

STUDIES ON THE FLUCTUATION OF GROUND WATER TABLE

**A Thesis
submitted to the
Bidhan Chandra Krishi Viswavidyalaya
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in
AGRICULTURE (SOIL AND WATER CONSERVATION)**

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ABSTRACT

The availabilities of water for human consumption, crop and industrial management have become very competitive in the recent years. Ground water is a naturally filtered water resource and is considered as an wealth in any region. Moreover, in case of ground water, the non-uniformity of distribution in time scale (specially during the twelve months period in a year) is not very dominant when compared with surface water. Hence, it has attracted attention of the scientists in the present era.

This study was based upon the District of Nadia (Latitude 22°53' to 24°11' N, Longitude 88°09' to 88°48' E) under the state of West Bengal. Initially, piezometric depth data were studied with reference to rainfall in the locality. But the phenomenon is complex and a large number of parameters operate in the process. Thus, it is difficult to assess the resultant effect of the whole process. Hence, the researchers are compelled to study the individual effect of one or two important but measureable parameters on the fluctuations of ground water table. Likewise, in the present case, time and rainfall were chosen as the dominant parameters to influence the water table depth. Ten years' (1976-1985) data were pocessed and the following models, statistically significant, were obtained.

$$D = A + B_1 t_i + B_2 t_i^2 + B_3 t_i^3$$

where, D = depth of ground water table with respect to mean sea level (m)

t = concerned month, values are June = 1, July= 2,
....., May = 12

i = 1 to 12

A, B₁, B₂ and B₃ are empirical constants.

This model, though ignores many important parameters, however, is mostly applicable for prediction of D in the region.

Considering rainfall as one of the most important parameters to influence the ground water depth, the above model was recast as follows :

$$\begin{aligned} D &= R_c (A + B_1 t_1 + B_2 t_1^2 + B_3 t_1^3 + B_4 t_1^4 + B_5 t_1^5) \\ &= R_c (A + B_1 t_1^{-0.5} + B_2 t_1^{-1} + B_3 t_1^{-1.5} + B_4 t_1^{-2}) \end{aligned}$$

Where, D, t and 1 are as above and

R_c = monthly cumulative rainfall, starting from June and ending in the month of May in the next year (m)

A, B_1 to B_5 are empirical constants

The second equation holds good for normal rainfall year, while the third equation is applicable for the low rainfall year as well as late monsoon year.

Prediction of ground water recharge could be evaluated from the model :

$$\Delta d = a R^b$$

where, Δd = ground water recharge for July - August - September (m)

R = total rainfall for the period July - August - September (cm)

a and b are empirical constants.



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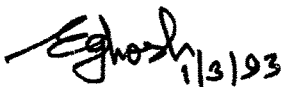


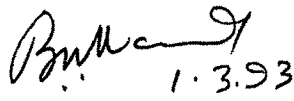
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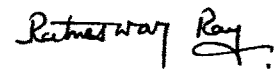
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CONTENTS

Chapter	Page
1. INTRODUCTION	1
2. REVIEW OF LITERATURE	
2.1 General	4
2.2 Water table and its fluctuation	4
2.3 Water table and hydrostatic balance	5
2.4 Rainfall and ground water level fluctuation	6
2.5 Effect of recharge and discharge on ground water level fluctuation	7
2.6 Ground water level fluctuation due to irrigation	10
2.7 Ground water level fluctuation due to evaporation	12
2.8 Ground water table fluctuation due to evapotranspiration	13
2.9 Ground water level fluctuation due to the change in atmospheric pressure	14
2.10 Ground water level fluctuation due to temperature	14
2.11 Ground water level fluctuation due to ocean tide	15
2.12 Ground water level fluctuation due to earth tide	16
2.13 Ground water level fluctuation due to wind	16
2.14 Ground water level fluctuation due to external load	16
2.15 Ground water level fluctuation due to earth-quakes	17
2.16 Ground water level fluctuation due to stream flow	17
2.17 Ground water level and land subsidence	17
2.18 Ground water level fluctuation and content of soil moisture	18
2.19 Mathematical approach to ground water level fluctuation	19
2.20 Concluding remarks	21

3.	MATERIALS AND METHODS		
3.1	Location	....	23
3.2	Topography	....	23
3.3	Soil	....	24
3.3.1	Geology of the area	....	24
3.3.2	Soil association	....	24
3.4	Drainage system	....	28
3.5	Climate	....	29
3.6	Irrigation system	....	29
3.7	Land use pattern	....	30
3.8	Ground water condition and its fluctuation	....	31
3.9	Collection of data	....	33
3.10	Analysis of data	....	33
4.	RESULTS		
4.1	General	....	60
4.2	Study of recurrence interval of annual rainfall	....	60
4.3	Prediction of monthly variation in water table depths with reference to rainfall and time	....	60
4.4	Prediction of average position of water table depths for separate piezometer with reference to time and average rainfall	....	73
4.5	Prediction of monthly variation in water table depths with reference to time (month)	....	73
4.6	Prediction of ground water recharge during July-August-September	....	75
5.	DISCUSSION	....	76
6.	SUMMARY AND CONCLUSION	....	91
7.	FUTURE SCOPE OF RESEARCH	....	96
	BIBLIOGRAPHY	....	98
	APPENDIX - I		
	APPENDIX - II		
	APPENDIX - III		

LIST OF TABLES

Table No.	Contents of Tables	Page
3.1	Textural composition of surface soil profile of different villages in Nadia District ...	25
3.2	Surface and ground water exploitation in the year 1983-84 in Nadia district (conjunctive use) ...	30
3.3	Blockwise land use pattern in Nadia District in the year 1976 ...	32
3.4	Monthly rainfall of Water Management Research Centre, Ranaghat, for the year 1978-85 and the monthly piezometric data from six sites within the area of influence of the said station (determined by Thiessen polygon method, KLMN from Fig. 3.6) ...	34
3.5	Monthly piezometric data from four sites within the area of influence (IJKL as determined by Thiessen polygon method and shown in Fig. 3.6) for the year 1978-85 of the raingauge stationed Santipur (Fulia) Gram Shevak Training centre and also the monthly rainfall of the said station ...	38
3.6	Monthly rainfall of Krishnagar Horticultural Farm for the year 1978-85 and the monthly piezometric data from nine sites within the area of influence of the said station (determined by Thiessen polygon method, GFHIJ from Fig. 3.6) ...	42

