- Determination of level of accuracy of groundwater resource estimation.
- Determination of frequency of observation in DWLR's.
- Stochastic Modelling of Groundwater levels.

1.4 ORGANISATION OF STUDY

Groundwater level data collection, processing, validation and preliminary analysis are very vital to any statistical observation. Procedure for acquisition of groundwater level data is relatively simple. The important aspects of data acquisition along with the study of hydrogeology for better understanding of various components of groundwater level time series are discussed in chapter 2. Chapter 3 deals with the crucial exercise regarding network and observation frequency analysis along with the determination of level of accuracy of the past data and groundwater resource estimation. In chapter 4, Time series analysis, methodology and groundwater level simulation by stochastic modeling are included. Chapter 5 embodies conclusions of the study.

Study Area, Data Availability and Processing

2.1 STUDY AREA

The study area selected is Aurangabad district, which is situated in the north central part of Maharashtra between North Latitudes 19^0 15' and 20^0 42' and East Longitudes 74^0 37' and 76^0 16'. It covers a total area of 10,099 sq. km. falling in survey of India toposheet Nos. 46 L and P and 47 I and M, (Fig 2.1).

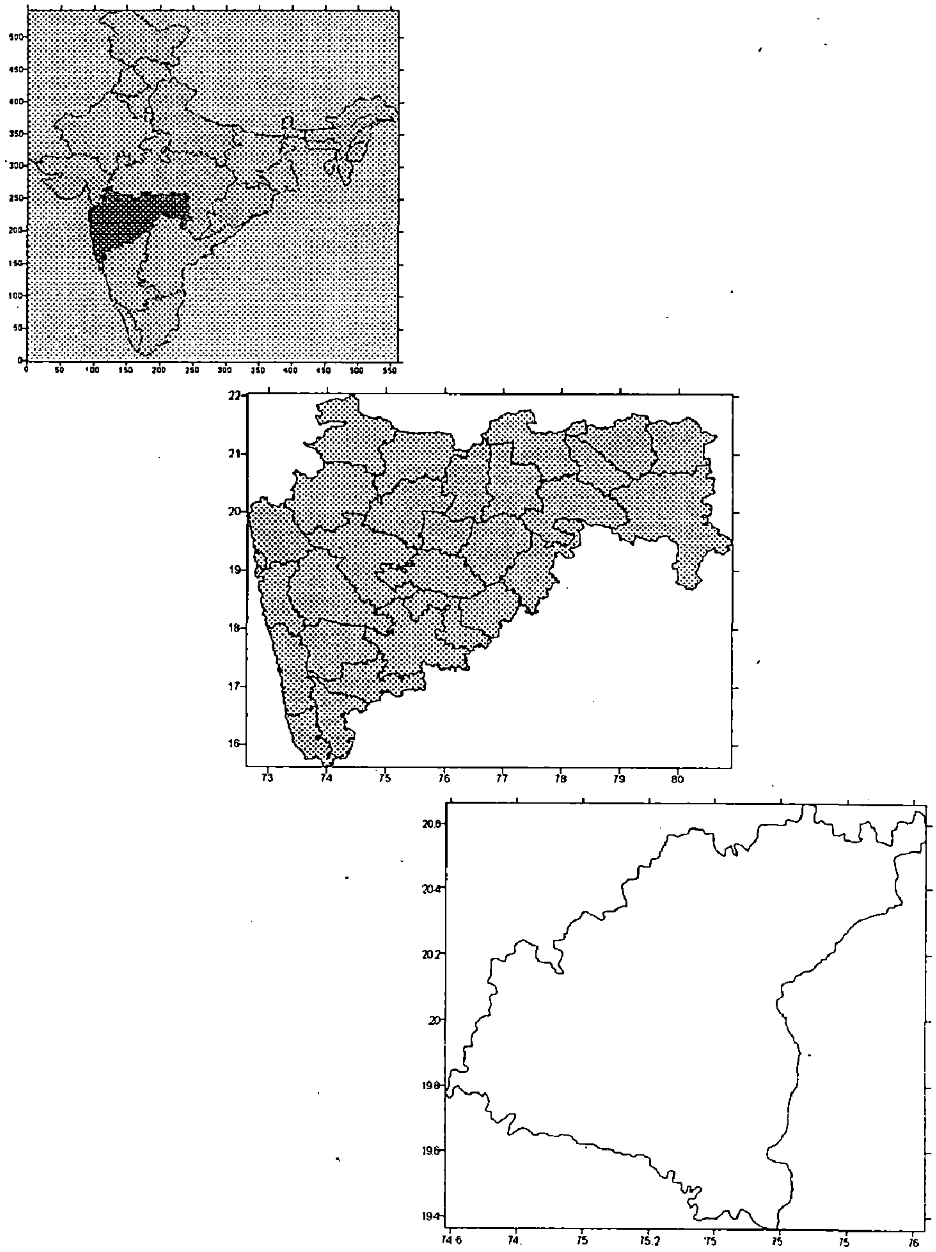
Aurangabad district is known for the world famous rock caves of Ellora and Ajanta. Besides, there are also a few caves near Aurangabad city. Other monuments of national fame are Bibi-Ka-Maqbara and Daulatabad fort.

2.1.1 Salient Features (CGWB, 1992)

i) Population: 22.09 Lakh (1991 census)
ii) No. of tahsils : 8
iii) No. of villages : 1323
iv) Climate: Average Annual temperature
Maximum: 40^0 c 'May-June'
Minimum: 10^0 c 'January'
v) Rainfall: Average annual normal – 711.4 mm
vi) No. of Watersheds : 52
vii) Land use: Net Area Irrigated – 78,432 ha
Surface Irrigation: 14,593 ha
Groundwater Irrigation: 63,839 ha
Area under forest: 79,400 ha
viii) Groundwater resources
Total groundwater resource: 1026.18 MCM
Net annual draft: 353.55 MCM
Stage of groundwater development: 40.5%
Dark or Grey Watersheds: 4 Grey
ix) Surface Water Resources
Major Projects – 1
Medium Projects – 15
Minor Projects – 132

Fig.2.1

INDEX MAP OF AURANGABAD DISTRICT



2.1.2 Geographic Features

Physiographically, the district comprises varied topographic features and landscapes consisting of high hills and plains, low lying hills and badland topography near riverbanks. The hill ranges located in the northern portion are Satmala and Ajanta, extends from east to west. The district, being a part of the Deecan Plateau, is sloping south-eastwords from the Sahyadris. In general the district slopes towards south and southeast. The average elevation of the district is in the order of 500 mm. above mean sea level.

The district is situated in the Godavari basin except for a small part in northeastern portion, which is falling in the Tapi basin. The major river is the Godavari with its tributaries namely; the Purna, and the Shivna. (Fig 2.2).

The major part of the soils in the district is black cotton soil formed by the weathering of the Trap rocks.

2.1.3 Geology

The geological succession of the rocks found in the district may be given as follows (Fig 2.3):

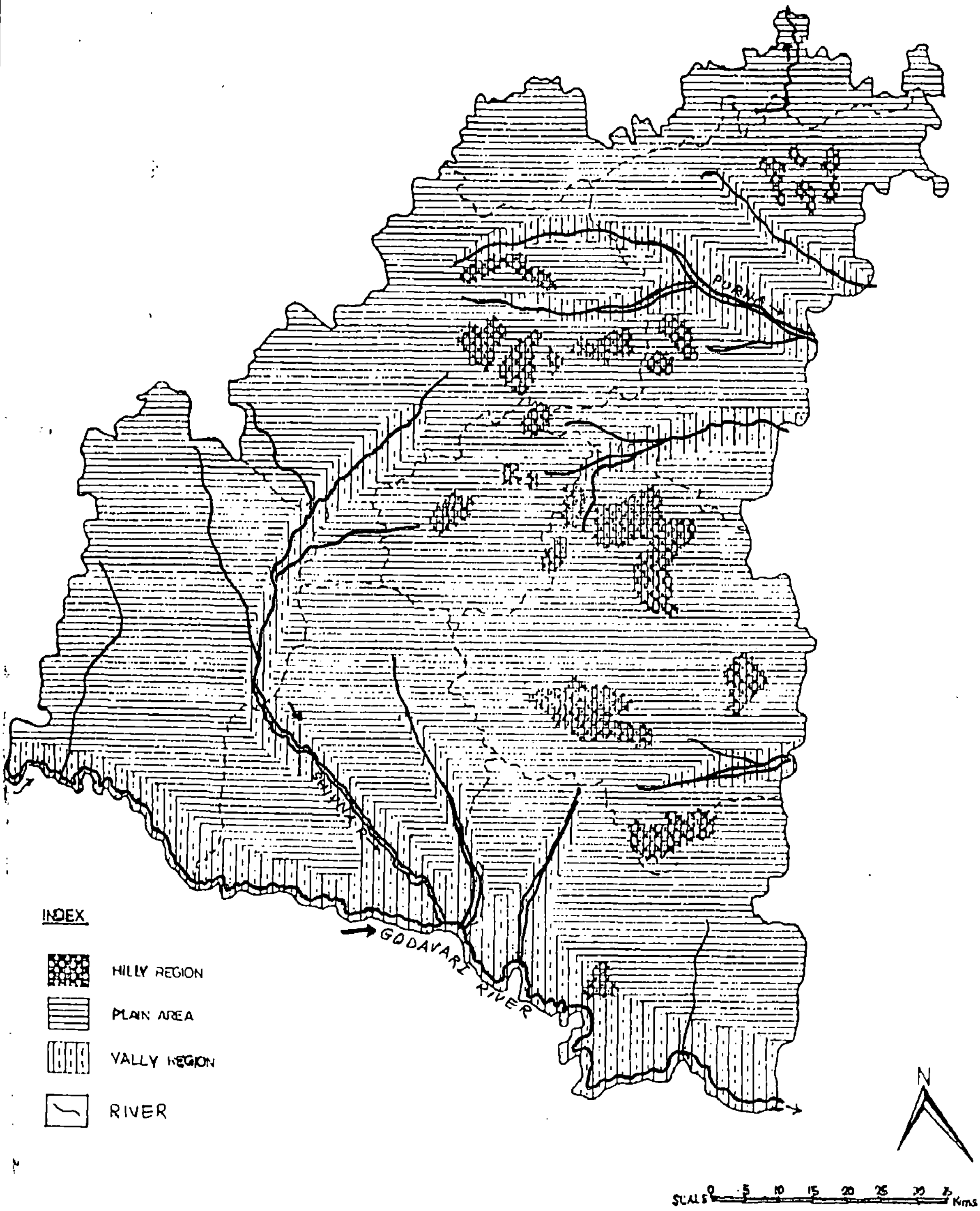
Unit	Age	Lithology
Top Soil	Recent to sub Recent	Block cotton Soil, Kankar etc.
Alluvium	Pleistocene.	Alluvium consisting of sand, silt, etc along the course of rivers.
Deccan Traps	Lower Eocene to Upper Cretaceous	Basalt, red boles and intertrappean sediments.

The Deccan Trap rocks are comprised of no. of lava flows. 21 Such flows have been identified in the district by Geological survey of India. Each flow is marked by massive lower part and upper vesicular part.

The massive traps are hard, compact, dark grey to greenish in colour and exhibit characteristic spheroidal weathering on the top. Joints, cracks and columnar jointing at the surface are very common. The vesicular traps are greenish grey to purplish in colour. They are relatively softer than the massive traps. The vesicles

Fig.2.2

PHYSIOGRAPHY AND DRAINAGE MAP OF AURANGABAD DISTRICT



G P & P Pune-1992

Fig.2.3

GEOLOGICAL MAP OF AURANGABAD DISTRICT

often filled with zeolites. These vesicles may be open or connected at places while at other places they may be filled and disconnected. The upper exposed surface of the vesicular trap is generally weathered.

The red bole, ranges in thickness from 0.20 to a few meters, crop out at different places and attitudes in hill sections. They occur as the top undulating layer of the flow.

The alluvium occurs as disconnected lenticular patches along the banks of rivers like, Godavari, Shivna etc. The thickness ranges from 16 to 26 meters.
A few dykes traverse the basaltic flows in the SW part of the district. Similarly various lineaments are also observed.

2.1.4 Hydrogeology

In the district the groundwater is a function of physiography (terrain condition), geology and rainfall pattern. The occurrence and movement of groundwater is primarily controlled by these factors. There are two distinct hydrogeological units in the district i.e. different units of basaltic lava flows, and isolated patches of alluvial deposits. 95% of the area is occupied by basaltic lava flows; hence hydrogeology of Aurangabad is hydrogeology of Deccan Traps only. So hydrogeology of basaltic lava flows is of utmost importance from groundwater point of view of the district.

Regional Hydrogeology

In basalts, groundwater occurs in the weathered mantle, in joints, factures, faults and other similar weaker zones. The degree of weathering and topographic setting plays a dominant role in respect of storage. Vesicular basalts are characterized by both primary porosity and secondary porosity caused by tectonic disturbances. When vesicles are interconnected the yield potential of the formation becomes quite significant. The massive units are almost devoid of any openings and have low porosity and permeability and hence are not productive. Fracture porosity introduced due to tectonism in the form of closely spaced interconnected joints/ fractures render them moderately potential.

The alluvium, being mainly unconsolidated in nature, has good primary porosity. Hence contain fairly good potential of groundwater.

The groundwater occurs under water table and semi confined conditions in Deccan Traps. Precipitation forms the principal source of recharge of groundwater in the basaltic flows and alluvial cover. Besides, seepage from surface water bodies also augment recharge of groundwater in these formations. The elevation of water 260m table ranges from 460m to 720m amsl and generally follows topography. The movement of groundwater in general is towards the Godavari River. Though there is hydraulic continuity between the trappean units, still due to the heterogeneous nature of the aquifer materials, there is wide variation in the water table gradient from 2 to 15 m/km. (CGWB, 1992). The groundwater movement is generally sluggish in alluvial area due to high sand shale ratio. The transmissivity (T) of basaltic aquifers in the district is generally less than 80 m^2/day and specific yield is within 2%. Further it is observed that generally the specific yield reduces at depth and during pre monsoon season also (CGWB, 1992). Generally dug wells and borewells are constructed for monitoring, exploration and exploitation of groundwater for different usages like drinking, irrigation etc.

Local Hydrogeology

Locally the hydrogeology differs from well to well. This is because of the heterogeneous nature of Deccan trap (Commission Report, 1999). This is very well reflected into lithological logs of piezometers constructed for monitoring the groundwater levels within district.

The lithological logs of the piezometers considered for study are given in table 2.1

Table 2.1 Lithological logs of Piezometers

Piezometer	Well No/Litholog	Depth (m)
Peerbavada	Top Soil	0-1.0
	Highly weathered / fractured ves. Basalt	1-6.00
	Mod. Weathered vesicular Basalt	6.00-12.3
	Fractured / Jointed Massive Basalt.	12.3-24.00
	Massive Basalt	24-30
Dhavalapuri	Top Soil	0-1.0
	Highly weathered / fractured ves. Basalt	1.0-6.0
	Mod. to poorly Weathered ves. Basalt	6.0-15.00
	Fractured / Jointed Massive Basalt.	15.00-17.0
	Massive Basalt	17-21.0

2.1.5 Groundwater Level Fluctuation

The depth to water and fluctuation of water table is observed in the observation wells. From the data of existing observation wells for last twelve years, it is observed that the depth to water table in pre monsoon period i.e. May / June vary from 3.37 to 15.77 m bgl, while in post monsoon period i.e. in October varies between 1.42 to 15.85 m bgl. However, physiographic location of wells exerts great influence on the depth to water table. Similarly the average seasonal fluctuation observed for last seven years in these stations varies from 0.26 m to 4.92 meters. While the average seasonal fluctuation of groundwater level in the district is found to be 3.00 m. (CGWB, 1992).

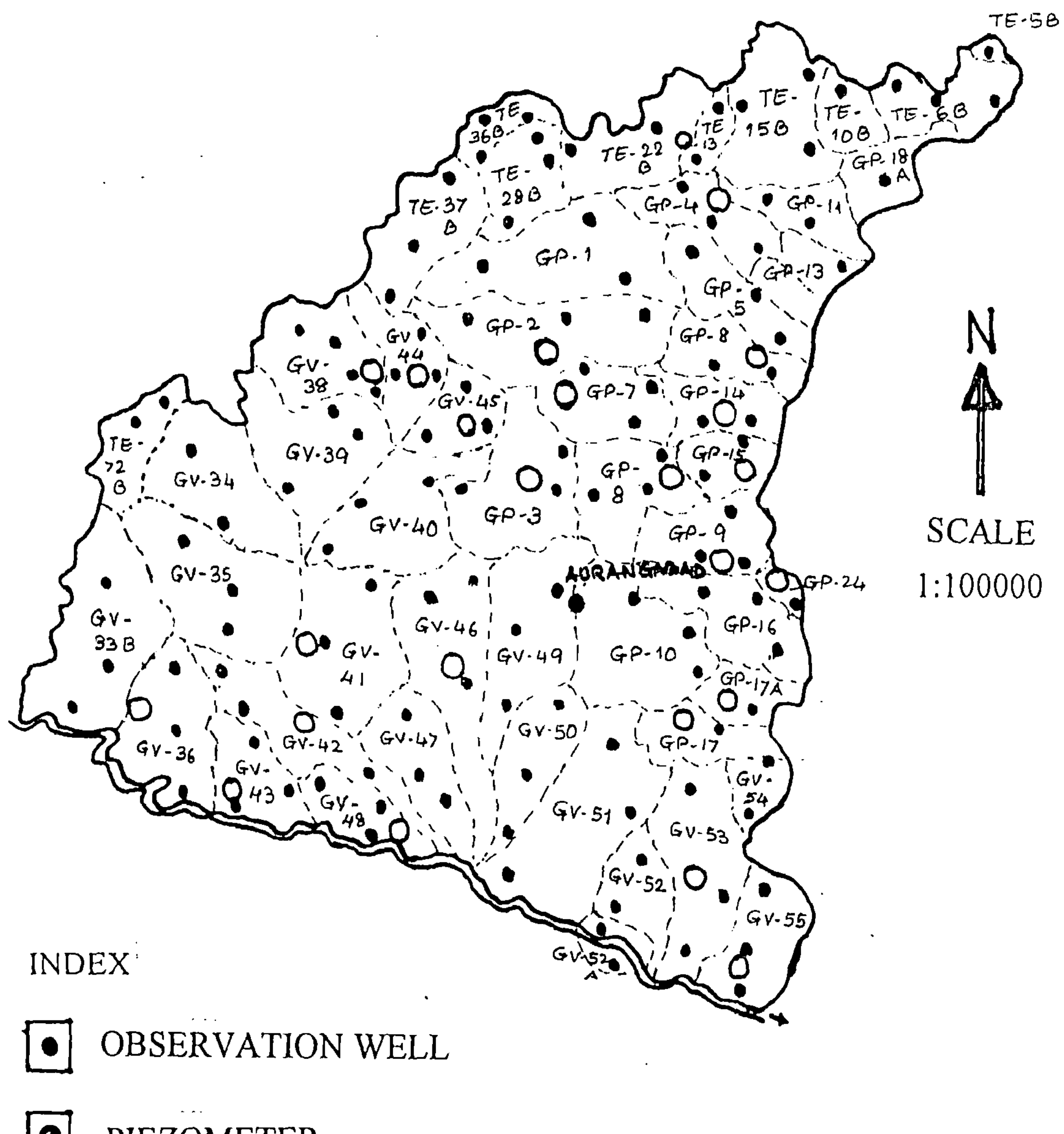
2.2 PRESENT NETWORK

In the district 141 observation wells are fixed for monitoring the groundwater levels of shallow aquifer. These are non-pumping dug wells. To get more realistic picture of groundwater levels, considering the physiography, the observation wells are located in 3 different physiographic divisions within a watershed i.e. 'a'- run-off zone, 'b'- recharge zone and 'c'- storage zone (Maggirwar, 1990). Accordingly the 141 observation wells are set up in 52 watersheds within the district with a network density of one well per 72 sq. km. The water levels in these wells are being monitored manually four times a year i.e. in last week of Jan, Mar, May and first week of Oct. every year.