3.7	Monthly rainfall of Block Development Office, Kaliganj for the year 1978-85 and the monthly piezometric data from five sites within the area of influence of the said station (determined by Thiessen polygon method, EFG from Fig. 3.6)	...	46
3.8	Monthly piezometric data from five sites within the area of influence (BCEFG as determined by Thiessen polygon method and shown in Fig. 3.6) for the year 1978-85 for the raingauge stationed at Block Seed Farm, Tehatta and also the monthly rainfall of the said station	...	50
3.9	Monthly rainfall data of Block Seed Farm, Karimpur for the year 1978-85 and the monthly piezometric data from three sites within the area of influence of the said station (determined by Thiessen polygon method, ABCD from Fig. 3.6)	...	54
3.10	Annual rainfall (mm) for the period 1976 to 1985 at six raingauge station in Nadia District	...	58
4.1	The auto-regression equation of different order for different raingauge station and their correlation coefficient	...	61
4.2	Elevation of thirty two piezometric point on the ground surface with reference to mean sea level	...	63
4.3	The influencing area of thirty two piezometers of six raingauge stations situated in Nadia district	...	64

Table No.		Page
4.4	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1978-79	65
4.5	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1979-80	66
4.6	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1980-81	67
4.7	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1981-82	68
4.8	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1982-83	69
4.9	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1983-84	70
4.10	The values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1984-85	71
4.11	Statistically obtained values of A, B_1, B_2, B_3 and B_4 of the Eq (4.3) along with the r^2 for different years	72
4.12	Best fit values of A, B_1, B_2, B_3, B_4 and B_5 of the Eq (4.4) along with their r^2 for thirty two piezometers	74

Table No		Page
4.13	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1978-79 and the time for minimum and maximum water table depth ...	76
4.14	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1979-80 and the time for minimum and maximum water table depth ...	77
4.15	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1980-81 and the time for minimum and maximum water table depth ...	78
4.16	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1981-82 and the time for minimum and maximum water table depth ...	79
4.17	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1982-83 and the time for minimum and maximum water table depth ...	80
4.18	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1983-84 and the time for minimum and maximum water table depth ...	81
4.19	The values of A, B_1, B_2, B_3 of the Eq (4.5) for different piezometers for the year 1984-85 and the time for minimum and maximum water table depth ...	82
5.1	Piezometer situated in different coefficient of determination classes in different year ...	86

LIST OF FIGURE

Fig No.		Page in between
3.1	General map of Nadia District ..	23 - 24
3.2	Location of 25 boreholes of deep tubewell in Nadia district ..	27 - 28
3.3	Subsurface details of boreholes along the line AB of Fig 3.2 ..	27 - 28
3.4	Subsurface details of boreholes along the line CD of fig 3.2 ..	27 - 28
3.5	Isohyetal map (on the basis of average rainfall data for the period of 1976-85) of district Nadia, West Bengal ..	29 - 30
3.6	The map of Nadia district showing the locations of thirty two piezometers and six Thiessen polygon area influenced by raingauge station ..	33 - 34
3.7	Monthly average cumulative rainfall for the period of 1976-85 at six raingauge stations in Nadia district ..	57 - 58
4.1	Comperison between actual recharge and estimated recharge using Eq (4.7) to (4.12) ..	83 - 84
5.1	Sample plot of depth versus time for eight cases (vide Eq 4.1) ..	86 - 87
5.2	Sample plot of depth versus time for eight cases (vide Eq 4.5) ..	89 - 90

SYMBOLS USED

A	Constant term of polynomial equation (Eq 3.2, 4.1 to 4.6)
B ₁ , B ₂ , B ₃ , B ₄ , B ₅	Empirical Constant term or co- efficient (Eq 4.1, 4.3, 4.4, 4.5, 4.6)
°C	Degree centigrade
cm	Centimetre
D _{obs}	Observed depth of ground water table
D _{est}	Depth of ground water table estimated from Eq (4.1) to (4.12)
Δd	Ground water recharge (expressed in height unit)
E _t	Evapotranspiration
hr	hours
<and>	leas than and greater than
Km	Kilometre
m	metre
m ha m	Million hectare metre
MSL	Mean sea level
PT	Piezometer
R	Rainfall
R _c	Cumulative rainfall
R _T	Yearly total rainfall
r	Simple correlation coefficient
r ²	Coefficient of determination
RL	Reduced Level
Σ	Summation
t	time in month
t _{max}	The value of time (t) when ground water table is lowest from ground surface
t _{min}	The value of time (t) when ground water table is nearest to the ground surface

INTRODUCTION

1. INTRODUCTION

Water is the most important single input for increasing the productivity of agricultural lands. The growth of civilisation is greatly dependent on this resource.

The use of water in human life is varied , agriculture requires huge amount of water. Industrial thrust is equally enogasuzed. Moreover, under the pressure of population growth at a super-exponential rate and with consequent development of agriculture and industries, the demand for water is increasing at a very fast rate. As such, the surface water is not sufficient to meet the total demand as it can not be retained for a longer period. Thus, the demand for ground water which is the largest available source of fresh water is increasing at a very fast rate.

The water resources are made available to human beings and are maintained through a remarkable hydrologic cycle. Water resources are divisible into two distinct categories, viz, the surface water resource and the ground water resource. However, these two sources are intimately connected with each other.

Ground water is one of the earth's widely distributed resource . It is also one of the most important resource of the world and contributes significantly in the development plans of most of the countries. Ground water exists wherever water penetrates the surface which is permeable enough to transmit the water and the rate of infiltration is sufficient to keep the rocks saturated.

India is rich in water resources being endowed with a network of great rivers and vast alluvial basins to hold ground water which can be successfully exploited for irrigation and other purposes.

Utilization of any resource needs efficient planning. Ground water being an important resource, its exploitation

should be done in a systematic manner. This is particularly true because ground water is a replenishable resource. It is a dynamic object and maintains a dynamic equilibrium with its environment. Thus, over exploitation or inefficient management of this resource can disturb the dynamic ecological balance and brings about disastrous results in future. Example of this type of situation can be had with the increase in salinity in coastal aquifers, land subsidence due to over exploitation, etc. (Leggette, 1947, Ohrt, 1947, Poland, 1961, Domenico and Clark, 1964).

The assessment of ground water resources is also difficult as it involves the evaluation of the various hydrologic components within the frame work of a complex geological environment.

Evaluation, development and management of ground water resources are handicapped by the absence of historic water table data which is essential to assess the changes in the storage of ground water in response to rainfall, evaporation, pumpage, surface irrigation, soil conservation, afforestation and deforestation besides a host of other causative factors.

Thus, it is very essential to make a detailed study of ground water resources of an area before exploiting this natural resource. Any good hydrological study needs collection of data for a considerable period. Efficient planning of ground water exploitation needs long time data on various features of the ground water. One such data is fluctuation of water table. The water table, which forms the upper surface of the saturated zone of the under ground water, fluctuates from day to day, season to season and year to year. The reasons for this fluctuation are many and the factors are meteorological, soil and hydrological, etc.

The occurrence of high water table has an important bearing on the choice of crops to be grown, soil management, need for artificial drainage, suitability of soils for home sites, basements, septic tank installation, waste disposal,

off-road traffic and civil constructions, etc.

The system of fluctuation of water table due to various natural factors is a hydrologic system and are purely deterministic in nature. Due to complexity of the system, no effort had been made in this line. Till now, there is no sound analytical model for determining the daily or monthly variation of ground water table. However, it is very essential to have comprehensive and quantitative knowledge of monthly fluctuation of water table.

In order to achieve this, there is a need to establish a mathematical (or at least an empirical) model of the water table fluctuation process as related to major hydrometeorological factors, i.e., rainfall and time which are easily measurable.

With the above background in view, the present investigation was undertaken to meet the following objectives.

1. To predict the recurrence interval (i.e., return period) of annual rainfall,
 2. to establish models to predict monthly variation in water table depths with reference to rainfall and time,
 3. to predict time corresponding to the occurrences of maximum and minimum water table depths and
 4. to predict ground water recharge.
- .

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 General

The ground water is a renewable natural resource and has remarkable distinction of being highly dependable, safe and ubiquitous. The ground water level is an important feature of the free ground water regime and is governed by various geological, geomorphological, climatic, hydrological and other factors. The geological and geomorphological factors include surface topography, lithologic rock properties and the structure of the region. The climatic factors include atmospheric precipitation, temperature, humidity, barometric pressure and wind velocity. The hydrologic factors include: the flow in rivers in the vicinity of the aquifer and proximity to the sea. In case, where a river drains the free ground water of the irrigated land, one can clearly observe the dependence of the sub-surface flow regime of the river. During the flood period, the river water percolates into the banks and causes a rise of the free ground water level. Among the other factors, the most important one is the irrigation, i.e., main irrigation canals and shallow irrigation canals (Veatch, 1906, Todd, 1959).

2.2 Water table and its fluctuation

Different methods for studying water level fluctuations could be utilized advantageously in areas unaffected by high artificial withdrawals (Wenzel, 1936). However, those methods generally did not yield satisfactory results in areas where there was considerable pumping or artesian flow. Fluctuation of water table appeared to be dependent on several factors like rainfall, evapotranspiration, lateral drainage and geological substrata (Vandmme and De Leenheen, 1969), and were affected by direct recharge from precipitation, evapotranspiration by crops, withdrawals from wells, discharge to the streams and sometimes due to the changes in atmospheric pressure (Walton, 1970).

Depth of water table makes an important factor in moisture loss by evaporation, variation in water quality, air-water relationships in the soil as well as suitability of particular quality of water for the purpose of irrigation. Fluctuation in water table took place as a result of water balance due to recharge and discharge. Generally, the water balance equation for irrigated areas used to be expressed as:

$$I + R - r - E_t - S_m = P - C_r \dots\dots\dots (2.1)$$

Where, I = irrigation or overflow from river plus seepage contribution

R = rainfall

E_t = evapotranspiration

S_m = change in soil moisture

P = percolation

r = run off

C_r = capillary rise

If the overall sum in right hand side of the equation appeared to be positive, as happened with the onset of monsoon (July to September), the water level rose upward depending upon the quantity of recharging and discharging factors. On the contrary, when E_t exceeded R, water table receded (Paliwal and Yadav, 1976).

2.3 water table and hydrostatic balance

The water table represents the top of the zone of complete saturation in permeable rock and soil near the earth's surface. Above the water table, water percolates downwards. That water is steadily incorporated into the ground water reservoir and is transported through permeable deposits to springs and wells. Water usually does not move laterally through the layers of unsaturated soil that overlies the water table and remains in contact with it in view of the fact that its passage in that zone, through wet soil, is interrupted at innumerable points by entrapped air (Deming, 1975).

It was revealed from the literature that the net recharge was the algebraic sum of intermittent additions through vertical seepage and continuous obstruction through evapotranspiration. In this connection, Sagar and Preller (1980) presented a solution to the linearised Boussinesq's equation with net recharge.

2.4 Rainfall and ground water level fluctuation

Rainfall was found to be mainly responsible for the rise of water table (Pandey et al., 1972). Even a slight shower of rain resulted water level in shallow wells to rise considerably (Afzal and Viadhianathan, 1939). The seasonal as well as long term fluctuation of water level in wells, in response to changes in precipitation had been observed by several workers (Gleason, 1942, Manson and Miller, 1955, Fishel, 1956, Nicholson and Firth, 1958, Vanschaik and Stevenson, 1967). In the presence of dense vegetation, it was observed that the mean annual ground water levels remained constant from year to year and cleaning of native forest had significant effect towards the rise of ground water table (Ter, 1956 and Biddiscombe et al., 1985).

There was a definite relation between the rainfall rate and ground water table depth (Keech and Dreeszen, 1959, Youngs, 1975). The rate of replenishment of the ground water reservoir varied with the pattern of precipitation, surface runoff, stream flow and also with the intrinsic permeability of the soil and other porous mediums through which the water must percolate to reach the zone of saturation. In some places, the ground water reservoirs replenished quickly by the rain falling directly on the land surface. In other places, surface water in streams, rivers, canals and lakes fed the ground water reservoir when water levels in those bodies of surface water were higher than the water table and the intervening layer became permeable (Michael, 1978).