In the year 1995, under Hydrology Project, the concept of piezometer was introduced for the hydrograph network within hard rock terrain. A piezometer is a purpose built, non pumping observation well that facilitates measurement of vertically averaged piezometric head of a single layer. 24 such piezometers of 115 mm diameter are constructed in the shallow aquifer within the district in different watersheds. These piezometers are constructed with the aim of continuous monitoring of groundwater levels at high frequency (close interval). The water levels of these piezometers are supposed to be monitored automatically by Digital Water Level Recorder (DWLR). Presently the monitoring frequency is six hours. Now the network density is one well per 61 sq. km. The present network (observation wells and piezometers) is shown in Fig. 2.4.

Fig.2.4

LOCATION OF OBSERVATION WELLS AND PIEZOMETERS IN AURANGABAD DISTRICT



2.3 DATA COLLECTION AND PROCESSING

2.3.1 Data Collection

Groundwater level record of any groundwater structure such as dug well, borewell or tubewell can be had in continuous state or discrete state. A continuous record can be had with the help of mechanical (float) instruments or pressure transducers. A discrete record i.e. record of groundwater levels measured once a day, week or month, can be had with the help of groundwater measuring tape or acoustic measuring system, or electrical sounder or air line (CGWB, 1995).

It depends upon the objective of the study whether a continuous or a discrete record of groundwater levels is to be maintained. A high precision continuous record may be used to analyse effect of tide, wind, vehicular movements, diurnal fluctuations etc. It requires good monitory support and constant surveillance. A discrete record may serve the purpose of groundwater estimation calculation, study of groundwater movement, and in the study of changing climate and land use pattern and their impact or groundwater levels. It is more viable to maintain a discrete record in view of the fact that groundwater levels do not show high fluctuations over time as are observed in stream flows.

The Central Groundwater Board (CGWB) and the State Governments in India maintain water levels of dug wells, borewells / tubewells etc. representing different hydrogeological environments, on monthly / quarterly basis in a year. These records are used for study of regional groundwater levels, their rising and falling trends, and resource availability for exploitation before on set of monsoon.

As a part of its monitoring programme, the Groundwater Surveys and Development Agency (GSDA), maintains the records of depth to groundwater levels for both observation wells and piezometers. The groundwater levels of the observation wells in the district are monitored four times a year. The water levels are measured with the help of graduated measuring tape. Similarly the groundwater levels of the piezometers in the district are monitored on six hourly basis with the help of digital water level recorders. Out of 24 piezometers 15 are fitted with DWLRs and remaining are yet to be fitted. Presently only 4 piezometers are working and rest 11 are not working due to mechanical problems. The details of piezometers are given in Table 2.2.

Table 2.2 Details of Piezometers in the district.

Piezometer Code No.	Taluka	Name	Water shed No.	R.L. in mts.	Depth in mts.	DWLR Installed	Working
AUPZ001	Sillod	Peerbavada	GP-15	637.64	30.00	Yes	Yes
AUPZ002	Aurangabad	Kadrbad	GP-17'	543.8	33.00	Yes	No
AUPZ003	Sillod	Pendgaon al.	GP-14	586.21	33.00	Yes	No
AUPZ004	Gangapur	Singi	GV-42	496.38	30.00	Yes	No
AUPZ005	Aurangabad	Dhavalapuri	GP-24	550.32	21.00	Yes	Yes
AUPZ006	Paithan	Dera	GV-53	459.21	30.00	Yes	No
AUPZ007	Sillod	Waghalgaon	GP-8	617.54	30.00	Yes	Yes
AUPZ008	Soyegaon	Galwada	TE-13B	380.28	30.00	No	No
AUPZ009	Sillod	Hatti	GP-4	664.84	30.00	No	No
AUPZ010	Kannad	Wadali	GV-45	617.49	30.00	No	No
AUPZ011	Kannad	Rithi	GV-44	638.49	30.00	Yes	No
AUPZ012	Khultabad	Wadod bk.	GP-3	662.62	77.00	Yes	No
AUPZ013	Aurangabad	Kolghar	GP-17	513.8	30.00	Yes	No
AUPZ014	Kannad	Pimperkheda	GP-2	654.4	61.00	Yes	Yes
AUPZ015	Gangapur	Agathan	GV-41	511.3	70.00	Yes	No
AUPZ016	Sillod	Nillod	GP-1	612	30.00	No	No
AUPZ017	Paithan	Vihamandva	GV-55A	453.5	15.00	No	No
AUPZ018	Gangapur	Ambegaon	GV-46	544.51	30.00	No	No
AUPZ019	Sillod	Babra	GP-7	644.81	30.00	No	No
AUPZ020	Gangapur	Lakhamapur	GV-48	490.85	30.00	No	No
AUPZ021	Vaijapur	Kapus Wad.	GV-36	505.48	30.00	No	No
AUPZ022	Gangapur	Wahegaon	GP-9	489.63	30.00	No	No
AUPZ023	Aurangabad	Selud	GP-9	590	30.00	No	No
AUPZ024	Kannad	Vithalpur	GV-38A	609.75	30.00	No	No

The groundwater level data recorded by the DWLR is retrieved once in a month through palm top. The data are then transferred from palm top to the computers in the district data center. For this purpose software provided under hydrology project are used. Similarly, manually also the water levels of piezometers are measured every month and are checked with the recorded values. The DWLR readings along with the manual readings are entered in GWDES (Groundwater Data Entry System) software. In this software the observation well readings are entered separately.

The main constraint in the data collection was the conversion of DWLR data into user-friendly format. Up till now there was no provision that directly the data form DWLR can be converted into user format and can be analysed with the help of easily available software like Excel, Access etc. It is mandatory to use the software supplied under hydrology project for data conversion, entry and analysis. Presently there is no system working in the organisation by which even in the absence of these software the data entry and its analysis is possible. Under this study this constraint has been removed. Following procedure is followed for conversion of the data into user format.

Basic DWLR data is first converted into meters by using suitable factor depending upon pressure settings. The file is then saved with .txt extension. This .txt extension file is then converted into excel format from where it is available for use. The basic groundwater level data recorded by DWLR contain date and hour of reading in the first column, temperature in °c in 2^{nd} column, water level in meters below measuring point in in 3^{rd} and session no in the fourth column. The session represents the data retrieval rotation. A sample sheet data is given in Table 2.3.

Availability of Data

Presently the continuous high frequency groundwater level data are available for four piezometers only viz. Peerbavada (001), Dhavalapuri (005), Waghalgaon (007) and Pimperkheda (014). In the beginning the observation frequency was 1 hour and then it has been set to six and presently it is six only. The period of availability of hourly data are presented in Table 2.4.

Table 2.3 Basic data form of recorded data in DWLR

DWLR Data (Well No: AUPZ005)

Location: Dhavalapuri

Date : 29/08/98 to 15/10/98

Date	Temperature	Water level	Session No.
29/08/98 2:00:00	28.03	2.049 PM	0
29/08/98 3:00:00	28.05	2.049 PM	0
29/08/98 4:00:00	28.05	2.049 PM	0
29/08/98 5:00:00	28.05	2.049 PM	0
29/08/98 6:00:00 PM	28.05	2.039	0
29/08/98 7:00:00	28.05	2.039 PM	0
29/08/98 8:00:00	28.05	2.035 PM	0
29/08/98 9:00:00	28.05	2.035 PM	0
29/08/98	28.05	2.035 10:00:00 PM	0
29/08/98	28.05	2.045 11:00:00 PM	0
30/08/98	28.05	2.049	0
30/08/98 1:00:00	28.05	2.059 AM	0
30/08/98 2:00:00	28.05	2.059 AM	0

Table 2.4 Availability of high frequency data.

Pz.No	Name	Total data available	Hourly data available	Hourly data Days
001	Peerbavada	29/8/98 to 26/7/2001	30/8/98 to 25/9/98	27
005	Dhavalapuri	29/8/98 to 27/7/2001	29/8/98 to 15/10/98	48
007	Waghalgaon	29/8/98 to 18/12/99	30/8/98 to 24/9/98	25
014	Pimperkheda	6/9/2000 to 8/9/2001	6/9/2000 to 22/11/2000	76

2.3.2 Data Processing

Validation

Before analysis of any time series data it is very essential to cheek its authenticity, reliability and then apply validation cheeks. Though the groundwater level data are recorded by a microprocessor-based instrument (DWLR), it doesn't mean that the observations recorded will be accurate. Hence, it is very essential to counter cheek manually at every retrieval time, so that crosscheck is possible. This system is being followed in the district.

The DWLR is based on pressure principle (transducer), hence it is very essential that the pressure probe should be property set and duly protected from moisture. At the same time if the water level goes down beyond the sensors, it is essential to shutdown the DWLR operations, otherwise there are chances of getting erroneous results. This generally happens during summer, in case of hard rocks, when the aquifer gets emptied almost completely. This problem is encountered in the Dhavalapuri piezometer. Even after sufficient rainfall from 1st June 2001, no rise in groundwater level is observed till 27th July 2001, it is showing a continuous horizontal line below 17 meters datum. This clearly shows that the DWLR is not responding to the rise in water levels. This event is clearly observed in the composite hydrograph of Dhavalapuri (Fig 2.6).

Many a times it happens that the DWLR won't work for some specific period. In that period the data will not be available. So the missing data has to be interpolated by suitable technique and the corresponding data should be year marked separately. This problem is observed in almost all piezometers.

The use of wrong conversion factors may lead to erroneous readings. Hence it is essential to give the exact conversion factor for particular piezometer. Along with this it is also essential to fix up and feed the height of measuring point in DWLR setting. This plays a key role in measuring the accurate groundwater level below ground level.

Processing

After due validation checks the high frequency groundwater level data, of four piezometers in the district where processed by plotting the data in different forms. The means of all the data are calculated on daily basis and then the correlation between daily water levels and rainfall is computed. Similarly the correlation with temperature is also worked out. The correlation coefficients with rainfall and temperature are as follows;

Parameter	Peerbavada	Dhavalapuri	Waghalgaon	Pimpekheda
Rainfall	–0.062	0.45	0.018	0.094
Temperature	0.55	0.093	0.33	-0.173

These values indicate that no strong correlation exists between the water levels and rainfall and temperature too.

As groundwater levels does not show wide fluctuation in water levels over short intervals, the missing records were calculated by linear interpolation between two available values. The missing records for longer periods (in case of Pimperkheda 22/11/00 to 24/3/01) were not interpolated due large data gap.

The graphic facility of Excel is used for plotting the rainfall and water levels of different frequencies. The composite hydrograph of daily rainfall and water levels for complete period are given in Figures 2.5, 2.6, 2.7 and 2.8 respectively. Similarly the composite hydrograph of daily rainfall and hourly water levels of available periods for the four piezometers are given in Figures 2.9, 2.10, 2.11 and 2.12.

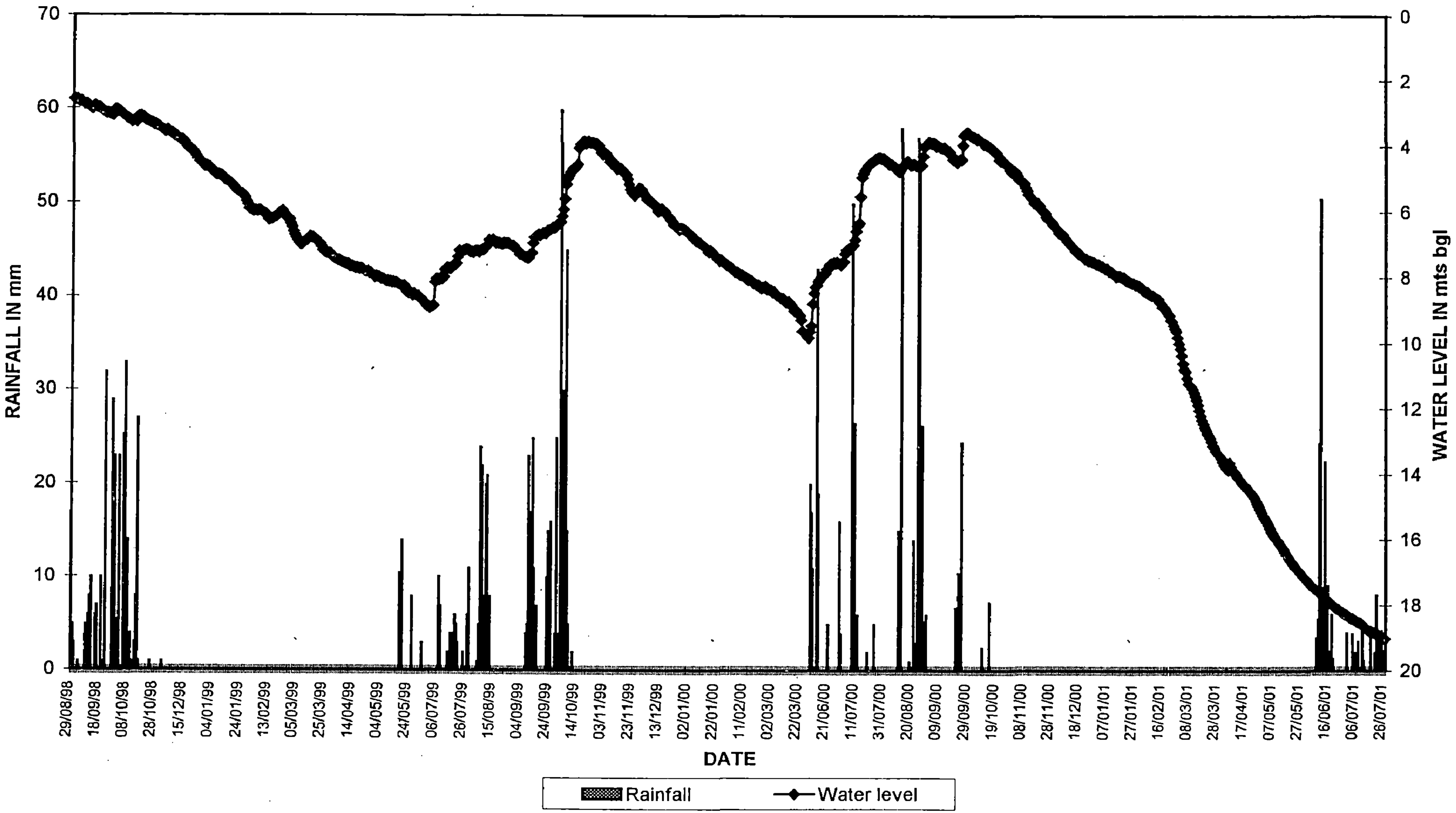


Fig. 2.5 COMPOSITE HYDROGRAPH OF DAILY RAINFALL & AVG. GW LEVELS OF PEERBAVADA (29/8/98 TO 26/7/01)

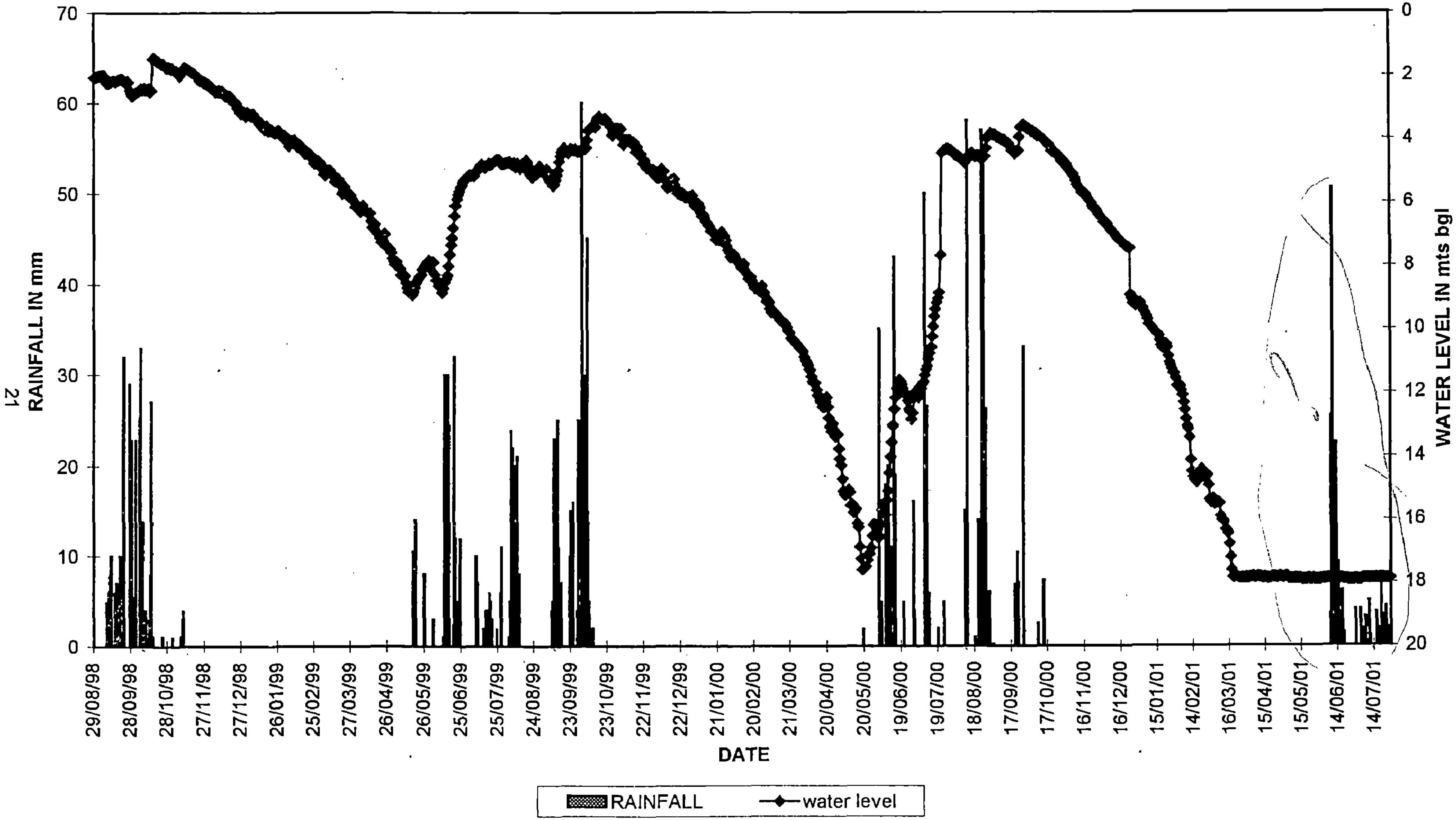


Fig.2.6 COMPOSITE HYDROGRAPH OF DAILY RAINFALL & AVG. GW LEVELS OF DHAVALAPURI (28/8/98 TO 27/7/01)