On the basis of studies on water level fluctuation in two National Observation Well Net-Work Stations under

U.N.D.P. at Rajasthan, it was observed that the low rainfall cycle over the study period indicated a decline in the water levels, whereas in subsequent years with higher rainfall, there was a steady rise in the water levels (Verma, 1978).

A first order auto-regressive model was introduced by Rennolls et al. (1980) to predict the response of water level in a borehole in response to given rainfall events. Another mathematical model was established by Rushton and Tomlinson (1980) for predicting precipitation and evaporation from recharge data.

2.5 Effect of recharge and discharge on ground water level fluctuation

Fluctuation in ground water levels indicated both change in the actual quantity of water stored in the aquifers and movement of ground water. A continual decline in water level resulted when the discharge exceeded the recharge. Water levels usually rose when the recharge was greater than the discharge. Recharge was the governing factor assuming the annual withdrawals to be constant which depended upon rainfall intensity and distribution of surface runoff. As rainfall was the primary source of recharge in many aquifers, variation of rainfall and ground water levels were closely correlated. The correlation was imperfect, however, because differences in rainfall intensity and distribution brought about different amounts of recharge from the same amount of total annual rainfall. Hence, quantitative estimation of recharge was considered to be complicated.

To assess, broadly the ground water resources on the basis of rainfall infiltration to the ground water bodies and the contribution of seepage from canals, ponds, etc. to the ground water recharge, Raghava Rao et al. (1969) observed the magnitude of canal seepage to the tune of 115 ha m per annum per kilometer length of distributary canals. The total possible recharge in India, due to canal seepage,

was calculated to the extent of 5.463 m ha m per year which was based on the total length of the main canals and distributaries.

However, research work indicated that the topographical slope (Kowal and Omolokun, 1972), land configuration, surface topography, geological and climatic conditions affected the magnitude of recharge to the ground water reservoir (Seth and Burman, 1969).

Recharge involved vertical leakage of water through deposits. However, the quantity of vertical leakage varied from place to place and used to be controlled by the permeability, thickness and area of the deposits through which leakage occurred, as well as on the head difference between sources of water and the aquifer (Walton, 1970).

In a study at Chandrapalan Basin, in India, Sharma and Subba Rao (1973) observed that 1 mm rainfall caused 3 mm rise in water table. Similar type of study was conducted by Sharma et al. (1983) in Visakhapatnam coastal area and observed that an average water level rose to the tune of 3.5 mm for every 1 mm of rainfall in the coast. The recession rates were found to vary with the change in monthly rates of rainfall, although the geohydrological situation appeared to be the same.

While evaluating the ground water fluctuations at IARI Farm, New Delhi, Sharma et al. (1974) calculated the change in ground water storage by multiplying the change in mean ground water table depth with the gravity yield. There was a wide fluctuation in mean monthly values of ground water levels and change of ground water storage. The upper and lower limits of annual change in ground water storages were 1.347 and 0.626 ha m, respectively.

The rate of recharge might also be established by analysing the drawdown curves obtained from pumping test data of some wells considering uniform recharge over the area of influence (Garg, 1978). The empirical formula had

been worked out on those problems for various regions in India (Chaturvedi, 1947; Sehgal, 1973).

Rushton and Tomlinson (1980) calculated from forecast precipitation and evaporation as well as used as an input for a mathematical model of the Southern Lincolnshire lime stone aquifer. Of the possible methods which could be used to forecast precipitation and evaporation were: an overall average, a monthly average and a value dependent on certain earlier months. The suitability of the estimates of recharge based on those forecasts were examined and were subsequently included in the model.

In South-Central Iowa in Loss-driven soil, Coleman and Fenton (1982) observed that the character of water table was cyclic in nature. The highest water table was recorded during the spring while the lowest one was recorded during the fall months on flat and sloppy area. However, the water table showed less cyclic as the buried geomorphic surface decreased. The shallower depths to water table on the South-Eastern part of the area were attributed to the stratigraphic characteristics of the area. The relationship between the depth of the buried geomorphic surface (X) and the average depth to the water table (Y) of the area was expressed mathematically by regression equation:

$$Y = -83.32 + 0.85 X \dots\dots\dots(2.2)$$

$$Y = 20.03 + 61.0 X \dots\dots\dots(2.3)$$

for the flat and sloppy area, respectively.

A linear relationship was observed between the maximum range of fluctuation and the elevation of the ground surface (Sharma et al., 1983). However, in semi-infinite unconfined aquifer, the recharge rate was linearly decreased upto a certain time and thereafter remained constant (Rai and Singh, 1979).

Water table was reported to rise, at Pusa, from the beginning of April and rose to the peak either towards the end of July or in early August which resulted from the receipt of showers in good amounts with a lag period of one to two weeks (Rajput, 1985).

The infiltration, due to rainfall at an unconfined coastal aquifer, was estimated from a mathematical model of the aquifer. The model based on auto-regression moving average (ARMA) equation was developed on the basis of water levels from the rainfall of that location as well as the past history of water levels (Viswanathan and Evans, 1983). Another technique to estimate the recharge was developed by Dasgupta and Paudyal (1988) which combined a hydro-meteorological model linking rainfall and evapotranspiration to the effective ground water recharge and geohydrological model which linked the recharge to the water level in the aquifer.

Two methods of ground water recharge in sandy soil, using water table fluctuations, had been developed by Johansson (1987). The variation of recharge with ground water level was also described earlier by Boochs et al. (1985).

Steenhuis and Van der Molen (1986) modified the Thornthwait-Mather procedure for calculating recharge from soil moisture balance.

2.6 Ground water level fluctuation due to irrigation

Irrigation water had a definite effect on ground water fluctuation which, in turn, varied with the increase in permeability of soil (Voigt, 1965).

A simplified approach of the fluctuation on water table analysis was presented by Dumm (1964) for irrigated land, in that analysis, the falling water table equations were used to predict water table fluctuation during a growing season.