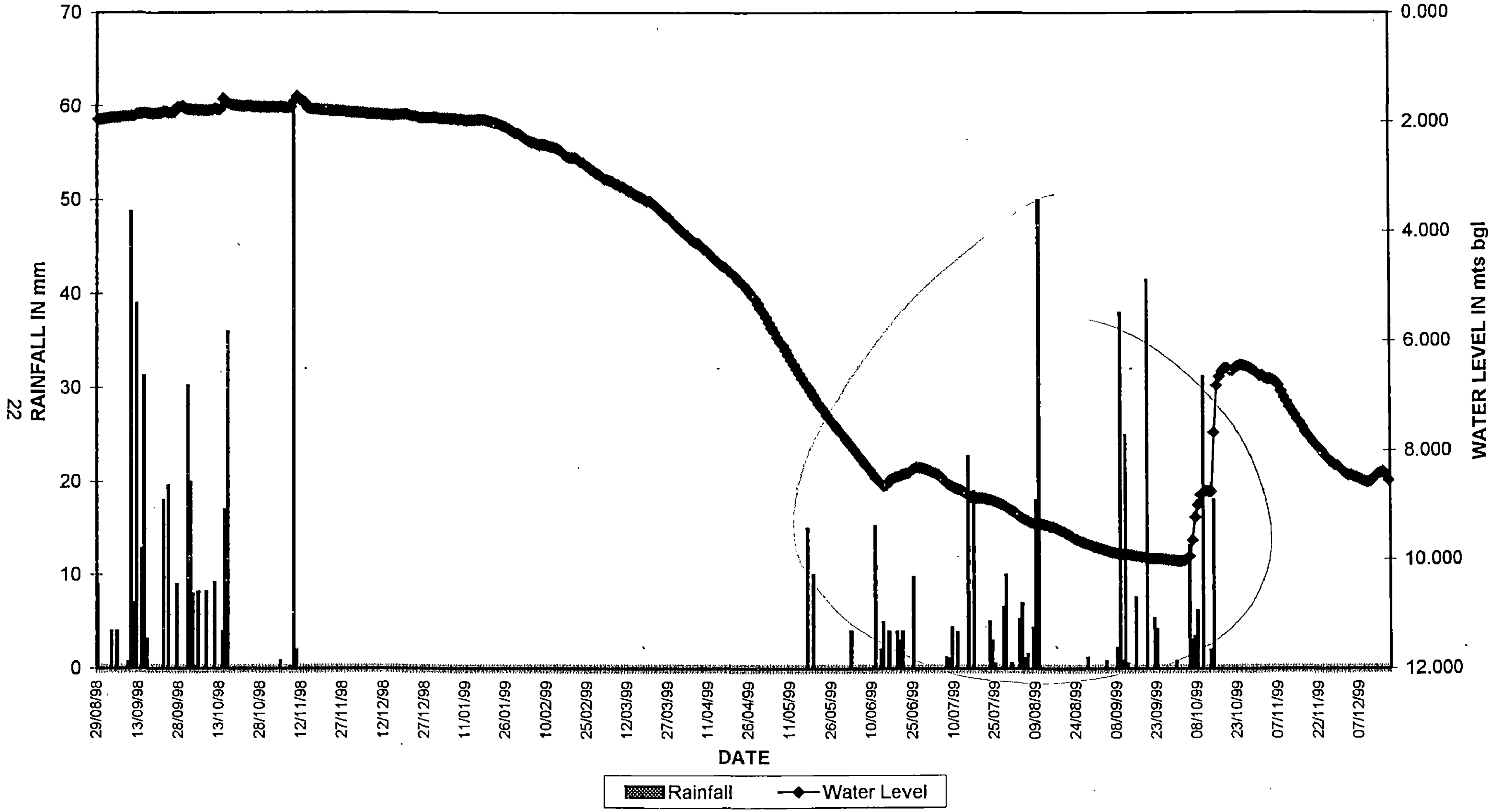


Fig. 2.7 COMPOSITE HYDROGRAPH OF DAILY RAINFALL & AVG. GW LEVELS OF WAGHALGAON (29/8/98 TO 18/12/99)

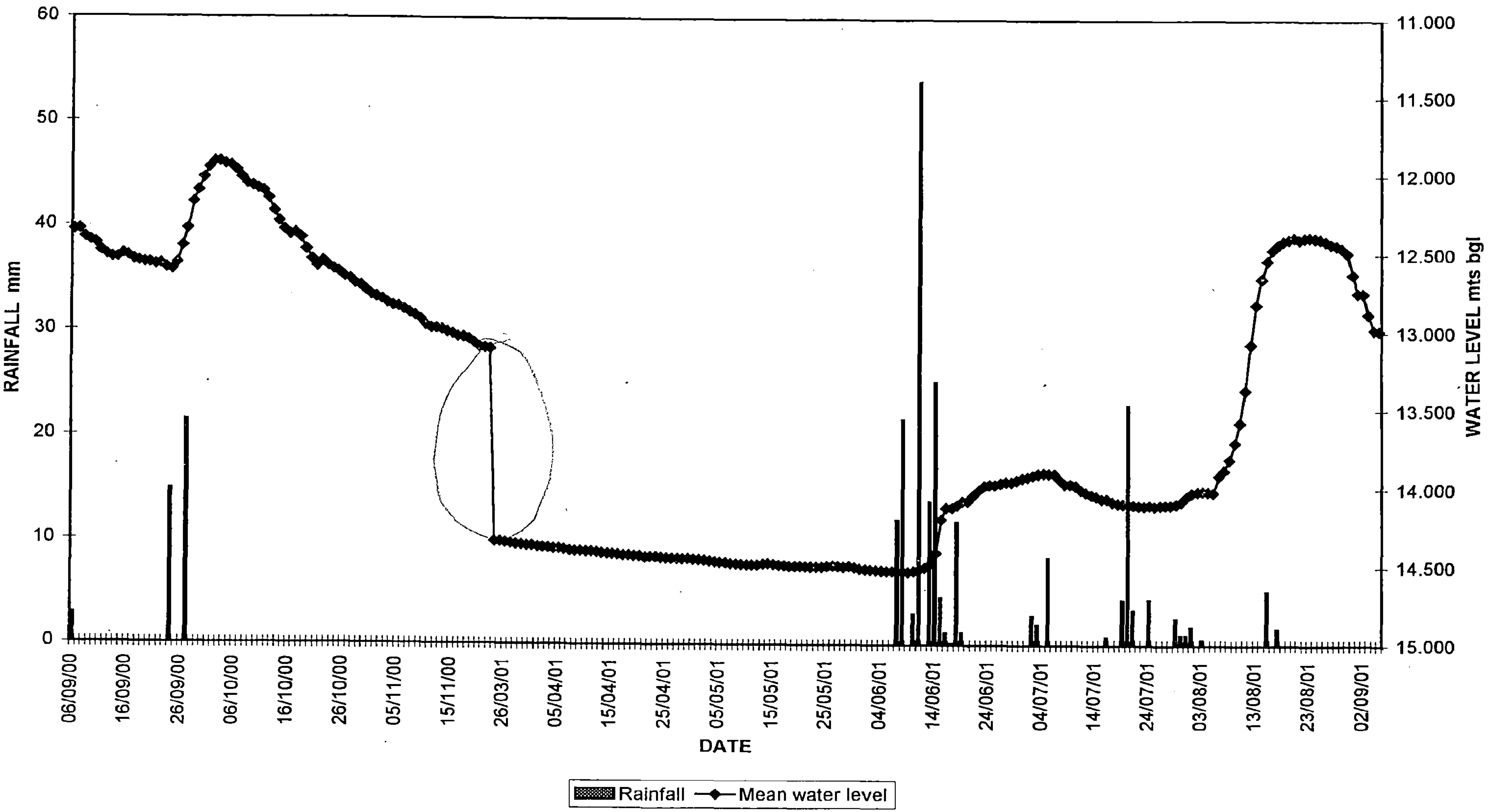


Fig.2.8 COMPOSITE HYDROGRAPH OF DAILY RAINFALL & AVG. GW LEVELS OF PIMPERKHEDA (6/9/00 TO 5/9/01)

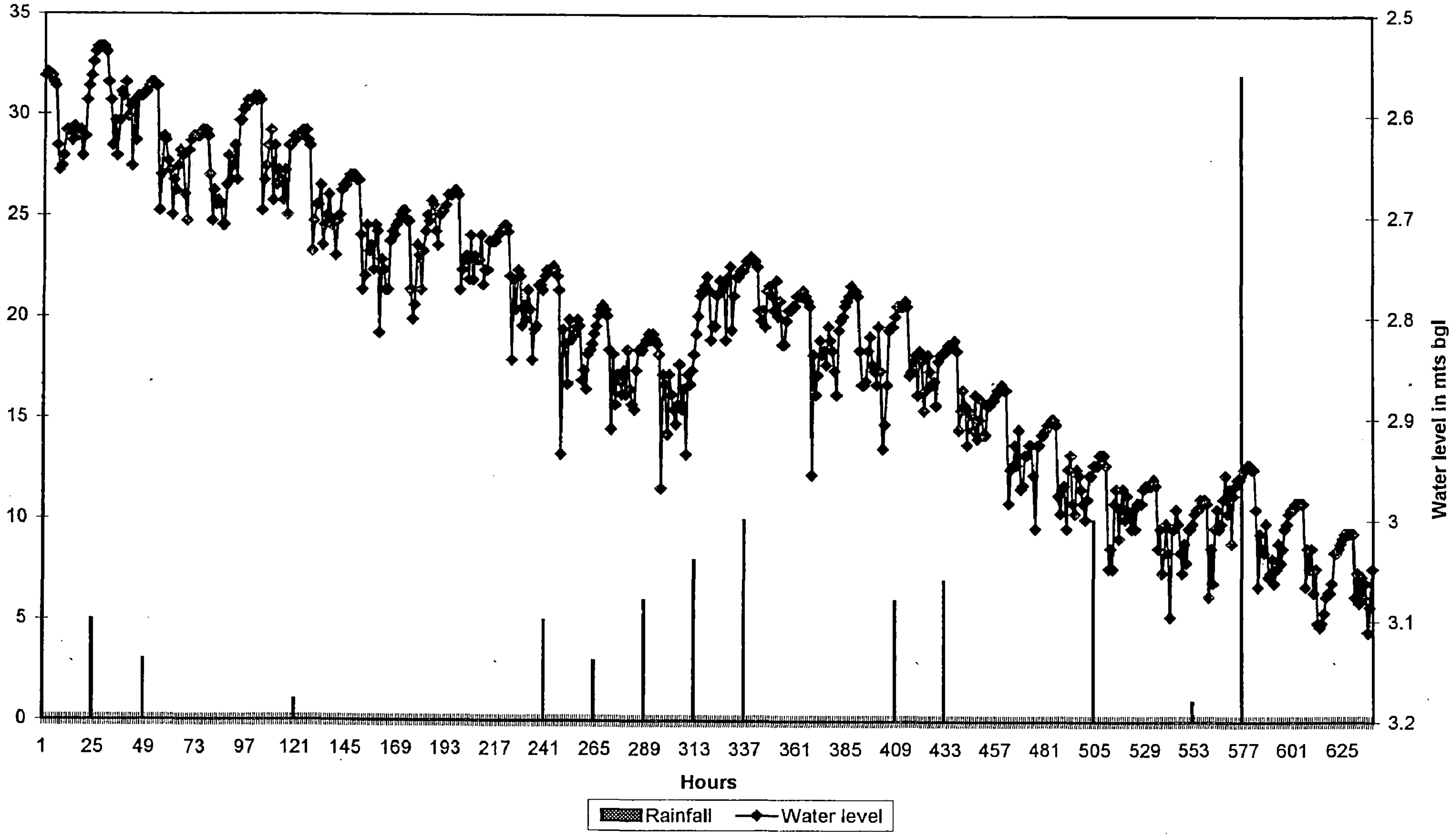


Fig.2.9 Composite hydrograph of daily rainfall & hourly Groundwater levels of Peerbavada (30/8/98 to 25/9/98)

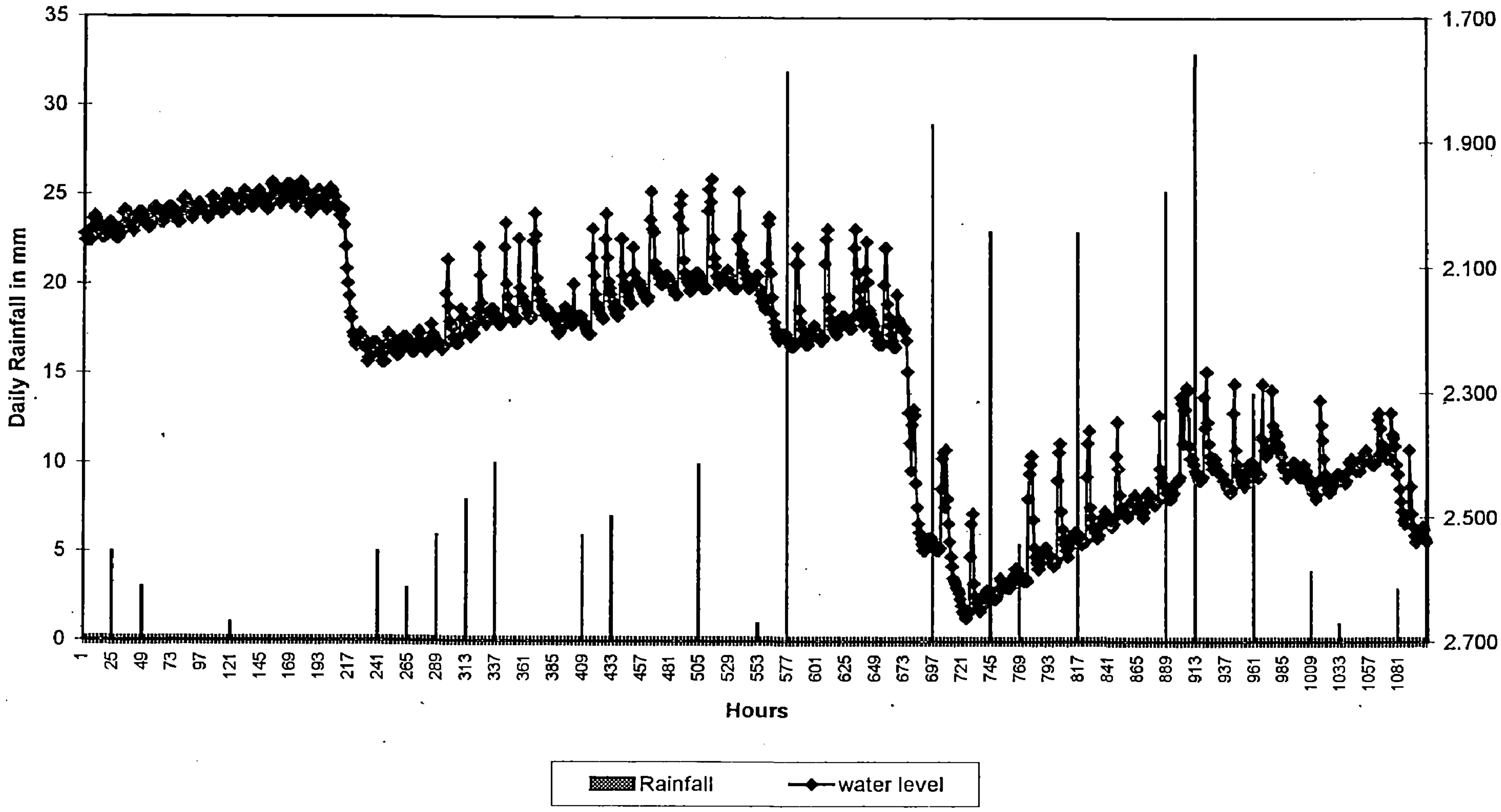


Fig.2.10 Composite Hydrograph of daily rainfall & hourly Groundwater Levels of Dhavalapuri (30/8/98 to 14/10/98)

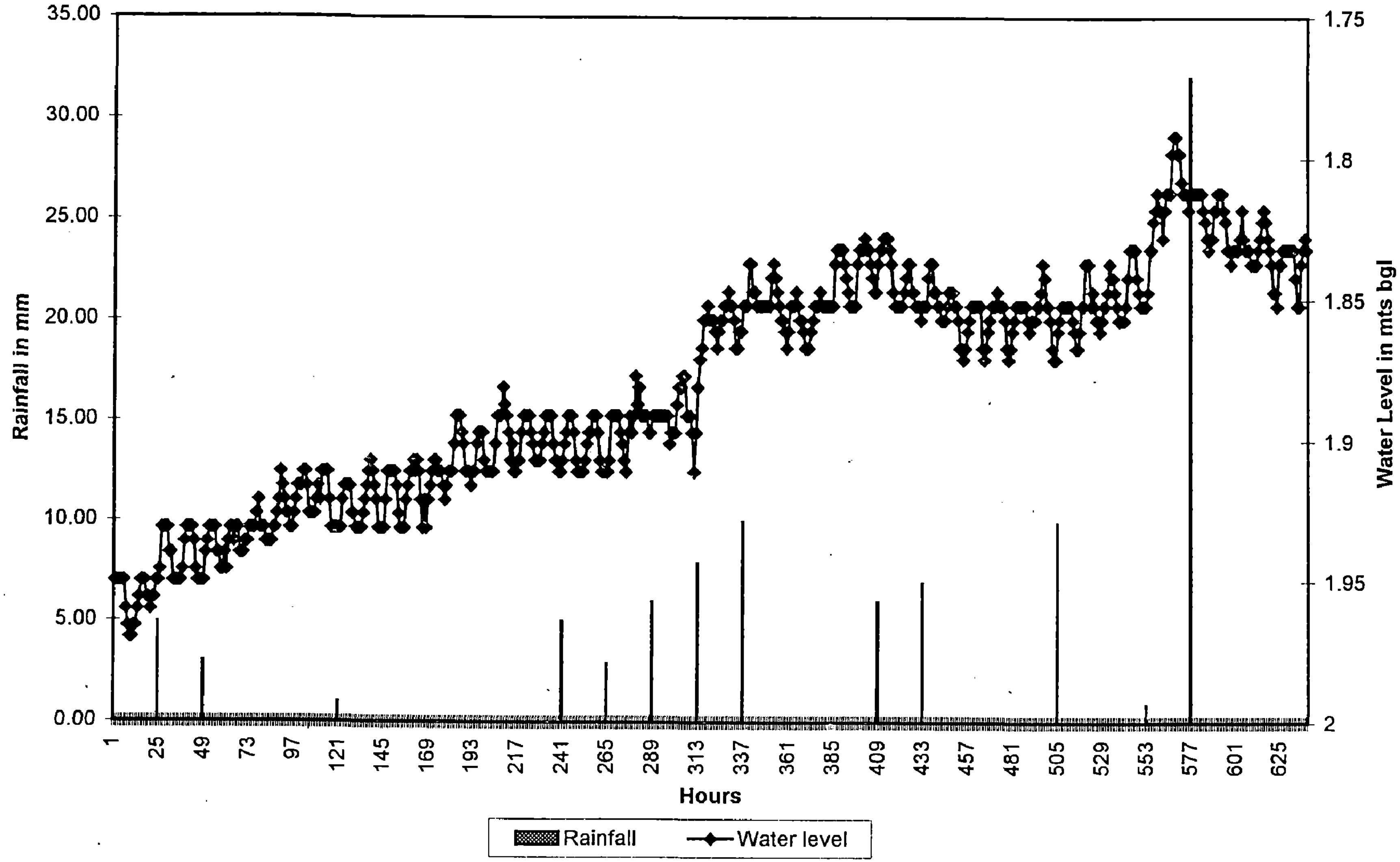


Fig.2.11 Composite Hydrograph of daily rainfall & hourly Groundwater levels of Waghalgaon (30/8/98 to 25/9/98)

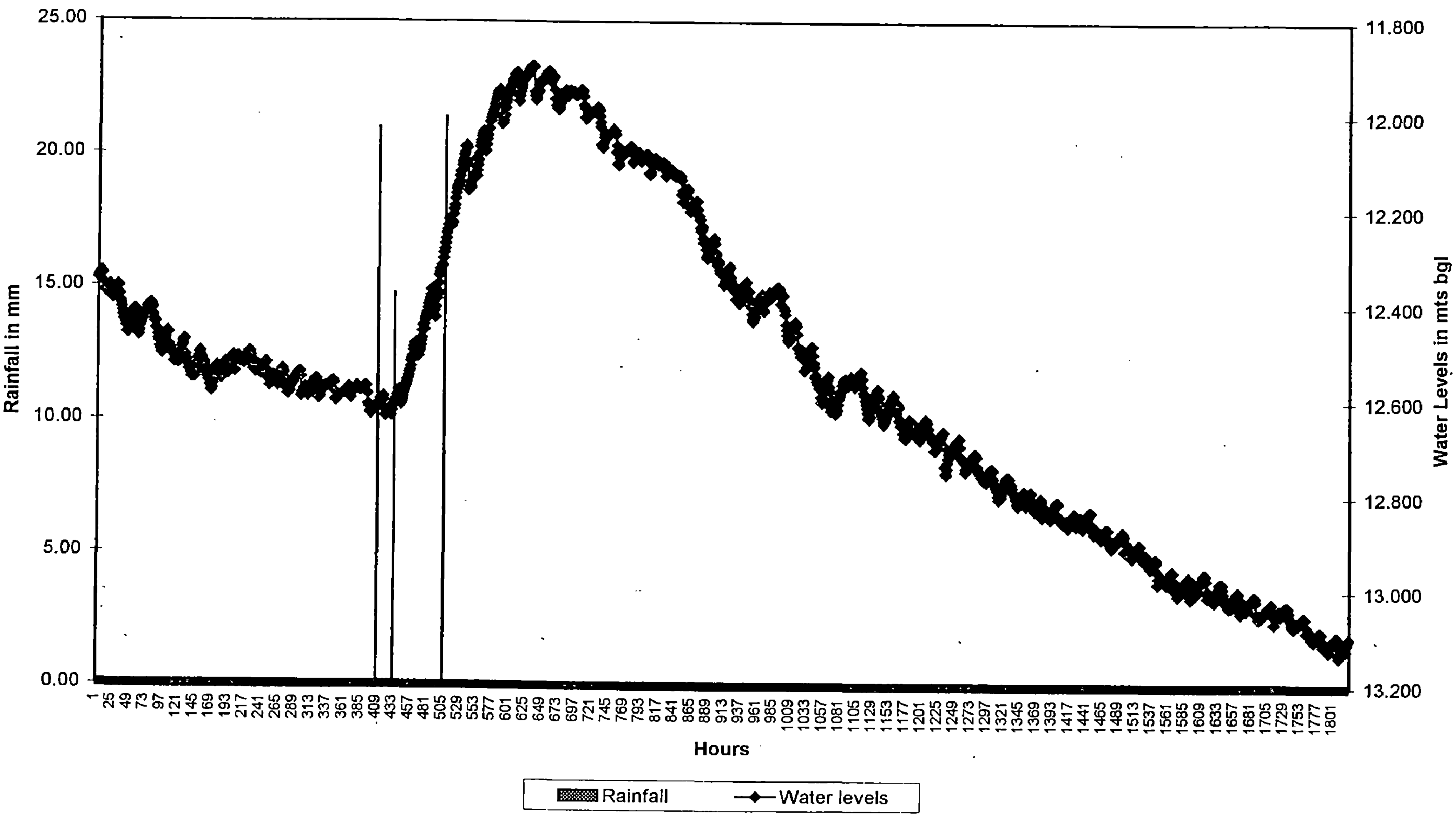


Fig.2.12 Composite hydrograph of daily rainfall & hourly Groundwater levels of Pimperkheda(7/9/00 to 21/11/00)

Analyses

3.1 GENERAL

The use of groundwater level data for different purposes like study of regional groundwater flow, scarcity prediction, groundwater resources estimation etc is well known. For this purpose the available data is analysed by using different methodologies. The high frequency groundwater level data is being collected for the first time in the Maharashtra state as well as in the district. Presently no standard methodology is available for its analysis. Hence an attempt is made to analyse the data.