The ground water level in the North-Eastern sectors of the ravine plain at Murrumbidgees region was, generally, found at a depth of 20.28 m below the surface prior to irrigation (Stannard, 1977). Since commencement of irrigation, this ground water level tended to rise at an average rate of 70 cm per year, while the rates of rise were lower in places where lateral dissipation occurred. It was also found that the fluctuations around average level were mostly dependent on climatic conditions and practices of irrigation along with the receipt of rainfall during the cooler months.

In the Goulburn valley in South-East Australia, where rate of evaporation was relatively high for almost half of the year, the introduction of irrigation towards 1880's initiated the rising of water table. The hydrological balance, due to high water inputs along with 70 years of irrigation accompanied by inadequate drainage, was noted. Heavy rainfall periods in that command area also resulted sharp rise in the water table (Mehanni, 1977).

Singh et al. (1984) developed a simulation model to predict the dynamic behaviour of water table in response to ground water pumpage and net recharge in part of the lower Ghaggar basin, Haryana.

A significant correlation existed between the amount of irrigation and the rise of water table as dependent variable, developed on analytical solution for transient water table profiles in finite unconfined aquifers due to infiltration occurring from a single canal or more than one canal (Kamal et al., 1983, Gill, 1984).

Lyle et al. (1986) observed that only three to fourteen per cent of the total water input (rainfall and irrigation) reached the aquifer of the Shepparton region of Northern Victoria, which possessed shallow top soils with heavy clay subsoils of low permeability. The proportion of accession due to irrigation appeared to be less than 20 per cent.

Monitoring of water table from observation wells during 1975-83, it was shown that most of the major rise of water tables occurred in cases where effective rainfalls were higher compared with the average.

Mustafa(1987) obtained a solution with regard to fluctuation of unsteady state flow condition in a semi-confined and finite aquifer with recharge from canals and surface infiltration.

2.7 Ground water level fluctuation due to evaporation

Soil evaporation and transpiration caused diurnal fluctuation of water table of unconfined aquifer near the ground surface (White, 1932, Troxell, 1936, Nichelsen and Firth, 1958). However, when the depth of water table was increased to 3 m below, the fluctuation was negligible. Capillary conductivity of the soil might be calculated by studying evaporation loss from soil column and taking detailed measurements of suction as the function of depth and time in the soil (Moore, 1939, Veihmeyer and Brooks, 1954). The mean recession of water table varied with the textural difference (Nath and Rai Singh, 1985) and with months due to variation in evaporation loss (Seth and Khanna, 1962, Mishra, 1971). The fluctuations were almost negligible during January to February and gradually receded during summer and thereafter progressively increased during the month of August due to variation in surface evaporation (Sharma et al., 1974).

Upward movement of saline ground water and its subsequent evaporation from soil surface caused the accumulation of salts over the soil surface which, in turn, brought about decrease in productivity (Nakayama et al., 1973). To minimise the salt accumulation, attempts were made to find out critical depth of ground water table corresponding to possible evaporation to the extent of 1 mm per day (Logostaev, 1958, Gardner, 1958, Talsma, 1963). There was further attempts to lower the water table below the capillary zone by pumping or by

installation of subsurface drains. For a given degree of evaporation, the depth of water table had been found to rise from sandy to loamy and thereafter went down upto clayey soil. Soils of medium texture, however, were not affected by the accumulation of salts and called for lowering of water table to a greater depth as compared to either clayey or sandy soils (Jackson et al., 1956, Oswal and Khanna, 1978).

The relationship between water table depths and evaporation was found to be curvilinear (Singh, 1981, Roy, 1983). The equation presented by Roy (1983) was as follows:

$$E = 8.2929 - 2.682 H + 0.2857 H^2 \dots\dots\dots(2.4)$$

Where, H = height above water table (m)

E = rate of evaporation (mm/day)

The relationship indicated greater loss of water by evaporation at shallower depth of water table and the rate of evaporation decreased with the increase in depth.

In an experiment to study the dynamics of soil moisture tension at different depths in soil column with varying depths of water table, Roy(1983) showed that the order of increase of soil moisture tension at topmost layer as. clay > clay loam > sandy clay loam.

2.8 Ground water table fluctuation due to evapotranspiration

Though the short term fluctuations of ground water levels were influenced by evapotranspiration (Jaworski, 1968), however, the magnitude of fluctuation was relatively small (white, 1932, Walton, 1970). The greatest drawdown occurred during the bright sunshine hours, particularly during hot windy days when the rate of evapotranspiration was higher which brought about the maximum rate of drawdown towards mid day. In general, drawdown of water level started at about 8 a.m., each day and continued till 6 p.m., and the drawdown started to decline thereafter. The decreased rate of drawdown during the hours of darkness usually happened to be the stages

of recovery, however, water level did not rise over the stages at the day break (Walton, 1970). The diurnal fluctuations of the ground water level occurred only during the summer months due to the variation in the rate of evapotranspiration (Johansson, 1986).

2.9 Ground water level fluctuation due to the change in atmospheric pressure.

Changes in atmospheric pressure did not have exerted any influence on the water table aquifers but sizable fluctuations occurred in wells penetrating confined aquifers (Jacob, 1939, Parker and Stringfield, 1950, Meissner, 1953, Tuinzaad, 1954).

Water levels in wells receded with the increase in atmospheric pressure and vice verse. The ratio of water level change to pressure change, both in terms of the same limit was defined as the barometric efficiency of an aquifer (Todd, 1959).

A model was developed by Weeks (1979) to predict the fluctuation of water table due to the change in barometric pressure. According to Weeks (1979), water level from wells in unconfined aquifers with screen below the water table fluctuated in response to the changes of atmospheric pressure. Those fluctuations occurred because the materials composing the unsaturated zone resisted air movement and had a capacity to store air with the change in pressure. Consequently, the translocation of any pressure change at land surface was slowed as it moved through the unsaturated zone to the water surface in the well instantaneously. Thus, a pressure imbalance was created resulting in a water level fluctuation.

2.10 Ground water level fluctuation due to temperature

During the hot season, Pouquet (1965) observed that water stored in the first few mm of the profile moved downwards in response to increased pressure resulting from expansion of the soil air. The process was reversed during cold season due to the surface cooling. However, Tyul'pavon (1965),

on the other hand, observed that the ground water level rose in winter and in spring seasons but declined in summer.