3.2 PRILIMINARY ANALYSIS

For any time series data, its plot against time is very important. It gives much of the basic information about time series like trend, periodicity etc. Accordingly the time series plots of all the piezometers are taken (Fig. 2.5, 2.6, 2.7 and 2.8). In these plots rainfall is also considered as third parameter as it is the primary source of groundwater recharge.

The high frequency groundwater level time series data for larger duration is not available at any of the piezometers. Hence, it will be improper to draw any conclusion regarding trend i.e. rising or falling. But seasonality is observed in all the time series plots of piezometers, as it is a common feature of the groundwater level time series. Similarly in all the 4 cases the water level response to rainfall is clearly noticed. But there is a time lag i.e. aquifer response is slow. It may be because of the low values of aquifer parameters. Within dry spells during rainy season, due to Kharif pumpage remarkable fall in water levels are clearly observed in Dhavalapuri (31/08/98 to 9/9/98) and Peerbavada (11/7/00 to 3/8/00). This is value addition of high frequency data, as it gives accurate estimate of groundwater withdrawal for Kharif draft. This will help in computing more accurate Kharif pumpage.

3.3 NETWORK DESIGN ANALYSIS

A piezometric network is required for estimating the average piezometric / water table head in an area at discrete times. Such an averaging is required for estimating the groundwater storage. The network is also necessary to arrive at spatial distribution of the piezometric head at discrete times, for understanding the groundwater regime and also the aquifer response modelling. The design of a piezometric network include:

i) Identification of aquifer system
ii) Evaluation of the existing network
iii) Enhancement of the network

3.3.1 Identification of Aquifer System

Based on the geological, hydrogeological map of the district, along with the maps of systematic hydrogeological surveys, drilling information, geophysical exploration, landsat imagery and aerial photograph study detailed study of aquifer system of Aurangabad district is carried out (GSDA, 1990). The study revealed that primarily the unconfined (water table) aquifer of the Deccan Traps is dominant in the district. Similarly at some places semi- confined aquifer within Deccan Traps are quite common, which are encountered in shallow borewells (upto 60 meters). The exploratory borewells drilled for deeper confined aquifer are found dry. There seems no possibility of existence of confined aquifers within district (GSDA, 1990).

The unconfined aquifer, being dominant, is of prime importance from network design point of view. The average depth of this aquifer ranges from 4 to 25 meters, depending upon the morphological conditions. The dependence on groundwater for different usages (irrigation, drinking, industrial) is more. So the shallow unconfined aquifer is of utmost importance from groundwater estimation point of view in the district. Hence the network design for the district is restricted for shallow aquifer only.

3.3.2 Evaluation of the Existing Network

Presently 141 observation wells exist in the district. Discrete data at 4 times in a year (Jan, Mar, May and Oct) are available since 1990 for these wells. The evaluation of the existing network is done by using the coefficient of variation-based technique (HP Manual, 1998).

First the mean (μ) and standard deviation (σ) of the yearly average water level is computed by using equations (1) and (2).

$$\mu = \frac{\sum hi}{N} \quad \text{....(1)}$$

$$\sigma = \left[\frac{\sum (hi-\mu)^2}{N-1}\right]^{1/2} \quad \text{....(2)}$$

Where μ = mean, σ = standard deviation, N = no. of monitoring wells / piezometers, hi = water level in mts bgl, i = 1.........N.

m = no. of actual monitoring wells / piezometers for which data are available.

Instead of 'N' the value of 'm' is used in calculations.

The normalised spatial variation of the water levels within district is indexed with coefficient of variation (Cv) and percent-expected error (P), which are computed as follows.

$$Cv = \frac{\sigma}{\mu} \times 100 \quad \text{...(3)}$$

$$P = \frac{Cv}{\sqrt{N}} \quad \text{....(4)}$$

This analysis is carried out for yearly mean of observation wells from 1990. Similarly after 1998 the data from piezometers are also considered. The details of data and calculations are shown in Table 3.1.

The results show that upper bound on percent expected error (*P*) is 4.26 during 1998. So after considering upper bound error of 5% the values of N are coming much lesser and the average value of N is 73. These results clearly show that the old network (prior to hydrology project) was sufficient and today also the network is much denser than the desired for 5% error in estimation of average groundwater level. Hence it is necessary to discard / abandon the observation in some of the observation wells. The numbers of piezometers equipped with DWLR's are now few. There is need that unoperational DWLR's made operational. The observation wells to be discarded may be selected on the basis of groundwater contours, shown in Fig. 3.3 in later section.

Table 3.1 NETWORK DESIGN ANALYSIS FOR AURANGABAD DISTRICT

Year	m	μ	σ_t	C_{vt}	P	N for 5% Error
1990	136	6.747	2.668	0.396	3.391	63
1991	140	6.257	2.809	0.449	3.795	81
1992	140	7.790	3.149	0.404	3.417	65
1993	140	7.803	3.428	0.439	3.713	77
1994	140	8.382	3.545	0.423	3.574	72
1995	140	8.817	3.824	0.434	3.666	75
1996	140	9.687	3.625	0.374	3.163	56
1997	140	9.272	4.020	0.434	3.664	75
1998	**143**	**8.211**	**4.181**	**0.509**	**4.258**	**104**
1999	147	6.825	3.106	0.455	3.753	83
2000	147	8.505	3.537	0.416	3.431	69
2001	140	9.811	3.680	0.375	3.170	56
					Average	73

3.4 DETERMINATION OF LEVEL OF ACCURACY

Presently the observation wells and piezometers are giving the groundwater level in discrete and continuous state respectively. The groundwater level data are available in the district since 1974. From this time the data are being regularly used for estimation groundwater resources and scarcity prediction. Up till now with the assistance of this data all the six-groundwater assessments are carried out (Ist – 1973, II nd – 1977, IIIrd – 1980, IV th – 1985, Vth – 1990 and VIth – 2000) (Commission Report, 1999). Now also the estimation of VIth assessment is under progress.

From August 98 the DWLR data are available at high frequency. Being in continuous state, all peaks and troughs are recorded accurately. To bring both the system data on one datum, it is necessary to determine the level of accuracy.

3.4.1 For Past Data of Dug Wells

The hydrological year starts from June and ends in May in the district. The monitoring frequency is fixed based upon the hydrological cycle and groundwater use.

The district mainly receives rainfall from SW monsoon, which generally starts from 7th June and ends in Sept. last. Hence after the onset of monsoon, generally the aquifer saturate fully under normal rainfall conditions (CGWB, 1992) and the water levels attains minimum position below ground level. This situation is usually observed in the first week of October. Hence the first post-monsoon reading is recorded in first week of October every year. Then starts the Rabi season in the district, during which groundwater is used mainly for irrigation. This season lasts for 90-180 days. Hence the 2nd observation is taken in the first week of Jan and 3rd in the first week of Mar every year. The effect of groundwater draft for rabbi irrigation is reflected into the gradual fall in water levels. After Rabi season, except few places of perennial irrigation, the groundwater is exclusively used for drinking purpose. Hence after March the water levels deplete gradually and before monsoon it reaches deepest level in the last week of May. Hence the pre-monsoon water level is taken in the last week of May every year. The ideal hydrograph for the shallow Deecan Trap aquifers is shown in Fig 3.1. This clearly gives the idea of mechanism of groundwater recharge and discharge in hard rock terrain (Bagade, 2000).

<u>Procedure Adopted for Comparison</u>

The high frequency i.e. 6 hourly data of groundwater levels of three piezometers viz Dhavalapuri, Peerbavada and Waghalgaon, are used for finding the level of accuracy between the past and present data. Following steps are adopted for this.

- Two types of groundwater level readings are separated from the available piezometer data. In first type, maximum value for Jan, Mar and May and minimum value from July to Nov is separated. This is named as 'Actual Reading'
- In the second type, the average water level values are computed based on the first week values of Jan and Mar, last week values of May and

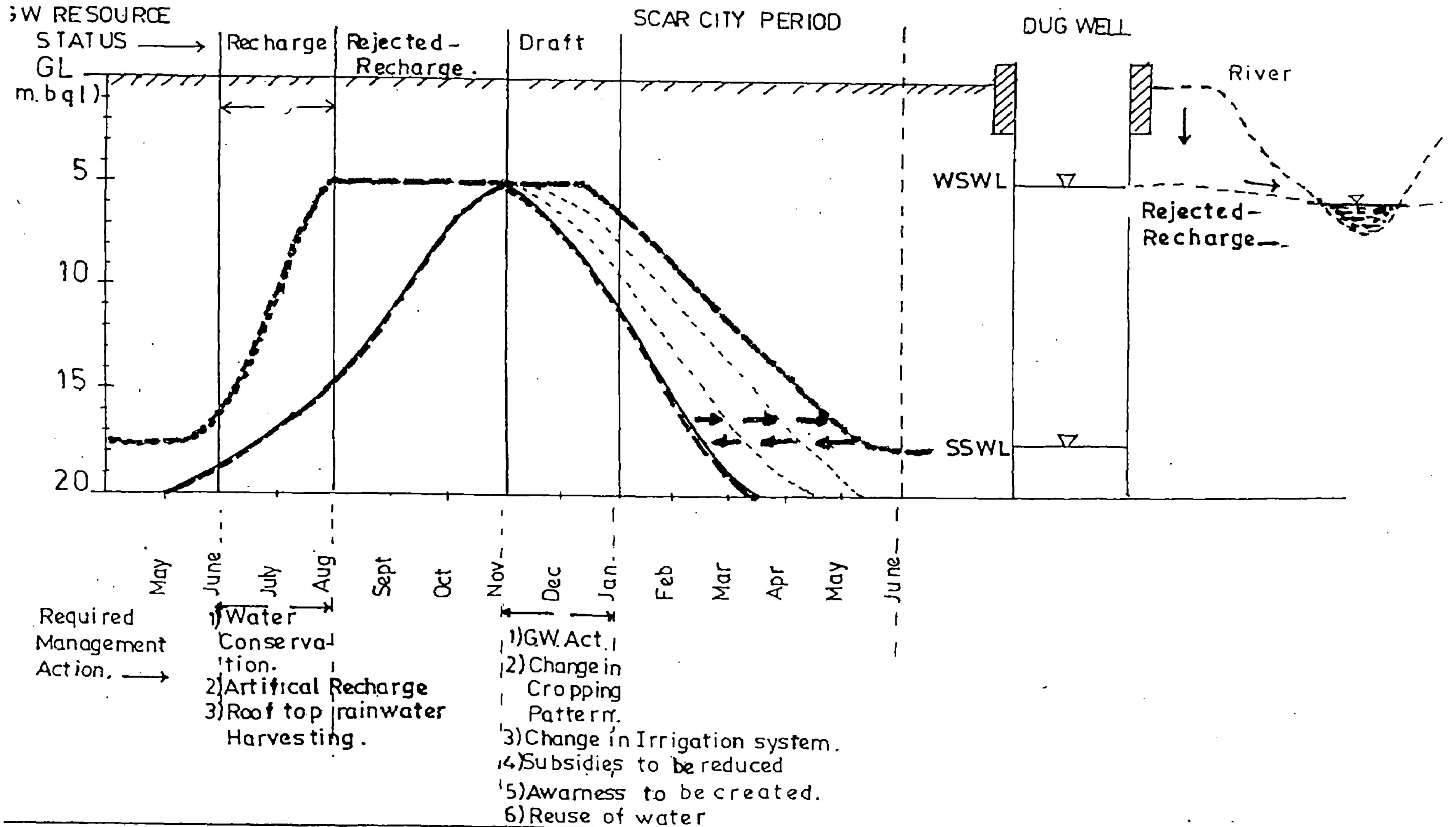


Fig.3.1 General Hydrograph for Shallow Aquifer of Deccan Trap

second week values of October. It is presumed that these values actually represent the values of the old system. This is named as 'Avg. Reading'.

- The 'Actual Reading' are considered true representatives of shallower aquifer considering the agroclimatic and hydrological condition of the district. It is because of the fact that they represent the real peak and through (minimum and maximum value), where as in the 'Avg. Reading' these peaks and troughs are averaged out. In the old system it is quite possible that the peaks or troughs may be missed because of various reasons. Hence the Avg. Reading is considered equivalent with the old system. Based on these assumptions, error is computed.

$$Persent\ \ Error = \frac{Acutal\,\mathrm{Re}ading - Avg.\,\mathrm{Re}ading}{Actual\,\mathrm{Re}ading} * 100$$

$$Error\ \ factor = \frac{Actual\,\mathrm{Re}ading}{Avg.\,\mathrm{Re}ading}$$

In this way the percent errors are computed for Jan, Mar, May and Oct every year from 1998 to 2001 and are given in Table 3.2. Yearly averages are also computed for all piezometers and then total average error is computed. The total average error is **5.73%** and the corresponding error factor is 1.06. For generalisation purpose this total average is calculated and can be used for estimating the accurate water levels of old system. For conversion of old water level simply the observed groundwater level should be multiplied by error factor.

Corrected Water level of old system = Actual Water level of old system * 1.06

The results show that the error range is between 2.94 to 7.81 with an average of 5.73%. This indicates that the error is within permissible limit, of 5-10% in any time series data. This clearly shows that there is no much significant error in the groundwater level data of old system, where monitoring is done manually. To find out more realistic value of old system, it will be more appropriate to use the percent error of the piezometer data within same or nearby watershed having homogeneous conditions.

Table 3.2 Calculation of Error to Determine the level of Accuracy for Observation Well Readings based on Piezometer readings

Name of Piezo. & Details	Monitoring Month	Piezometer data from		% Error	Error Factor
		Actual Reading	Avg. Reading		
Dhawalapuri					
AUPZ005 R.L. 550.32 mts	Jan-99	4.051	3.579	11.65	1.13
	Mar-99	6.368	5.367	15.72	1.19
Depth 21.00 m	May-99	9.035	8.285	8.30	1.09
	Oct-99	3.231	3.682	-13.96	0.88
	Avg	**5.67**	**5.23**	**7.81**	**1.08**
	Jan-00	7.899	6.792	14.01	1.16
	Mar-00	10.785	9.917	8.05	1.09
	May-00	17:806	16.15	9.30	1.10
	Oct-00	3.586	4.183	-16.65	0.86
	Avg	**10.02**	**9.26**	**7.57**	**1.08**
	Jan-01	12.035	10.335	14.13	1.16
	Apr-01	17.877	16.782	6.13	1.07
	May-01	17.907	17.877	0.17	1.00
	Avg	**15.94**	**15.00**	**5.91**	**1.06**
Peerbawada	Oct-98	2.533	2.882	-13.78	0.88
AUPZ001 R.L. 637.64	Jan-99	6.086	5.263	13.52	1.16
mts Depth 30.00	Mar-99	7.496	7.008	6.51	1.07
mts	May-99	8.784	8.284	5.69	1.06
	Oct-99	3.754	4.45	-18.54	0.84
	Avg	**6.53**	**6.25**	**4.27**	**1.04**
	Jan-00	7.833	7.195	8.15	1.09
	Mar-00	10.005	8.949	10.55	1.12
	Oct-00	3.586	4.183	-16.65	0.86
	Avg	**7.14**	**6.78**	**5.12**	**1.05**

	Jan-01	8.462	7.976	5.74	1.06
	Mar-01	13.627	12.195	10.51	1.12
	May-01	17.264	16.4	5.00	1.05
	Avg	**13.12**	**12.19**	**7.07**	**1.08**
Waghalgaon	Oct-98	1.555	1.734	-11.51	0.90
R.L. 617.54	Jan-99	2.269	2.019	11.02	1.12
AUPZ007 Depth 30.00 mts	Mar-99	3.973	3.41	14.17	1.17
	May-99	7.814	6.75	13.62	1.16
	Oct-99	6.422	7.697	-19.85	0.83
	Avg	**5.1195**	**4.969**	**2.94**	**1.03**
		Average Error		**5.73**	**1.06**

3.4.2 For Groundwater Estimation

Quantification of groundwater resources is often critical and no single comprehensive technique is yet identified which is capable of estimating accurate groundwater assessment. The complexicities of the process governing occurrence and movement of groundwater make the problem of groundwater assessment difficult, mainly because not only enormous data is to be procured, but a multidisciplinary scientific approach is to be adopted for space and time location of groundwater, in quantity as well as quality. Groundwater being a replenishable resource, its proper and economic development on a sustainable basis requires its realistic assessment.

Groundwater resource estimation must be seen as an interactive procedure. Initial estimates are revised and refined by comparing these to results of other methods and ultimately with its field manifestation. The methodologies adopted for computing groundwater resources have undergone a continuous change and adohocism adopted earlier have given way to define field-tested norms. The computation methods, like the groundwater resources itself, have been dynamic in nature and gradual refinement has taken place with the generation of more and more data input and with better understanding of science of groundwater. At present 'Groundwater Resource Estimation Methodology –1997' (GREM – 1997) is being used in the district for estimation of groundwater (MOWR, 1997).

Two approaches recommended by the GREM –1997, namely water level fluctuation method and rainfall infiltration factor method, form the basis for groundwater assessment. Watershed with well-defined hydrological boundaries is an appropriate hydrological unit for groundwater resource estimation. The assessment within watershed is carried out separately for non-command and command areas. For present study all these norms (prescribed by GREM –1997) are followed and the groundwater assessment is carried out. These calculations are made in Excel spreadsheet. The Dhavalapuri and Peerbavada piezometers, which are having minimum 3 years of data, are considered. The estimates are computed for non-command areas of the respective watersheds only. The aim is to compare these estimation results with respect to the old system.

Procedure Adopted

The water levels obtained from observed data for Actual Reading and Avg. Reading in the section 3.4.1, are used here for assessment. The data for different parameters, like worthy area, specific yield, no. of domestic and irrigation wells with unit draft, crop type, no. of water conservation structures, no. of ponds/tanks, rainfall etc, is collected from different government organisations within the district. The fluctuation in water levels is calculated from pre and post monsoon observations of successive years. Important equations are listed below.

Fluctuation of = Pre monsoon WL in meters. – Post monsoon WL in meters.
WL in meters.

Monsoon Recharge

The gross recharge during monsoon season is calculated by using the following equation

$$R = A*h*S_y + D_G$$

Where R = Gross recharge in m^3

A = Worthy area in m^2

h = Yearly water table fluctuation in meters.

S_y = Specific yield

D_G = Gross groundwater draft for drinking and irrigation purpose during monsoon.

Here the data of Kharif pumpage could not be made available though it has been reflected in both the hydrographs. Hence D_G for irrigation is considered as zero (GREM –1997).

The recharge form rainfall during particular monsoon for 1999, 2000 and 2001 are computed separately by using equation.

$$\mathbf{R_f = R - R_{gw} - R_{wc} - R_t}$$

R_f = Rainfall recharge in m^3

R = Gross recharge in m^3

R_{gw} = Recharge from groundwater irrigation during monsoon in m^3

R_{wc} = Recharge from water conservation structures during monsoon m^3

R_{gw} is considered as zero due to non-availability of Kharif irrigation data.

R_{wc} = 0.25 * gross storage * no. of fillings

R_t = 0.0014 * No. of days for which tank / pond has water(GREM-1997)

Based on these three values of R_f the rainfall recharge during monsoon for normal monsoon season rainfall R_{rf} (normal) is calculated by using normalisation technique. The detailed normalisation calculations are given in Table 3.3.

$$S_1 = \sum_{i=1}^{N} r_i$$ Where r_i is rainfall of i^{th} year

$$S_2 = \sum_{i=1}^{N} R_i$$ R_i is Recharge of i^{th} year

$$S_3 = \sum_{i=1}^{N} r_i^2$$

$$S_4 = \sum_{i=1}^{N} r_i R_i$$

The regression constants 'a' and 'b' are computed as,

$$a = \frac{NS_4 - S_1 S_2}{NS_3 - S_1^2}, \quad b = \frac{S_2 - aS_1}{N}$$

R_{rf} (normal) = a * r (normal) + b

Total Recharge form monsoon season for normal monsoon rainfall is computed by adding R_{rf} and R_{wc} and R_t. Similarly the recharge for non monsoon period is

Table 3.3 NORMALISATION CALCULATIONS

Sr.No	Watershed No	Taluka	Year	Rainfall in mts (ri)		Rcharge (Ri)
				Normal (r)	Actual	
GW Estimation as per Piezometer data (considering min.water level for Oct & max. for May)						
1	GP-24	Aurangabad	1998	740	984	4276555.4
			1999	740	722	8711195.0
			2000	740	640	8548279.4
GW Estimation as per Piezometer data (considering average water level for Oct & May)						
1	GP-24	Aurangabad	1998	740	984	2921277.2
			1999	740	722	7617608.0
			2000	740	640	8310320.0
GW Estimation as per Piezometer data (considering min.water level for Oct & max. for May)						
2	GP-15	Sillod	1999	609	465	12687846.6
			2000	609	365	12687846.6
GW Estimation as per Piezometer data (considering average water level for Oct & May)						
2	GP-15	Sillod	1999	609	465	10789518.2
			2000	609	365	10126475.8

Sr.No.	S1	S2	S3	S4	a	b
1	2346	21536029.8	1899140	1.6E+10	-13515.4	17747729.53
1	2346	18849205.2	1899140	1.37E+10	-16215.8	18963850.05
2	830	25375693.2	349450	1.05E+10	3.81E-10	12687846.6
2	830	20915994	349450	8.71E+09	6630.424	7706371.04

estimated by adding recharge from water conversation structures (R_{wc}), ponds / tanks (R_t) and from groundwater irrigation (R_{gw}). Here the rainfall during non-monsoon period is less then 10% of normal annual rainfall. Hence the rainfall recharge during non-monsoon is considered equal to zero (GREM, 1997). Total annual groundwater recharge is computed by adding monsoon and non-monsoon recharge. After deducting 5% recharge from non-monsoon season, the net groundwater availability estimated for two watersheds namely GP-24 (Dhavalapuri) and GP-15 (Peerbavada) is as follows. ? Why ?

GP-24 (Dhavalapuri)		GP- 15 (Peerbavada)	(figs in MCM)
Actual Reading	Avg.Reading	Actual Reading	Avg.Reading
87.43	79.99	151.94	142.97

The detailed calculations are given in Table 3.4. The stage of development for GP - 24 and GP-15 are 17 and 53%. The category for these could not be assigned, as the trend of WL is not possible from the available data. The error between the estimated groundwater resource by Actual readings and Avg. Reading is computed, considering the Actual Reading value as more accurate and realistic. The errors for GP-24 and GP-15 are 8.50 and 5.90% respectively and over all error is 7.20%. These results show that the error is less then 10%. Hence error in estimation of groundwater resources (by GREM – 1997) by using piezometer data is less then 10%, which is not much significant. This also confirms the fact that there is no much significant error is observed in the estimation of groundwater resources by using groundwater level data of old system.

3.5 DETERMINATION OF FREQUENCY OF OBSERVATION

Presently the frequency of observation of groundwater levels in the piezometers of the district is six hour. These data are presently used for estimation of groundwater resources (mainly monsoon recharge) and for scarcity prediction and management. Similarly it can also be used for different GW management purposes such as conjunctive use planning, regulation in over exploited areas.

In general the requirement of the frequency can apparently not be uniquely defined and shall depend upon the indented use of the high frequency data as well as upon the local hydrogeological and hydrological characteristics. For example, an aquifer having low specific yield may display faster water level variations and hence

Table 3.4 COMPUTATION OF LEVEL OF ACCURACY FOR ESTIMATION OF GROUNDWATER RESOURCES

Sr. No	Year	WS No.	Taluka	Total Area Sq km	Non Worthy Area Sq km	Worthy Area in Sq.mts **A**	Piezometer readings in mts bgl		Avg. WT FLN in mts **h**	Specific Yield **Sy**
							Pre monsoon	Post monsoon		
1	2	3	4	5	6	7	8	9	10	11
GW Estimation as per Piezometer data (considering min.water level for Oct & max. for May)										
1	1999	GP-24	Aurangabad	32.07	0	32070000	9.035	1.374	7.661	0.02
	2000	**Dhawalpuri piezometer**		32.07	0	32070000	17.806	3.231	14.575	0.02
	2001			32.07	0	32070000	17.907	3.586	14.321	0.02
GW Estimation as per Piezometer data (considering average water level for Oct (first week)& May (last week))										
1	1999	GP-24	Aurangabad	32.07	0	32070000	7.971	2.423	5.548	0.02
	2000	**Dhawalpuri piezometer**		32.07	0	32070000	16.48	3.61	12.87	0.02
	2001			32.07	0	32070000	17.887	3.937	13.95	0.02
GW Estimation as per Piezometer data (considering min.water level for Oct & max. for May)										
2	1999	GP-15	Sillod	105.58	0	105580000	8.784	2.533	6.251	0.02
	2000	**Peerbavada Piezometer**		105.58	0	105580000	10.005	3.754	6.251	0.02
GW Estimation as per Piezometer data (considering average water level for Oct (first week)& May (last week))										
2	1999	GP-15	Sillod	105.58	0	105580000	8.565	3.213	5.352	0.02
	2000	**Peerbavada Piezometer**		105.58	0	105580000	9.65	4.612	5.038	0.02

Total Draft of Domastic Wells for 365 days		Irrigation Draft During Non Monsoon (for **Rabbi** days of Irrigaion)		Gross Recharge (R=A*h*Sy+D_G)	Recharge due to GW Irrigation for non-monsoon season for **Rabbi** days of Irrigation (monsoon rechrage considered as zero)				Recharge due to water conservation structures/PT/Ponds (for ponds 1:4mm/day)	
No. of Wells m^3/day	Gross Draft D_G	No.of Wells m^3/d	Gross Draft D_G (m^3)	R=7*10*11+ (13+15)	Crop Types	No. of wells	Factor	Gross Rech R_{gw}	25% during (R_{wc}) monsoon	Non-mon
12	13	14	15	16	17	18	19	20	21	22
2	13140	200	1440000	4926905.4	Non-Paddy	200	0.25	360000	650350	446450
2	13140	200	1440000	9361545.0	Non-Paddy	200	0.25	360000	650350	446450
2	13140	200	1440000	9198629.4	Non-Paddy	200	0.25	360000	650350	446450
2	13140	200	1440000	3571627.2	Non-Paddy	200	0.25	360000	650350	446450
2	13140	200	1440000	8267958.0	Non-Paddy	200	0.25	360000	650350	446450
2	13140	200	1440000	8960670.0	Non-Paddy	200	0.25	360000	650350	446450
42	183960	851	7659000	13383571.6	Non-Paddy	851	0.25	1914750	695725	695725
42	183960	851	7659000	13383571.6	Non-Paddy	851	0.25	1914750	695725	695725
42	183960	851	7659000	11485243.2	Non-Paddy	851	0.25	1914750	695725	695725
42	183960	851	7659000	10822200.8	Non-Paddy	851	0.25	1914750	695725	695725

Recharge from Rainfall during particular monsoon	Rainfall recharge during monsoon for normal monsoon season R/f	Total Recharge from monsoon season for Normal monsoon R/F	Recharge during Non monsoon	Total Annual Recharge	Net GW availability(After deducting 5% recharge from Non monsoon season)	Stage of Development	Error in GW Availability wrt to old system
R_f=R-R_{gw}-R_{wc} -R_t	R_f(normal)=a*r(normal)+b	Recharge=R_f+R_{wc}	Recharge= R_{gw}+R_{wc}+R_t	25+26	27-.05*27		(AB7-AB11)/AB7*100
23	24	25	26	27	28	29	30
4276555.40 8711195.00 8548279.40	7746323.94	8396673.94	806450	9203123.94	8742967.75	16.62	**8.50**
2921277.20 7617608.00 8310320.00	6964133.40	7614483.40	806450	8420933.40	7999886.73	18.16	
12687846.60 12687846.60	12687846.60	13383571.60	2610475	15994046.60	15194344.27	51.62	**5.90**
10789518.20 10126475.80	11744299.26	12440024.26	2610475	15050499.26	14297974.29 **Averagr Error**	54.85	**7.20**

may need a higher frequency of monitoring. Similarly, if the objective is to estimate only the peaks and troughs, a higher frequency may be adopted around the beginning and the end of rainy seasons and a lower frequency may be adopted at other times. On the other hand if the objective is to arrive at a true hydrograph, a uniformly high frequency may have to be adopted. It follows that there does not exist any unique optimal monitoring frequency. The optimal monitoring frequency would depend upon the expectation from (or intended use/uses of) the hydrograph to be monitored. Considering the present use of groundwater level data in the district, for arriving at optimal monitoring frequency following strategy is followed.

- Observed hourly groundwater level data of available period of each piezometer is selected. This series is called Smallest Feasible Interval (SFI).
- Daily averages are computed from 1 hr data. Knocking off the intermittent data from SFI series, daily averages are generated from 2, 3, 4, 6, 8, 12 and 24 hours.
- Considering daily average from 1 hourly data being more reliable, summation error ($\sum \varepsilon_i^2$) is computed.

The data of summation error for calculation of frequency of observation for four piezometers is given in Table 3.5.

Table 3.5 Data of Summation Error for Calculation of Frequency of Observations in Piezometers

	Dhavalapuri	Peerbavada	Waghalgaon	Pimperkheda
Interval	$\sum \epsilon_i^2$	$\sum \epsilon_i^2$	$\sum \epsilon_i^2$	$\sum \epsilon_i^2$
1	0.0000000	0.000000000	0.00000000	0.00000000
2	0.0004315	0.000286594	1.2625E-05	0.00011615
3	0.0010410	0.000723264	3.6257E-05	0.00036214
4	0.0022929	0.001664828	6.9069E-05	0.00098446
6	0.0075306	0.004212024	1.5084E-04	0.00249691
8	0.0204859	0.002972813	2.2028E-04	0.00520369
12	0.0203218	0.00555664	5.5540E-04	0.01134647
24	0.0925787	0.057269644	1.0169E-03	0.05022557

The summation error ($\sum \varepsilon_i^2$) is then plotted against the interval. These plots are made separately for all the four-piezometer data and are shown in Figure 3.2.

The study of these plots show that for all piezometers summation error in frequency of observation is much less (≤ 0.002) upto 4 hours and moderate (0.002 to

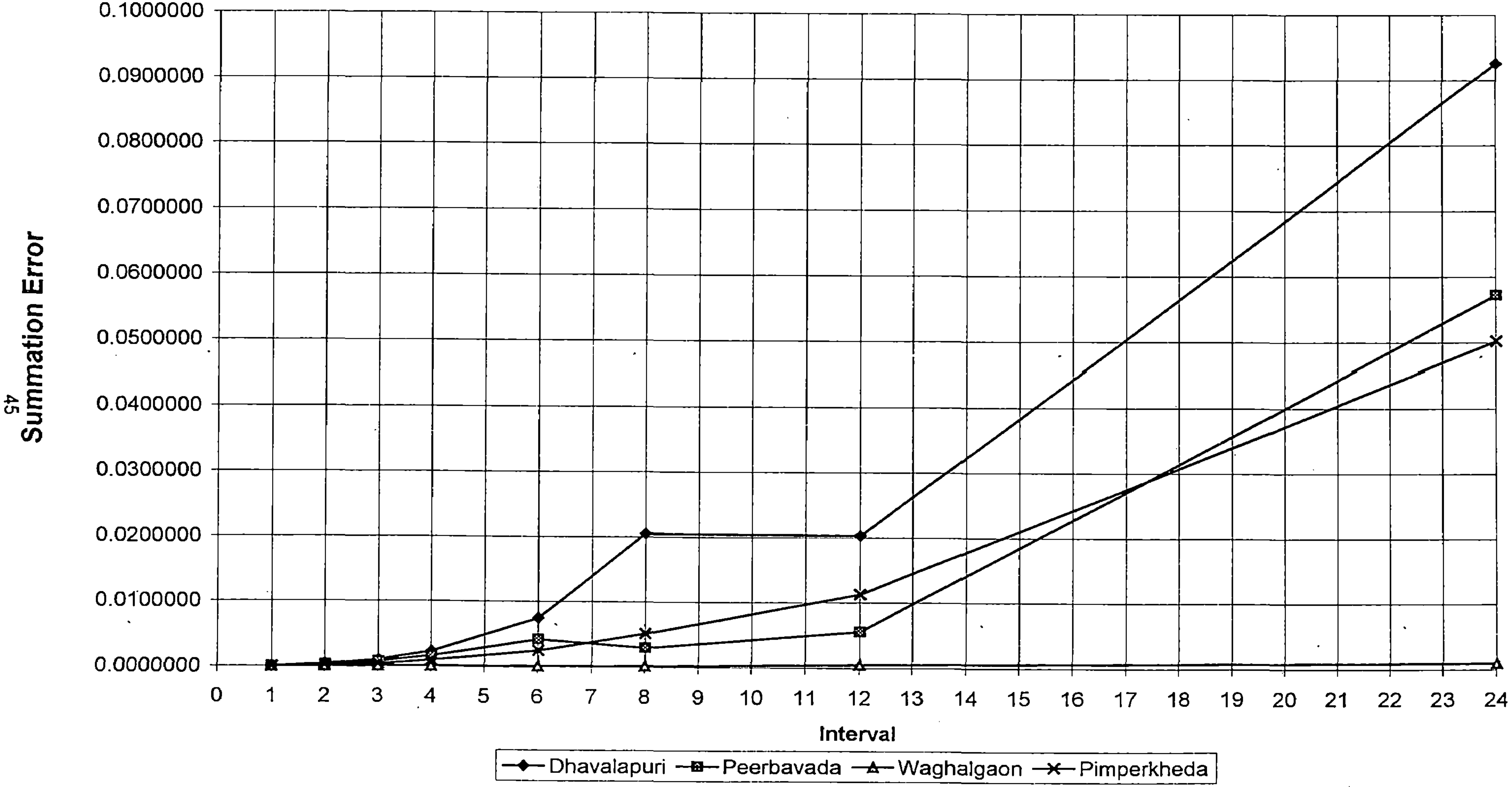


Fig. 3.2 Plot of Summation Error Vs Daily Average Interval for Calculation of Frequency of Observation in Piezometers

0.007) upto 6 hours and there after it increases very much. In case of Peerbavada and Waghalgaon the summation error is much less upto twelve and 24 hours respectively This indicate that if the frequency of observation of water levels in the piezometers is upto six hours, then there will not be much error in the peak and trough values. If the frequency exceeds six hours then it may be possible that the peak or trough values may not be picked up. Hence it is concluded that the present frequency of observation of groundwater levels i.e. six hours in all the piezometers of the district is optimal from the present data utility and hydrogeological point of view.

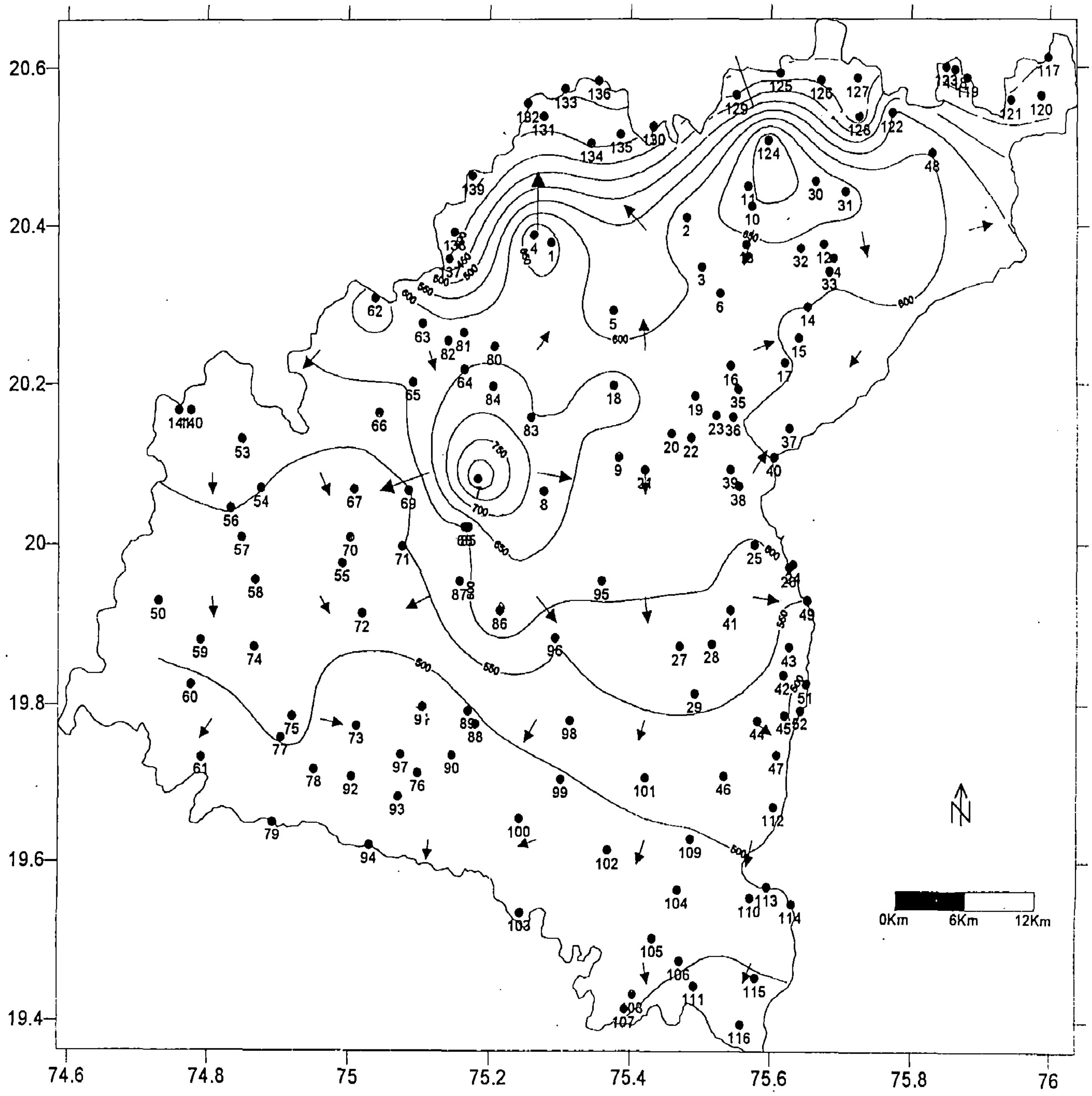
3.6 SPATIAL ANALYSIS

This is usually carried out to see whether the network is sufficient in space or not. For groundwater levels it is done by drawing the water table maps and seeing whether there is any variation within the water table contours.