From the results of both field and laboratory investigations, Meyer (1960) observed that ground water level fell down during winter with reduction in air temperature and rose about the same height during spring with increased air temperature. This phenomenon prevailed in different soils during the periods when there was neither evapotranspiration nor deep percolation. The observed changes primarily represented a migration and accumulation of liquid water over the surface of the soil grains, induced by changes in soil and water temperature so that a few hours of changed temperature gave rise to large changes in saturation level.

In case of perched water table, ^{Wij-}~~Palkovics~~ ^{et} ~~al.~~ (1975) observed that the water table responded ^{to} seasonal variations due to rainfall and temperature.

Mandal (1979) made an attempt to establish a mathematical relationship between recession of ground water level in absence of recharge and prevailing temperature.

2.11 Ground water level fluctuation due to ocean tides

In coastal aquifers, sinusoidal fluctuations of ground water levels occurred in response to tides. When the sea level varied with a simple harmonic motion, a chain of sinusoidal waves propagated in the inland and with the distance, those amplitudes decreased. The problem had been solved by the analogy to heat conduction in a semi-infinite solid state subjected to periodic temperature variations normal to the infinite dimension (Jacob, 1950, Ferris 1951, Werner and Noren, 1951).

The tidal fluctuations caused variation in piezometric surface of a confined aquifer and the relationship was a direct one (Todd, 1959).

Fukuda et al. (1970) reported that the fluctuation of a shallow ground water table in the down stream basin of the Aya river increased with the increasing elevation of the well above sea level with the decrease in distance of the well from the fan head of the study area and with the increased distance from the sea coast.

2.12 Ground water level fluctuation due to earth tide

Water levels in some wells fluctuated in response to earth tides in a regular semi-diurnal cycle fluctuations, caused due to earth tide, in a very negligible way (Robinson, 1939).

2.13 Ground water level fluctuation due to wind

Minor fluctuations of water levels were resulted from the wind blowing over the top of the wells (Parker and Stringfield, 1950). The effect was found to be identical to the action of a vacuum pump. As a gust of wind, blew across the top of a casing, the air pressure within the well suddenly dropped and as a consequence, the water level quickly rose. After the disappearance of the gust, the air pressure in the well was found to increase and the water level fell.

2.14 Ground water level fluctuation due to external load

Application of an additional load on an artesian aquifer in the form of a passing rail-road train compressed the aquifer and increased the hydrostatic pressure. A rapid rise in water level resulted and a maximum water level was recorded at about the time when the locomotive moved opposite to the well. The water level then gently reached to its original position within a few minutes. Water level fluctuations due to passing rail-road trains usually appeared as straight lines on normal recording gauge charts because of the compressed time scale (Jacob, 1939, Roberts and Romine, 1947, Parker and Stringfield, 1950).

2.15 Ground water level fluctuation due to earth-quakes

It was observed that earth-quakes had a variety of effects on ground water (Piper, 1933, Thomas, 1940, La Rocque, 1941, Parker and Stringfield, 1950, Vorhis, 1955). The most spectacular effect was noticed with the sudden rise and fall of water levels in wells, changes in discharge of springs, appearance of new springs and eruptions of water and mud out of the ground (Heck, 1933). More commonly, however, earthquake shocks gave rise to small fluctuations in wells penetrating confined aquifers. Fluctuations probably resulted from compression and expansion of elastic artesian aquifers with the passage of earth-quake waves. The speed of those waves was approximately calculated 125 miles per minute which resulted in water level fluctuation within an hour after the most distant earth-quakes (Parker and Stringfield, 1950).

2.16 Ground water level fluctuation due to stream flow

During the period of flood, ground water levels were found to be temporarily raised near the channel by inflow from the stream. It was observed that the stream fluctuation produced large variations in magnitude and direction of ground water flow (Todd, 1955), where a stream channel was found to have a direct contact with an unconfined aquifer. The stream might have recharged the ground water or received discharge from the ground water levels depending on the relative water levels (Todd, 1959).

2.17 Ground water level and land subsidence

Ground water level fluctuation brought about changes towards elevation of the land surface. Three distinct effects, all resulting in land subsidence, were identified. In peat lands, initially having water tables nearer the ground surface, land subsidence occurred when tables were lowered for agricultural purposes through drainage. In the peat soils of the Sacramento-San-Joaquin delta in California, a steady subsidence with a mean value of 7.6 cm/year was noticed for

a period of more than 30 years (Chow, 1964).

A second form of land subsidence occurred when excessive pumping resulted in a marked decline of water levels in confined aquifers. Here the subsidence occurred due to the reduction of hydrostatic pressure in the aquifer which brought about an increase in the stress on confining clay layers, causing the clay layers to be compressed. That form of subsidence had been noted in several locations in California by Poland (1961).

The third type of land subsidence noticed when water was applied to some soils in arid regions. Studies carried out by Lofgren (1960) in the San-Joaquin valley of California, showed a surface subsidence of 3 m within a period of 18 months after the application of water on a test plot. The subsidence was attributed to a compaction of the upper soil layers produced by wetting from above.

2.18 Ground water level fluctuation and content of soil moisture

The depth of water table for a particular site at any season varied linearly with the calculated moisture deficit in the soil profile below grasses (Coleman and Farrar, 1966). But a curvilinear relation between soil moisture reservoirs and depth of water table was observed by Konstantinov (1966) and the equation was

$$Y = aX^2 - bX + c \dots\dots\dots \dots\dots (2.5)$$

Where, Y was the soil moisture reservoirs (percentage)

X was the depth of water table (m)

a, b and c were the constants.

Young (1969) made step wise regression analysis to develop statistical models between depths of water table and moisture content in a study involving two wet land forest sites (clay loam and loamy sand) and reported that soil moisture was negatively correlated to the depth of water table.

2.19 Mathematical approach to ground water level fluctuation

Aquifers were recharged by precipitation and stream flow, in case where the geological formation appeared to be favourable. Ramachandra Rao et al. (1973) considered the rainfall and stream flow as a stochastic one. Consequently, recharge also occurred as a stochastic process.

The complex phenomenon of ground water hydrology had been analysed with the use of the concept of stochastic system by Kontur (1973) who analysed the ground water as a multiple input linear system. The inputs were. precipitation, evaporation while ground water storage was considered to be the output.