The groundwater level data of 141 observation wells are considered from 1990 to 2000 for this study. The yearly average water levels computed for network design are used here. The water table contour maps are genera el(fwz(each year using SURFER software. The representative maps of 1990 and 2000 are given in Fig. 3.3 and 3.4. These maps clearly give the idea of regional groundwater flow direction within district. Three directions of groundwater flow are prominently observed in concurrence with the basin slops. In Tapi-East (Northern portion) it is towards North, in Godavari-Purna it is towards E and SE and in Godavari it is due south and SE. The water table contours are drawn at 50 meters interval. The central and northern portion is recharge area where as the southern and Eastern areas are discharge areas. Similarly within each contour interval the density of observation wells is good and no drastic variation is observed in groundwater flow direction within the contour interval. All are following the regional flows. This clearly indicates that the observation well network is sufficient in space. So after adding the piezometers this sufficiency will increase more.

The degree of correlation between two stations may give an indication of how closely the two stations are connected in terms of similarities in groundwater level producing mechanisms governed by meteorological, topographical and geological features. Hence to find out statistically observation wells having good relationship, correlation coefficient has been computed for the yearly average values of 141 wells. The results show that 63 observation wells are having very strong correlation coefficient (>0.90). So it is suggested that, while discontinuing excess no. of observation wells of the district based on network design and spatial analyses, priority should be given to these 63 observation wells. Along with this criteria the hydrogeological and hydrological conditions of the observation wells should also be considered.

Fig.3.3 WATER TABLE CONTOUR MAP OF AURANGABAD DISTRICT YEAR 1990



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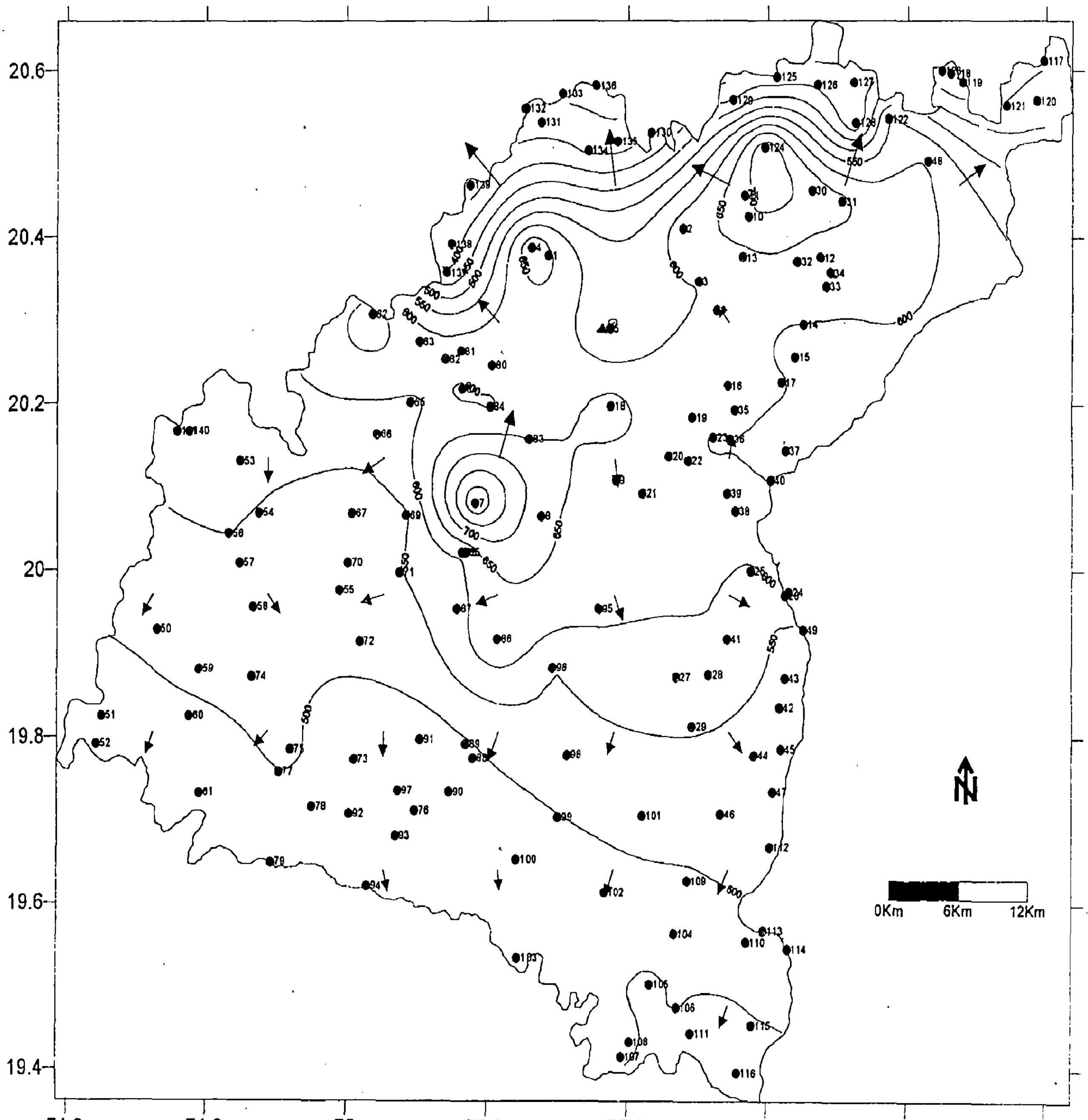
Observation Well ●

Water Table Contour —— 500

Fig.3.4 WATER TABLE CONTOUR MAP OF AURANGABAD DISTRICT YEAR 2000



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Observation Well •

Water Table Contour —500

Stochastic Modelling Of Groundwater Levels

4.1 GENERAL

The stochastic modelling of hourly groundwater levels of Peerbavada, Dhavalapuri, Waghalgaon and Pimpekheda has been attempted in order to study the time series structure. The results of time series analysis are presented in this chapter.

Stochastic modelling basically covers the time .series modelling of the variables under consideration. A typical hydrologic time series comprised of both deterministic and stochastic component. Deterministic component consist of periodicity trends and jumps, where as stochastic component consists of dependent and independent stochastic components. The steps involved in stochastic modelling are identification and removal of significant trend present in time series, identification and mathematical descriptions of periodicity in mean and removing periodicity in mean and standard deviations, identification and separation of dependent stochastic component and in the end modelling of residuals for frequency distribution.

4.2 DETERMINISTIC COMPONENTS ANALYSIS

4.2.1 Trend

Statistical characteristics of the series e.g. mean, variance and correlation coefficients can be affected by the natural and man-made changes over the groundwater system together with the systematic measurement error. In order to determine the trend component, historical data should be available for a considerably longer period. Since this is not available it is difficult to detect trend in hydrologic time series. For finding presence or absence of trend, some tests such as Kendall's Rank correlation Test and Linear Regression test, can be done.

4.2.2 Periodicity

The rotation of the earth about its axis and its revolution around sun causes periodicity in parameters of hydrologic time series. A periodic component may be of two types, i) long range periodicity and ii) short range periodicity in a time series. Long-range periodicity is having a period more than one year. Attempts have been made to relate long-range periodicity e.g. repetition of drought after every five year etc., with sunspot numbers. Studies show that long-range periodicity is not shown in river flow series. For groundwater level time series the study is non-existent. Short-range periodicity, with period less than one year, is caused by rotation of the earth about its axis, its revolution around sun and catchment's characteristics.

Periodicity of a hydrologic time series may be present in one, two or several of its parameters such as mean, standard deviation, and auto correlation coefficient. Periodicity can be removed by either non-parametric approach or parametric approach.

Non-parametric method of separating periodicity can be expressed as follows.

$$Z_{t,\tau} = \frac{X_{t,\tau} - \overline{X_\tau}}{\sigma_\tau} \qquad \text{....(4.1)}$$

Where $X_{t,\tau}$ is the original trend free series $\tau = 1,2......$

ω is number of seasons record in a year/month/day, $t = 1,2............n$, n is the numbers years of records $\overline{X_\tau}$ & σ_τ are sample mean and standard deviation respectively.

Non-parametric approach while removing the periodicity removes the variations in sample associated with the coefficients of the periodic functions of parameters. The method is very useful in any preliminary analysis or in detecting the characters of stationary stochastic components. It requires a large number of parameters when the periodicity of observations is large. Large parameters would have large sampling errors. They violate the concept of parsimony applied in statistical analysis. However, if number of parameters required is small, say upto 24, it gives satisfactory results.

In parametric approach the removal of periodicity in mean and standard deviation is based on harmonic representation of seasonal parameters. The periodic component in any parameters ν may be approximated by m harmonics of its basic period ω in the form

$$\nu_\tau = \nu_x + \sum_{j=i}^{m} (AjCos\frac{2\pi j\tau}{\omega} + BjSin\frac{2\pi j\tau}{\omega}) \qquad \ldots(4.2)$$

Where $\frac{2\pi j\tau}{\omega}$ is the circular frequency.

ω is the basic period in ν i.e. no. of seasons in a year.

m is no. of harmonics inferred as significant in the Fourier series mathematical description of the parameters ν i.e. no. of harmonics fitted to smoother the parameter.

ν_x is the overall mean of the parameter for τ^{th} season. Like $\overline{X}_\tau$ & σ_τ

$$A_j = \frac{2}{\omega}\sum_{\tau=1}^{\omega} \nu_\tau \cos\frac{2\pi j\tau}{\omega} \qquad \ldots(4.3)$$

$$B_j = \frac{2}{\omega}\sum_{\tau=1}^{\omega} \nu_\tau \sin\frac{2\pi j\tau}{\omega} \qquad \ldots(4.4)$$

The maximum number of harmonics to be fitted is either equal to $\frac{\omega}{2}$ if ω is even and $\frac{\omega-1}{2}$ if it is odd. For monthly series $\omega = 12$, $m = \frac{\omega}{2} = \frac{12}{2} = 6$

In general in a monthly series number of significant harmonics does not increase beyond 4. Greater parsimony in series in terms of number of parameters required is achieved in case of daily series where no. of significant harmonics does not increase beyond 8 to 12 (Yevjevich, 1972).

Test of significant of harmonics of periodic component is done either by P_{max} and P_{min} test or study of cumulative periodogram. The parameter that can be used in testing the significant of various harmonics is the varience of individual harmonics, $C_j^2/2$ provided by the Fourier coefficient A_j and B_j.

$$Var\ (h_j) = \frac{C_j^2}{2} = \frac{A_j^2 + B_j^2}{2} \qquad \ldots(4.5)$$

Variance explained by jth harmonics can be given by

$$\Delta P_j = \frac{Var(h_j)}{S^2(\nu_\tau)} \qquad \ldots(4.6)$$

where $S^2(\nu_\tau)$ is the variance of the parameter estimate. The sum of ΔP_j, $j=1$, 2................6 given P, the part of variation of ν_τ which is explained by the first six harmonics.

P_{max} and P_{min} test is empirical procedure of identification of significant harmonics. They are two critical values.

P_{max} = 1-Pmin and

$P_{min} = a\ (\omega\ /\ CN)^{0.5}$

Where a = 0.033, ω = 1.2, ...12 (for monthly data)

N = No. of years of record

C = 1 for mean and C = 2 for standard deviation

If $P_{\omega/2} \leq P_{\min}$, no significant harmonics exists in the sequence of ν_τ values or $\nu_\tau = \nu_x$ is a non-periodic parameter.

If $P_{\omega/2} \geq P_{\max}$, only a part of the harmonics are significant.

If $P_{\min} \leq P_{\omega/2} \leq P_{\max}$, all the harmonics are significant.

The use of cumulative periodogram and breaking point in the graphical estimation procedure is based on the concept that the variation of P_m as a function of m, P_m = f (m) is composed of the two distinct components. First the periodic part of a fast rising of P_m with m, and second the sampling part of a slow rising P_m with m, where

$$P_m = \frac{\sum_{j=1}^{m} Var(h_j)}{Var(\nu_\tau)} \qquad ....(4.7)$$

j refers to a sequence of harmonics from the smallest to the highest frequencies say j = 1, 2 ....ω/2.

<u>Steps followed in this approach are</u>

- Computation of A_j and B_j is done upto j = 1-m
- Computation of P_1, P_2 ,...........Pm is done
- Computation of $S^2(\nu_\tau)$ is done
- Plot is made of either P_m V_s m or P_m / S^2 (ν_τ) Versus m
- Identification of point on the curve where it becomes flat

The critical frequency at that point then gives the number of significant harmonics.

4.3 STOCHASTIC COMPONENTS ANALYSIS

4.3.1 Dependant Stochastic Component

Linear autoregressive model is used to evaluate dependence structure of stochastic component. The dependence can be often approximated by the first, second, third, or higher order autoregressive linear model. Higher order models beyond third order show a significant advantage in comparison with the first three models, only when the series are sufficiently long. Short hydrologic series rarely justify an investigation of higher order auto regressive model.

In general an m^{th} order auto regressive linear model is

$$Z_t = a_1 Z_{t-1} + a_2 Z_{t-2} + \dots\dots\dots\dots + a_m Z_{t-m} + \varepsilon_t \qquad \dots.(4.8)$$

Estimation of a_j coefficient are related to autocorrelation coefficient (r_k)

$$r_k = \frac{\sum_{t=1}^{N-k}(Z_t - \overline{Z})(Z_{t+k} - \overline{Z})}{\sum_{t=1}^{N}(Z_t - \overline{Z})^2} \qquad \dots.(4.9)$$

The measure of goodness of fit of the autoregressive linear models by this simplified method is the determination coefficient. R_i^2, i=1, 2, 3……….. It tells what portion of the total variation of X_t is explained by each term of autoregressive equation. The remaining portion of the variance Z_t is being explained by the term ε_t. The first three order autoregressive linear models are computed by

$m = 1$, $a_1 = r_1$, $R_1^2 = r_1^2$

$m = 2$, $R_2^2 = \dfrac{r_1^2 + r_2^2 - 2r_1^2 * r_2}{1 - r_1^2}$

$m = 3$,

$$R_3^2 = \frac{(r_1^2 + r_2^2 + r_3^2 + 2r_1^3 * r_3 + 2r_1^2 * r_2^2 + 2r_1 * r_2^2 * r_3 - 2r_1^2 * r_2 - 4r_1 * r_2 * r_3 - r_1^4 - r_2^4 - r_1^2 * r_3^2)}{(1 - 2r_1^2 - r_2^2 + 2r_1^2 * r_2)}$$

Where r_1, r_2 and r_3 are autocorrelation coefficient upto lag 3

AR (1) is selected if $R_2^2 - R_1^2 \le 0.01$ and $R_3^2 - R_1^2 \le 0.2$

AR (2) is selected if $R_2^2 - R_1^2 > 0.01$ and $R_3^2 - R_2^2 \le 0.01$

AR (3) is selected if $R_2^2 - R_1^2 > 0.01$ and $R_3^2 - R_2^2 > 0.01$

4.3.2 Independent stochastic Component

For modelling of independent stochastic component ε_t, probability distribution function of ε_t is obtained. This helps in generation of random numbers of the probability distribution of which ε_t series is a uniformly distributed random number (0,1) of the distribution is converted into random no. of the distribution. It is sometimes difficult to find out the distribution function of the independent stochastic component. Hence by suitable transformation, if possible, standardised series is converted into a normally distributed one with skewness zero and kurtosis three.

4.4 MODELLING OF HOURLY GROUNDWATER LEVELS

4.4.1 General

Analysis of hourly groundwater levels for different periods have been carried out for four piezometer data, following the steps outlines earlier. The statistical properties of hourly data are given in Table 4.1.

Table 4.1 Statistical properties of hourly groundwater levels of four piezometers.

Piezometer Name	Mean depth bgl	Standard deviation	Skewness	Kurtosis	r_1	r_2	r_3
Peerbavada	2.810	0.139	0.0515	1.6509	.9737	.9638	.9548
Dhavalapuri	2.255	0.195	0.3114	1.9393	0.9896	.9767	.9661
Waghalgaon	1.881	0.041	-0.3371	-5.7844	0.9914	.9740	.9647
Pimpekheda	12.549	0.33	-0.0227	-6.6569	.9997	.9992	.9986

4.4.2 Trend

Trend analysis could not be carried out on the annual data, as sufficient period of data are not available. Hence the data have been considered trend free for further analysis.

4.4.3 Periodicity

Periodograms of hourly groundwater levels of four piezometers of mean and standard deviations are given in Figures 4.1, 4.2, 4.3 and 4.4 respectively. The coefficients of different harmonics, variance explained by each harmonics and cumulative variance explained are given in Tables 4.2, 4.3, 4.4 and 4.5 respectively.

Table 4.2 Coefficients and variance explained by different harmonics of daily groundwater levels of Peerbavada piezometer.

Parameter	Aj	Bj	$(Aj^2+Bj^2)/2$	Variance Explained	Cumulative Variance explained	Remarks
Mean	-0.02509	-0.01987	0.00051	0.5710	0.5710	P_{min}=0.0317
	-0.00233	-0.01946	0.00019	0.2141	0.7852	P_{max}=0.9683
	0.00547	0.00296	0.00002	0.0216	0.8067	
	-0.00297	0.01008	0.00006	0.0616	0.8683	
	0.00200	-0.00656	0.00002	0.0262	0.8945	
	0.00513	-0.00421	0.00002	0.0246	0.9191	
	0.00119	0.00237	0.00000	0.0039	0.9230	
	-0.00410	-0.00256	0.00001	0.0130	0.9360	
	0.00293	-0.00275	0.00001	0.0090	0.9451	
	-0.00188	0.00345	0.00001	0.0086	0.9537	
	0.00265	0.00085	0.00000	0.0043	0.9580	
	0.00111	0.00000	0.00000	0.00070	0.9587	
Standard Deviation	0.0002	-0.0003	0.0000	0.0109	0.0109	P_{min}=0.0224
	0.0006	0.0002	0.0000	0.0265	0.0374	P_{max}=0.9776
	0.0010	-0.0018	0.0000	0.2803	0.3177	
	-0.0004	0.0009	0.0000	0.0586	0.3763	
	-0.0004	0.0000	0.0000	0.0084	0.3847	
	-0.0005	-0.0012	0.0000	0.1198	0.5044	
	0.0010	0.0007	0.0000	0.0924	0.5968	
	-0.0008	0.0007	0.0000	0.0776	0.6745	
	0.0003	-0.0002	0.0000	0.0101	0.6846	
	0.0011	-0.0006	0.0000	0.1110	0.7956	
	0.0001	-0.0006	0.0000	0.0253	0.8209	
	-0.0020	0.0000	0.0000	0.0	0.8209	

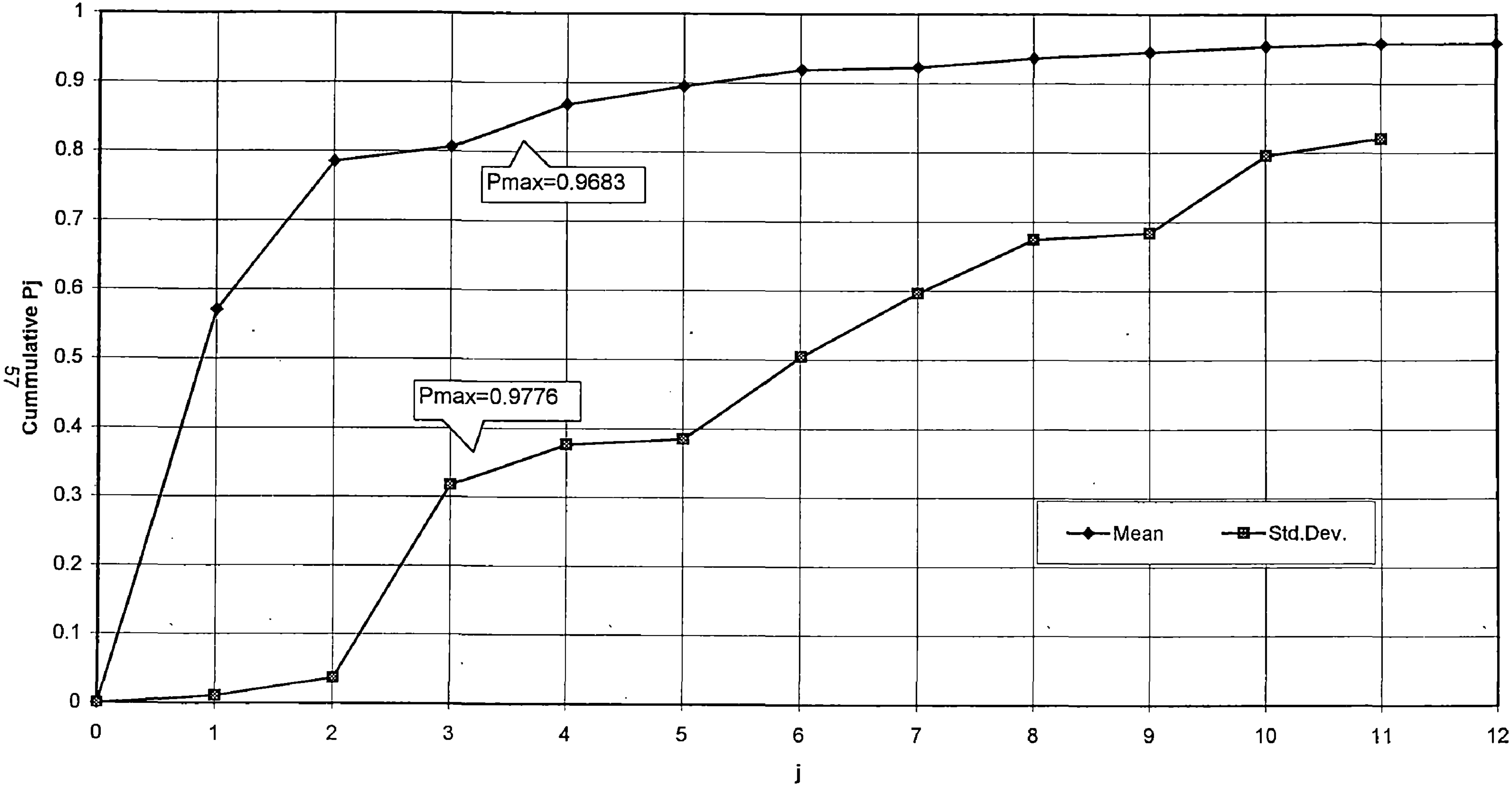

Fig. 4.1 Periodogram of hourly Groundwater levels of Peerbavada piezometer

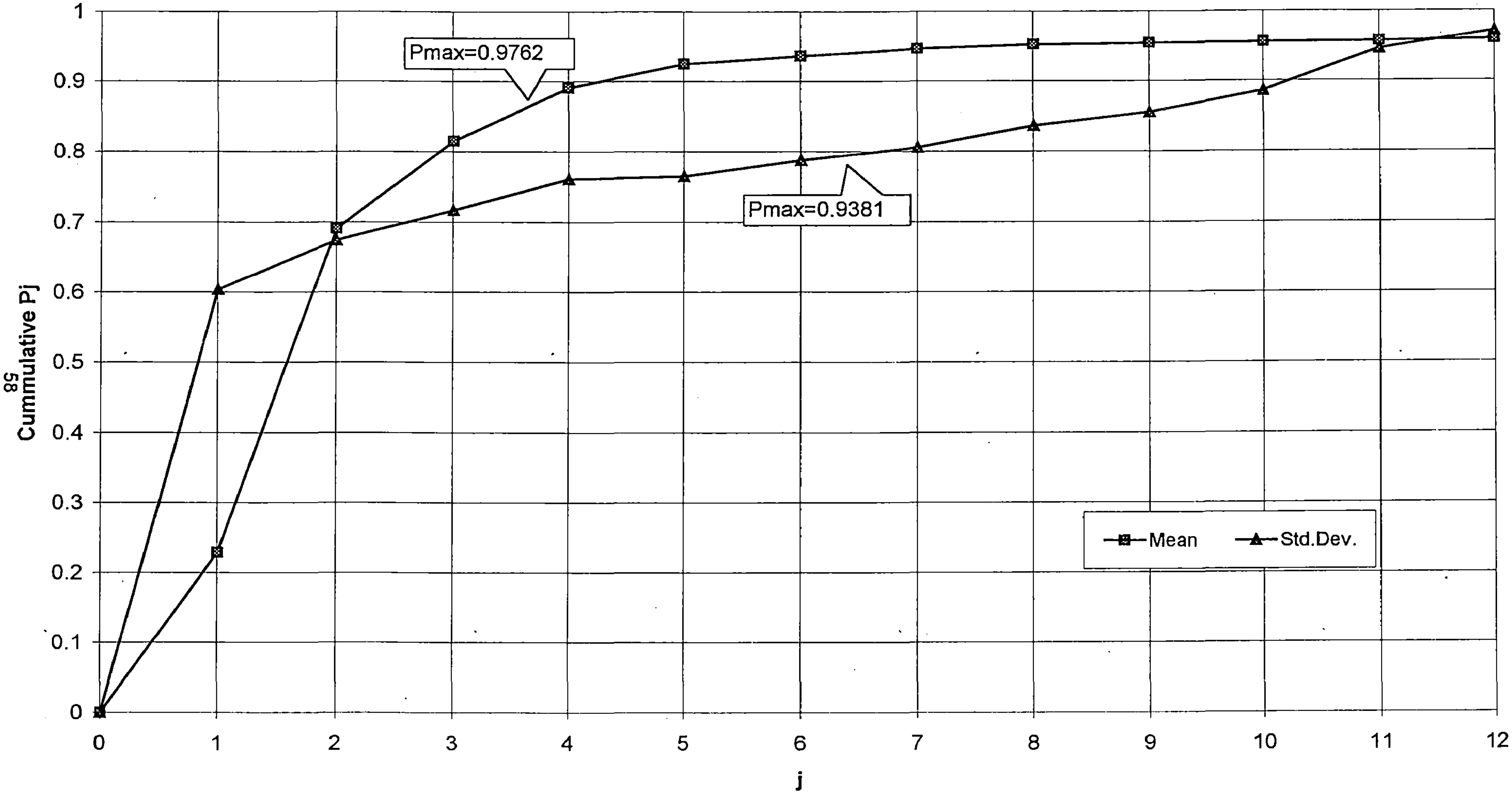

Fig. 4.2 Periodogram of hourly Groundwater levels of Dhavalapuri piezometer

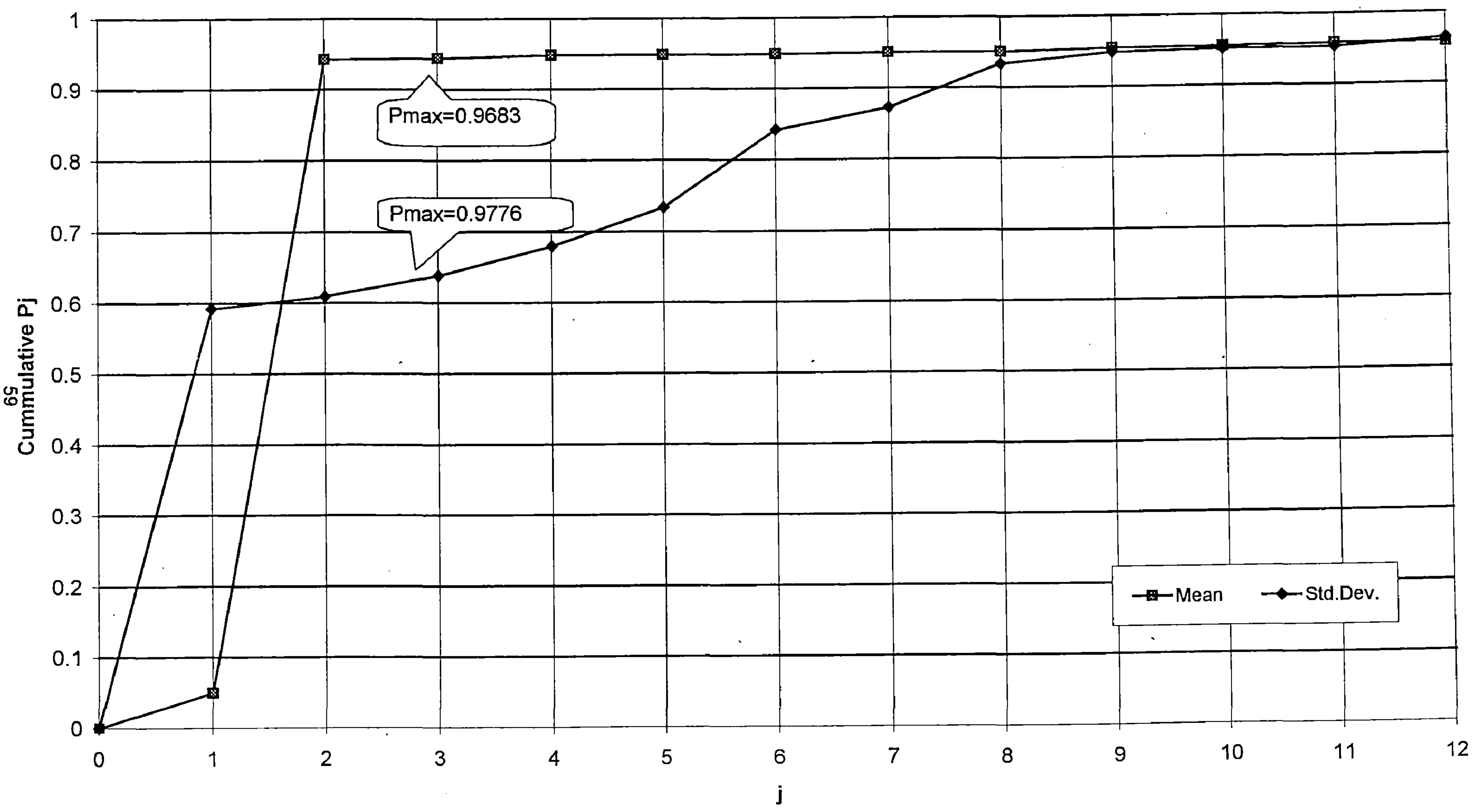

Fig. 4.3 Periodogram of hourly Groundwater levels of Waghalgon piezometer

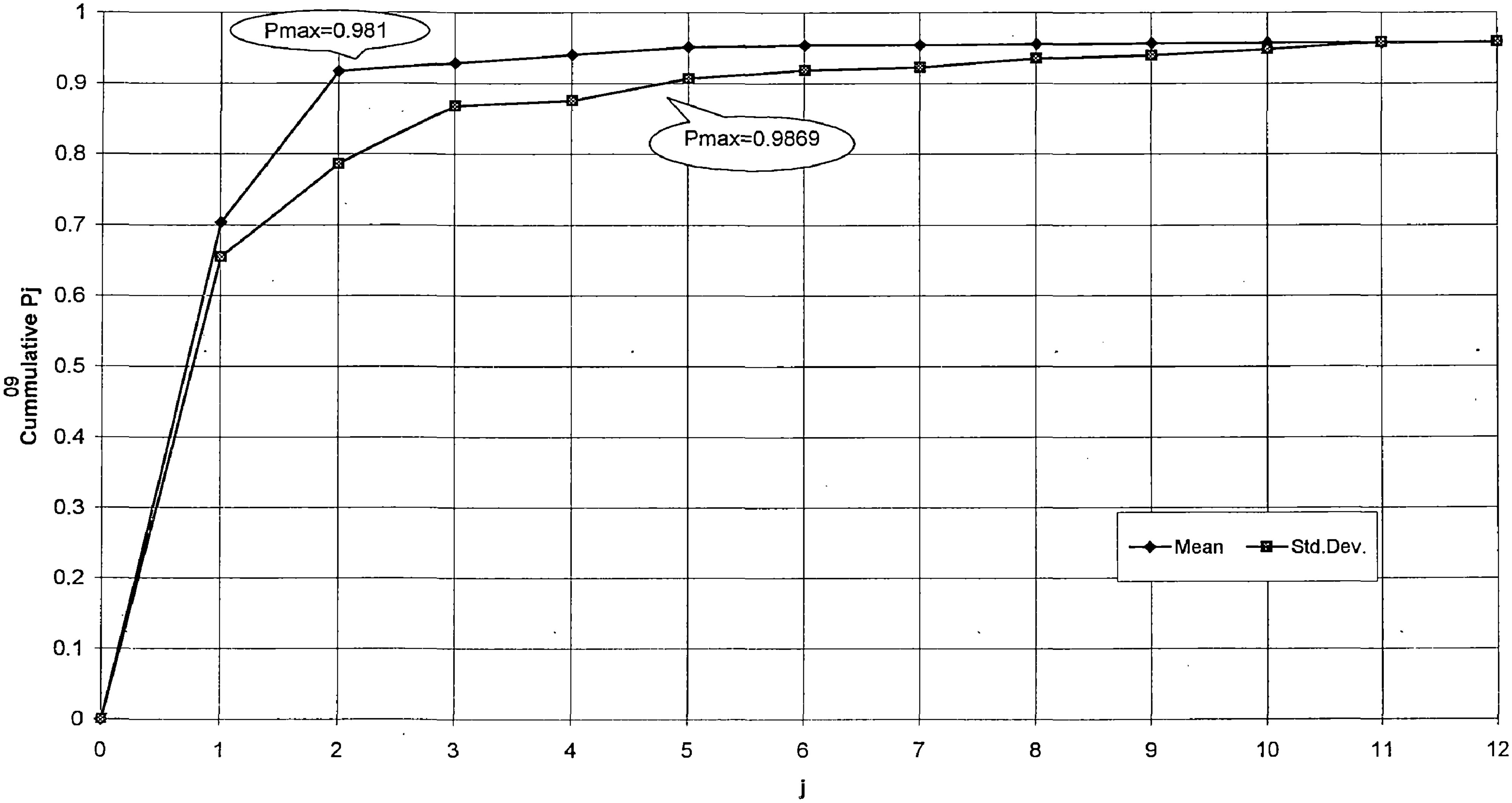

Fig. 4.4 Periodogram of hourly Groundwater levels of Pimperkheda piezometer

Table 4.3 Coefficients and variance explained by different harmonics of daily groundwater levels of Dhavalapuri piezometer.

Parameter	Aj	Bj	$(Aj^2+Bj^2)/2$	Variance Explained	Cumulative Variance explained	Remarks
Mean	0.0137	-0.0096	0.0001	0.2287	0.2287	P_{min}=0.0238
	0.0010	0.0237	0.0003	0.4616	0.6904	P_{max}=0.9762
	-0.0101	-0.0071	0.0001	0.1246	0.8150	
	0.0052	-0.0081	0.0001	0.0763	0.8913	
	0.0031	0.0057	0.0000	0.0339	0.9252	
	-0.0035	0.0009	0.0000	0.0107	0.9359	
	0.0012	-0.0034	0.0000	0.0109	0.9468	
	0.0025	-0.0007	0.0000	0.0054	0.9522	
	0.0003	0.0017	0.0000	0.0023	0.9545	
	-0.0011	-0.0001	0.0000	0.0010	0.9555	
	0.0004	-0.0014	0.0000	0.0017	0.9571	
	0.0017	0.0000	0.0000	0.0024	0.9595	
Standard Deviation	0.0018	-0.0028	0.0000	0.6039	0.6039	P_{min}=0.0169
	0.0001	0.0011	0.0000	0.0707	0.6746	P_{max}=0.9831
	-0.0007	-0.0006	0.0000	0.0422	0.7168	
	0.0009	-0.0001	0.0000	0.0440	0.7608	
	0.0002	0.0001	0.0000	0.0043	0.7650	
	0.0003	-0.0006	0.0000	0.0226	0.7876	
	0.0005	-0.0003	0.0000	0.0187	0.8063	
	-0.0007	-0.0002	0.0000	0.0305	0.8367	
	0.0006	-0.0001	0.0000	0.0193	0.8560	
	0.0005	0.0006	0.0000	0.0304	0.8864	
	-0.0005	-0.0009	0.0000	0.0592	0.9456	
	0.0007	0.0000	0.0000	0.0254	0.9711	

Table 4.4 Coefficients and variance explained by different harmonics of daily groundwater levels of Waghalgaon piezometer.

Parameter	Aj	Bj	$(Aj^2+Bj^2)/2$	Variance Explained	Cumulative Variance explained	Remarks
Mean	0.0006	0.0019	0.0000	0.0495	0.0495	P_{min}=0.0317
	0.0050	-0.0069	0.0000	0.8934	0.9428	P_{max}=0.9683
	-0.0004	0.0001	0.0000	0.0019	0.9448	
	-0.0004	0.0004	0.0000	0.0035	0.9482	
	0.0000	-0.0001	0.0000	0.0002	0.9484	
	-0.0002	0.0002	0.0000	0.0011	0.9494	
	-0.0003	-0.0001	0.0000	0.0011	0.9506	
	-0.0001	0.0000	0.0000	0.0001	0.9507	
	-0.0005	0.0001	0.0000	0.0033	0.9540	
	-0.0003	0.0000	0.0000	0.0013	0.9554	
	-0.0004	0.0003	0.0000	0.0029	0.9582	
	-0.0001	0.0000	0.0000	0.0002	0.9584	
Standard Deviation	-0.0010	0.0003	0.0000	0.5921	0.5921	P_{min}=0.0224
	-0.0001	0.0001	0.0000	0.0171	0.6092	P_{max}=0.9776
	0.0002	0.0000	0.0000	0.0293	0.6385	
	-0.0002	0.0002	0.0000	0.0411	0.6796	
	0.0001	0.0003	0.0000	0.0538	0.7334	
	0.0005	0.0000	0.0000	0.1089	0.8422	
	0.0001	0.0002	0.0000	0.0306	0.8728	
	-0.0001	0.0003	0.0000	0.0609	0.9337	
	0.0000	0.0002	0.0000	0.0150	0.9487	
	-0.0001	0.0000	0.0000	0.0033	0.9520	
	0.0000	0.0000	0.0000	0.0009	0.9529	
	0.0001	0.0000	0.0000	0.0109	0.9638	

Table 4.5 Coefficients and variance explained by different harmonics of daily groundwater levels of Pimpekheda piezometer.

Parameter	Aj	Bj	$(Aj^2+Bj^2)/2$	Variance Explained	Cumulative Variance explained	Remarks
Mean	-0.00645	-0.01521	0.0001	0.7039	0.7039	P_{min}=0.0185
	0.00498	-0.00759	0.0000	0.2127	0.9167	P_{max}=0.9815
	0.00143	0.00158	0.0000	0.0117	0.9284	
	-0.00215	-0.00036	0.0000	0.0122	0.9406	
	0.00112	-0.00175	0.0000	0.0111	0.9518	
	0.00100	0.00007	0.0000	0.0026	0.9543	
	-0.00011	-0.00011	0.0000	0.0001	0.9544	
	0.00007	-0.00059	0.0000	0.0009	0.9553	
	0.00075	-0.00003	0.0000	0.0014	0.9567	
	0.00034	0.00013	0.0000	0.0003	0.9571	
	0.00016	-0.00035	0.0000	0.0004	0.9575	
	0.0008	0.0000	0.0000	0.0016	0.9590	
Standard Deviation	0.00220	-0.00209	0.0000	0.6553	0.6553	P_{min}=0.0131
	-0.00135	-0.00016	0.0000	0.1310	0.7863	P_{max}=0.9869
	0.00081	-0.00070	0.0000	0.0819	0.8681	
	0.00027	-0.00016	0.0000	0.0070	0.8752	
	0.00008	-0.00066	0.0000	0.0317	0.9068	
	0.00041	0.00005	0.0000	0.0119	0.9187	
	-0.00012	-0.00019	0.0000	0.0036	0.9223	
	0.00037	-0.00020	0.0000	0.0128	0.9351	
	0.00021	0.00014	0.0000	0.0046	0.9397	
	0.00017	-0.00030	0.0000	0.0085	0.9482	
	0.00036	0.00011	0.0000	0.0099	0.9581	
	-0.00008	0.00000	0.0000	0.0004	0.9586	

To test the significant harmonics, data were analysed for 12 (ω/2) harmonics. Pmax –Pmin criteria did not confirm to the plots of periodogram where a distinct break in slope (steep slopes followed by gentle slope) was observed. Hence for the selection of significant harmonics break in slope in periodogram was considered most suitable for the hourly groundwater level time series. Summary of the significant harmonics in mean and standard deviations of all piezometers is given in Table 4.6

Table 4.6 Mean, variance and significant harmonics of periodicity in mean and standard deviation

Piezometer	Mean	Standard Deviation
	Significant Harmonics	Significant Harmonics
Peerbavada	8	11
Dhavalapuri	6	11
Waghalgaon	2	8
Pimpekheda	5	9

Plots of observed mean and smoothened mean by significant harmonics and observed standard deviation and smoothened standard deviations by significant harmonics were made (Fig.4.5, 4.6, 4.7 and 4.7) to cheek goodness of fit of smoothened values to unsmoothened ones. The standardisation of the series has been done using parametric approach.