Nelson et al. (1973) used multiple regression equations derived from water table data, involving 17 predictor variables to determine the levels of water table from North Carolina coastal plain soils. By simulating an "average" annual rainfall pattern, it was possible to compare water table depth and fluctuation curves among the different sites, even though the data upon which the various regressions were based, were collected at different times.

A modified runoff model based on saturated-unsaturated Daneyi law was applied, to a small watershed consisting of weathered granite in Shiga prefecture. The water budget and changes in ground water table were observed (Fubota et al., 1988). From this model, the location of ground water table and its rising could be reproduced from the hydrograph, the water budget, the changes in soil moisture and the location of the ground water table.

Tusker and Guswa (1978) applied a mathematical model for estimating daily water levels from an existing water level observation net work at CapeCod, Masachussetts. The model assumed that the water level fluctuation curve could be approximated by a simple harmonic function in the form given below :

$$W_1 = (X) = M + A \cos \left(2\frac{\pi}{T} X + C \right) + BX \dots\dots\dots(2.6)$$

where, W_1 = Water level for day number 'X'

M, A, B and C = constants

T = Harmonic period.

Ghosh (1981) reported that since water table functions were controlled by numerous hydrological, meteorological and other factors, it was worthwhile to consider the process as a stochastic one. Thus, a mathematical model was developed which included both deterministic and probabilistic components for the prediction of the water table fluctuation.

A linear model using the recursive least squares method was developed by Vishwanathan (1983). The model estimated the daily water level in borehole, given the rainfall on the same day and upto eight days before. The model was

$$h_t = \lambda_t h_{t-1} + \alpha_0 R_t + \alpha_1 R_{t-1} + \dots + \alpha_8 R_{t-8} + \beta_t \dots\dots(2.7)$$

The time dependent soil parameters λ_t , α_t and β_t were determined using recursive algorithms. The parameters λ_t accounted for drainage factor, β_t for various external disturbances that influenced water table variations and α_t for parameters that determined infiltration rates. From the parameters obtained, it appeared that most of the recharge took place within the first two days of the event. The parameters α_3 and α_4 were negative for most of the times suggesting that water level dropped after 3 or 4 days due to escape of entrapped air. Parameters α_5 to α_8 were negligible indicating no infiltration took place after 5 days of rainfall.

Mishra (1983) established two types of model, viz, one was multiple regression model with a random component and the other was a decoupled model with a recession component and a recharge component.

In the first case, multiple regression analysis was carried out with fluctuation of water table as dependent

variable and rainfall and evaporation as independent variables. The model was.

$$W.T.F. = a + b_1 R_L + b_2 E_N + \alpha \dots\dots\dots (2.8)$$

Where, W.T.F. = The water table fluctuation (m)

R_L = rainfall (cm)

E_N = evaporation (mm)

α = random component of multiple regression model.

a, b_1, b_2 = coefficients.

In the decoupled model, the recession component was characterised by an "average daily recession coefficient" which was related to mean daily evaporation by a linear relationship with the addition of a random component. The recharge component, on the other hand, was related to weekly total rainfall by a linear relationship with the addition of a random component. In both the cases random components were evaluated as the deviation from the trend component.

2.20 Concluding remarks

An examination of the "review of literature" presented herein revealed that quite a good number of variables, viz, season, rainfall or precipitation, recharge, irrigation, drainage, evaporation, transpiration, atmospheric pressure, temperature, ocean and earth tides, wind, external load, stream flow, soil moisture storage, earthquake, etc. were responsible for fluctuations of ground water table. The list furnished was not exhaustive. Many of those might interact with others. Hence it was difficult to assess the combined /resultant effect of all those variables. Moreover, the measurement of all those variables were not so easy with the present knowledge and available instruments. Thus, in most of the cases, researchers were compelled to study the

individual effect of one or two important but measurable variables on the fluctuations of water table. Consequently the attempt became highly empirical and thus applicable only to a local study area. Mathematical modelling in this line has been introduced in the seventies (1970-80) which also miserably failed to express the real world situations in every place as they could not be accommodated with all the influencing parameters.

Rainfall appeared to be one of the most important parameter and source of all water supplies in various parts of the earth surface. A part of this joined the ground water as recharge leading to increase in the elevations of ground water table. But it was surprising that rainfall had not been explicitly included in the existing mathematical or empirical models. The main probable reason of this was that rainfall versus time plot did not follow a specific pattern expressible in functional form.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The district of Nadia was selected to carry out the investigation. A brief introduction about Nadia district is given in the following sections. Detailed informations regarding the study as well as collection of data and the methodology adopted for their analyses are presented subsequently.

3.1 Location

Nadia district (West Bengal, India) is located in between 22°53' to 24°11' North Latitude and 88°09' to 88°48' East Longitude. The tropic of cancer passes almost across the middle of the district. The district is surrounded by the districts of Murshidabad in the North, 24-Parganas (North) in the South as well as in the South-East, Burdwan and Hooghly in the West, while Bangladesh is situated in the East. There are 16 blocks in the district. The number of villages and towns in the district are 1383 and 13, respectively. The general outline of the district Nadia along with main roads and railway tracks are shown in Fig. 3.1.

With a view to provide a detailed description of the area and to develop an efficient model to predict water table depth (with respect to ground surface and/or mean sea level), it's salient features such as topography, soil, climate, irrigation and drainage system, land use pattern, ground water conditions and its fluctuations are presented below.

3.2 Topography

Nadia district is almost flat. The maximum ground surface elevation is 28.84 m above mean sea level (MSL) near Jairampur in Karimpur block and 'minimum is 5.05 m above MSL near Nagarukhra in Haringhata block (Chakraborty and Vijayaraghavan, 1986). The general slope is from North to South with a slight inclination towards South-East. A number of saucer shaped depressions are found in several areas.