4.4.4 Dependent Stochastic Component

Groundwater level time series show a high dependence. Persistence or dependence was analysed using auto-regressive linear model. Selection of model was done on the basis of variance explained by each order of AR (P) model. It is observed that the hourly groundwater levels time series can be modelled with AR (1) in case of Dhavalapuri, Waghalgaon and Pimpekheda where as it can be modelled with AR (2) in case of Peerbavada. Models parameters are given in Table 4.7

Table 4.7 Model Parameters of Dependent Stochastic Component

Piezometer	AR(P) model	Model Parameters		Coefficient of Determination
		ϕ_1	ϕ_2	R^2
Peerbavada	AR(2)	0.4631	0.5273	0.9711
Dhavalapuri	AR(1)	0.9923		0.9847
Waghalgaon	AR(1)	0.9948		0.9896
Pimperkheda	AR(1)	0.0562		0.0032

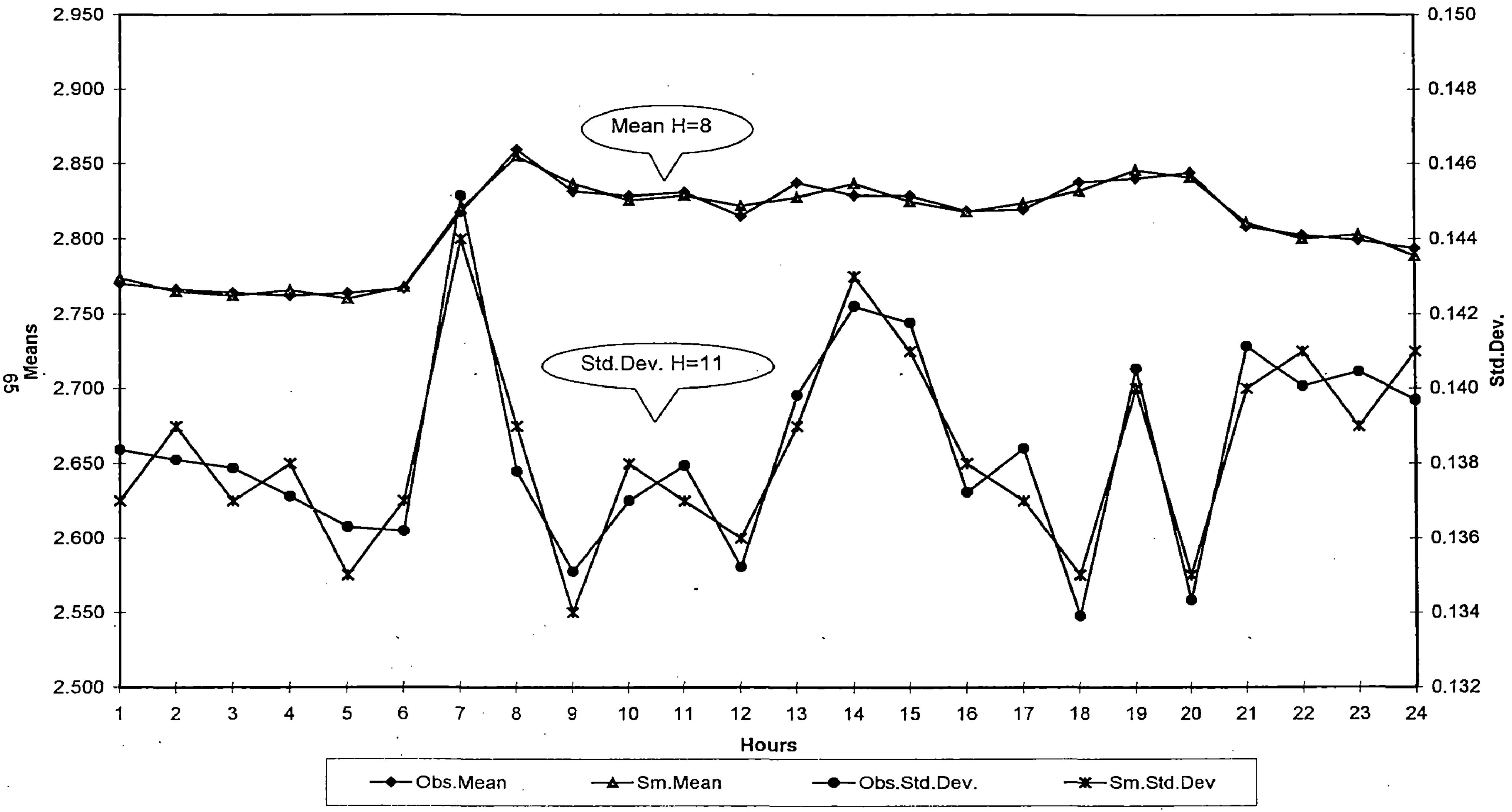

Fig. 4.5 Observed and Smoothened mean & standard deviation of hourly GW level data of Peerbavada Piezometer

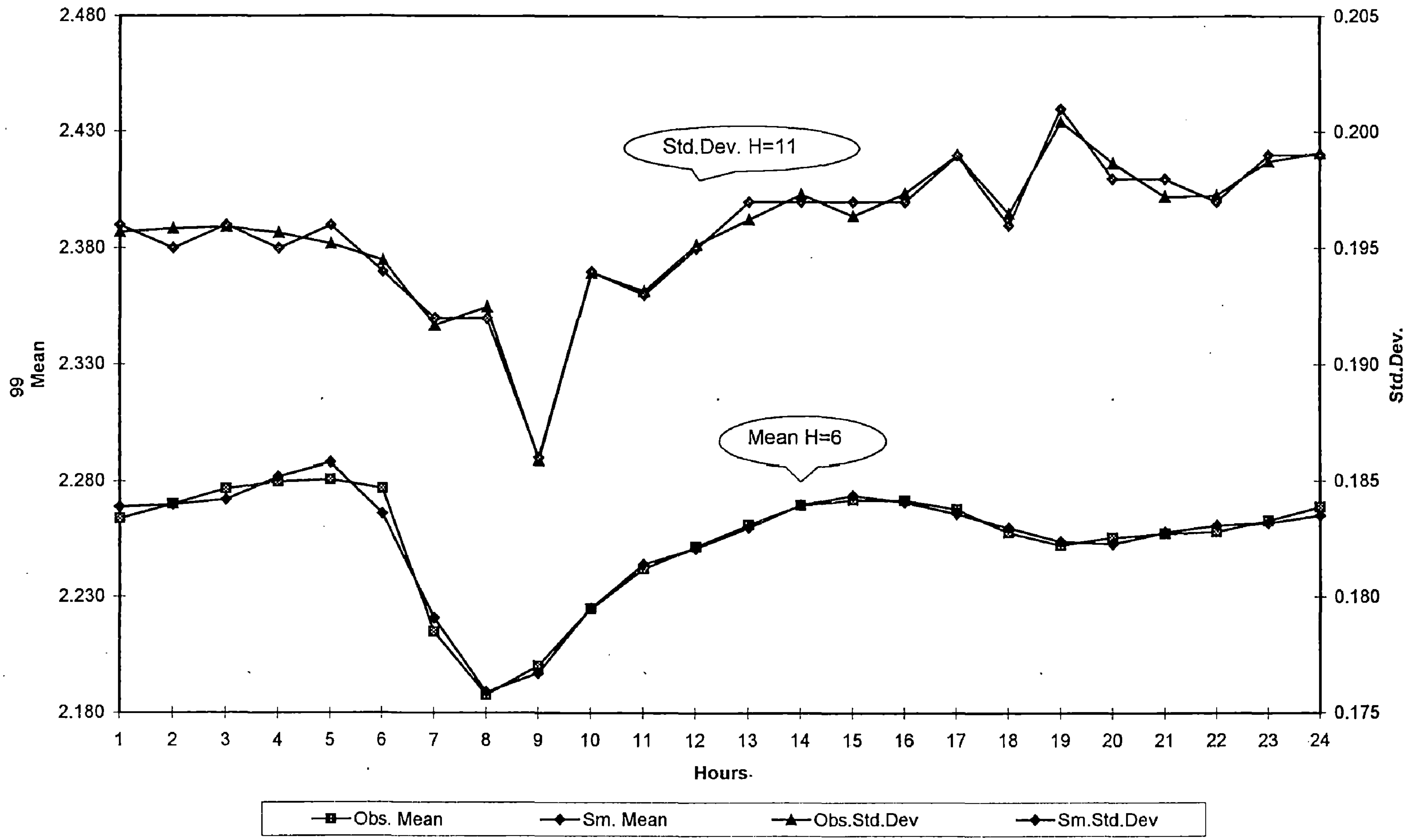

Fig. 4.6 Observed and Smoothened mean & standard deviation of hourly Gw level data of Dhavalapuri Piezometer

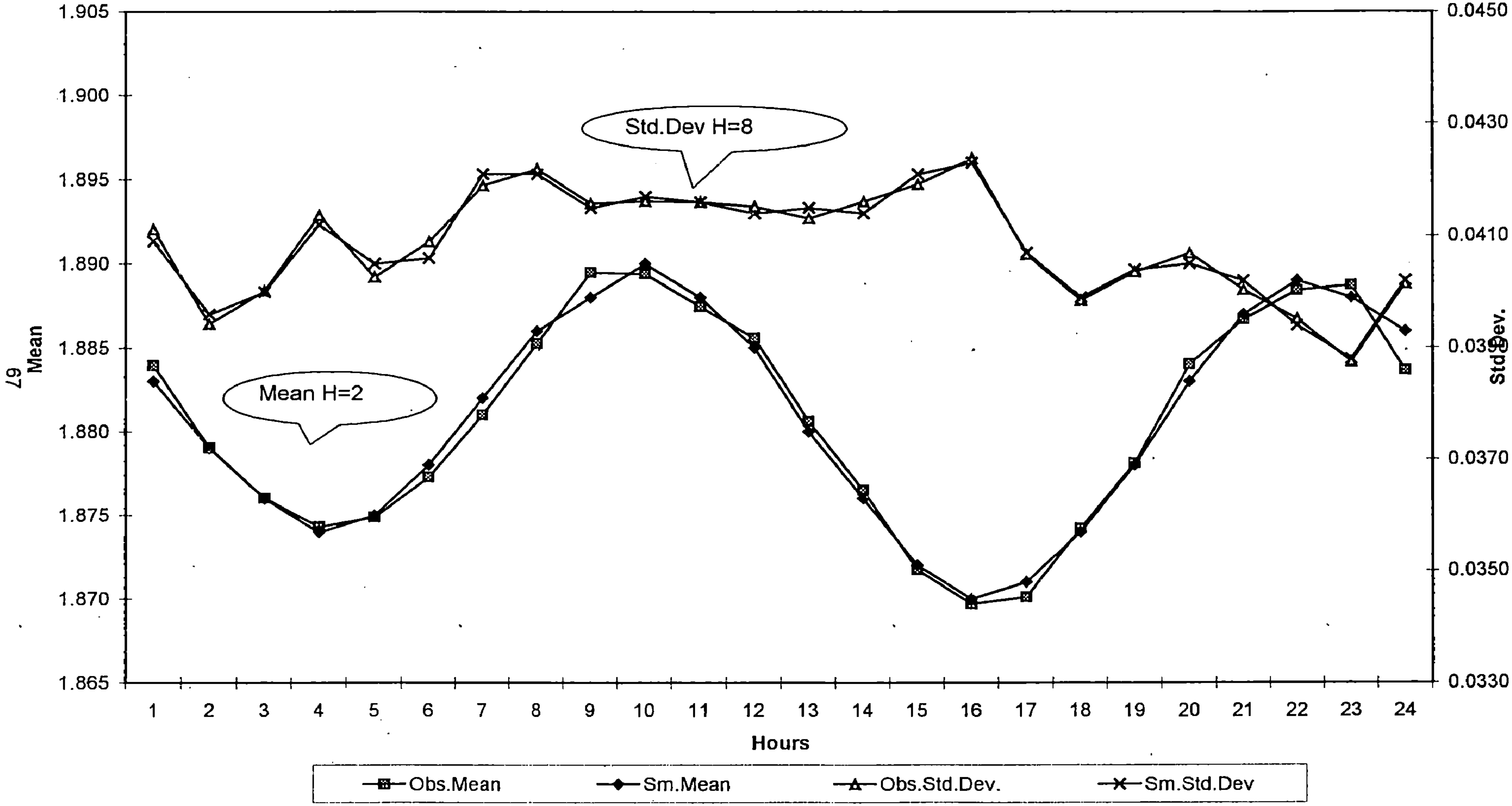

Fig. 4.7 Observed and Smoothened mean & standard deviation of hourly GW level data of Waghalgaon Piezometer

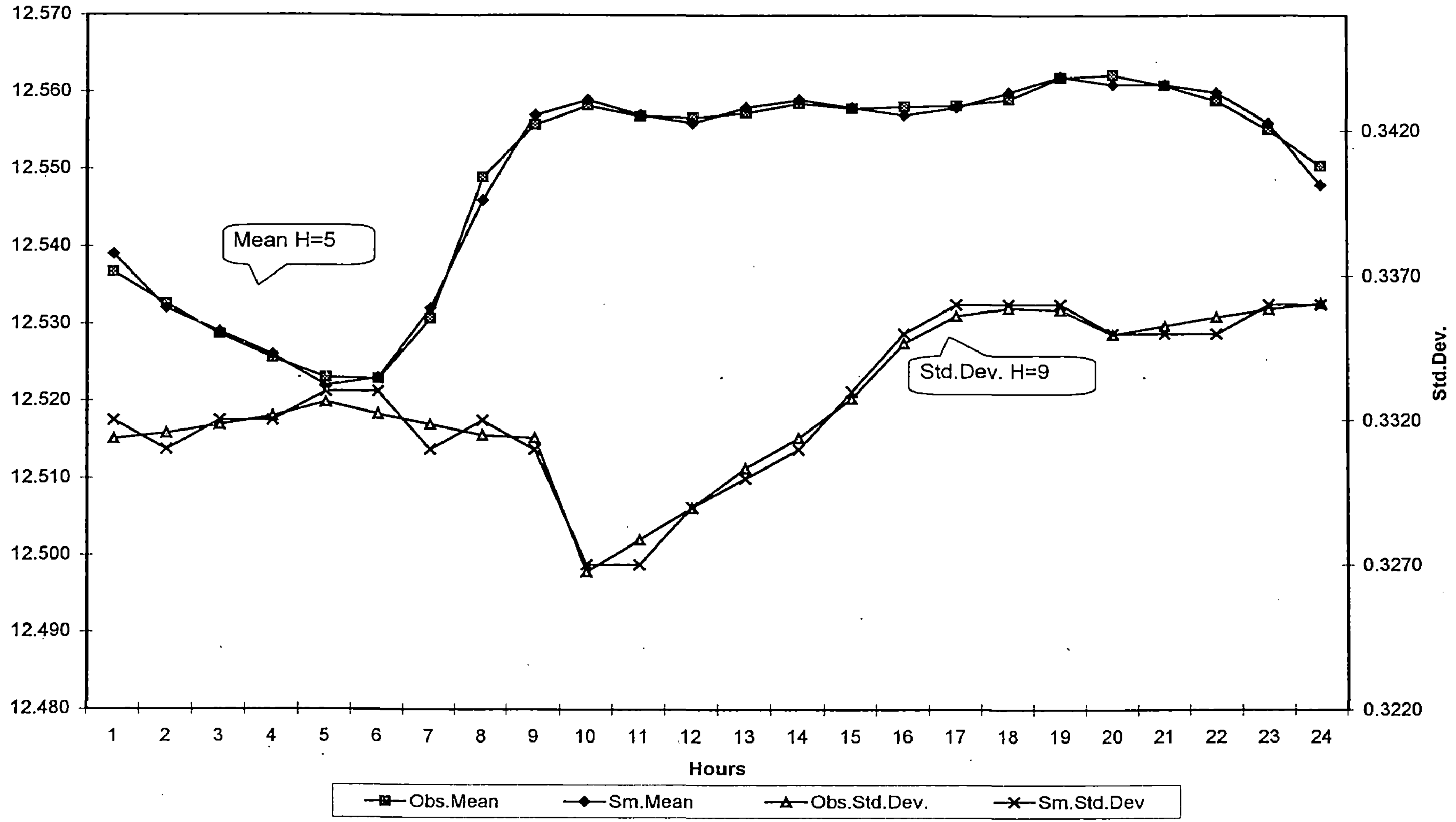

Fig. 4.8 Observed and Smoothened mean & standard deviation of hourly Gw level data of Pimperkheda Piezometer

4.4.5 Independent Stochastic Component

Independent stochastic components obtained by pre-whitening of the series are first tested for randomness in their serial correlation. For a random series serial correlations should be low. Statistics of independent stochastic components (Table 4.8), shows that they are random by their serial correlation. Hence AR(P) models fitted to the respective series appropriate.

Table 4.8 Statistical properties of independent stochastic components hourly groundwater levels.

Piezometer	Mean	Std. Dev.	Skew ness	Kurtosis	Serial Correlation		
					r_1	R_2	r_3
Peerbavada	0.01	0.17	0.56	5.82	-0.162	-0.25	0.062
Dhavalapuri	0.00	0.12	-0.82	12.20	-0.081	-0.116	-0.075
Waghalgaon	0.00	0.10	-0.25	3.75	-0.197	-0.125	0.001
Pimperkheda	0.00	0.02	0.06	0.05	0.053	0.054	0.055

CONCLUSIONS

The practice of monitoring the groundwater levels of observation wells of Maharashtra at discrete times (four times a year) persists since 1974 in the State of Maharashtra. The monitoring network of Maharashtra has been supplemented by piezometers with Digital Water Level Recorders (DWLR) under Hydrology Project from 1998.

The present study was aimed at, checking the adequacy of the network, estimating the level of accuracy of past data and groundwater resource estimation, examining the optimum frequency of observation in DWLR and simulating the groundwater levels by stochastic modelling, using the data of 141 observation wells and 24 piezometers of Aurangabad district.

Simpler tools have been developed and used for the conversion of the DWLR data as well as for different analyses. Following conclusions have been gleaned from this study.

1. The time lag between rainfall and rise in water level imply poor response of aquifer due to its poor characteristics of transmissivity and storativity.

2. The available network of 141 observation wells was much adequate for 5% error in estimation of average groundwater levels. The supplemented piezometers have increased the network density. Considering the monetary involvement it will be better to reform the network based on spatial analysis.

3. The level of accuracy of the past data has been estimated with a meagre error of 6%, showing the reliability of the old system data. Similarly the average error in estimation of groundwater resource is around 7%, which is commensurate with the typical hydrogeological conditions of the study area.

4. The summation error for optimising the frequency of monitoring is within tolerable limit (upto 0.007) at 6-hour interval. Hence the present frequency of monitoring the groundwater levels at 6 hours can be considered optimum.

5. The groundwater flow directions are in concurrence with the basin slopes. For Tapi-East it is towards N, for Godavari-Purna it is towards E and SE and for Godavari it is due S and SE. Similarly the density of observation wells within different water table contour intervals is good, showing sufficiency of network in space. Correlation coefficient can be considered as one of the reliable criteria for deletion of excess observation wells / piezometers.

6. Stochastic modelling of hourly groundwater levels data indicate that diurnal periodicity exist in it. The periodicities in mean were explained by 8, 6, 2 and 5 significant harmonics for Peerbavada, Dhavalapuri, Waghalgaon and Pimperkheda respectively. Periodicities in standard deviation were explained by 11, 11, 8 and 9 harmonics. Stochastic components can be modelled using AR(1) for Dhavalapuri, Waghalgaon and Pimperkheda and AR(2) for Peerbavada.

Similar type of studies are needed for other districts of Maharashtra also.

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