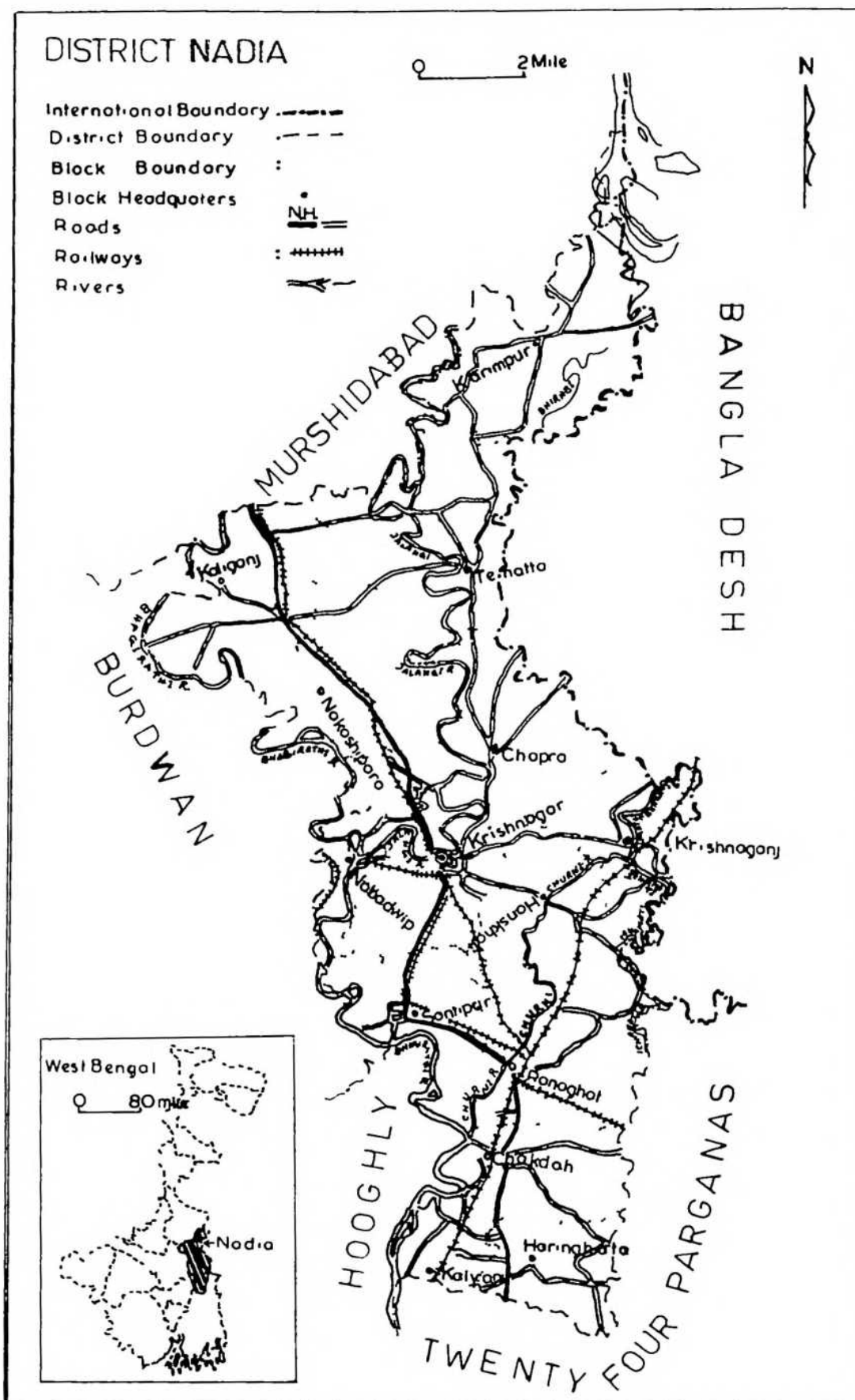


FIG 3.1 GENERAL MAP OF NADIA DISTRICT

3.3 Soil

The texture of surface soils of the district varies from loamy to clayey. There exist two distinct textural groups in 1 m depth of soil. The textural composition of surface soil profile of different villages in Nadia district is shown in Table 3.1 (Survey report of Directorate of Agriculture, Government of West Bengal, 1965).

3.3.1 Geology of the area

The entire district of Nadia is flanked by a huge thickness of Gangetic alluvium of recent age. The quarternary Sediments had been deposited in the wide deltaic flood plain built up by the river systems of Ganga and its tributaries. The alluvium consists of a succession of sand varying in texture from fine to coarse. It is more or less continuous sand horizons with clay lenses at places. Twenty boreholes of deep tube wells were selected along the line AB from Charmuktapur to Birohi and also six along the line CD from Baraitna to Kachuadanga to study the lithology of the area (Fig. 3.2).

A rough idea about the sub-surface lithology of the district was obtained and based on those boreholes log chart of the sub-surface lithological maps along AB and CD were prepared (Figs. 3.3 and 3.4, respectively).

3.3.2 Soil association

The Central Ground Water Board (Chakraborty and Vijayaraghavan, 1986) classified the soils of Nadia district in three association groups, e.g.,

- a. Ganga riverine lands,
- b. Ganga flat lands and
- c. Ganga low lands.

a. Ganga riverine lands : those lands were formed from soils of recent alluvial fans, flood plains or other secondary

Table 3.1 Textural composition of surface soil profile of different villages in Nadia District

Block	Village Name	Depth(cm)	Soil type
Karimpur	Durlavpur	0 - 30	Sandy clay loam
		31 - 71	Clay loam
	Fulkhali	0 - 40	Sandy loam
		41 - 71	Loam
	Dogachi	0 - 20	Loam
		21 - 43	Sandy clay loam
	Rahamatpur	0 - 46	Loam
		47 - 122	Clay loam
	Fazilnagar	0 - 30	Sandy loam
		31 - 97	Loam
	Singadanga	0 - 25	Clay
		26 - 122	Sandy loam
Tehatta	Taranipur	0 - 30	Clay
		31 - 68	Clay loam
	Nabinnagar	0 - 30	Silt loam
		31 - 94	Silty clay loam
	Azfullanagar	0 - 36	Clay loam
		37 - 91	Silty clay loam
	Kanainagar	0 - 36	Silty clay loam
		37 - 66	Loam
	Pollerpara	0 - 48	Loamy sand
		49 - 74	Silt loam
Kaliganj	Nischintapur	0 - 89	Sandy loam
		90 - 102	Sandy
	Bara Itna	0 - 69	Clay
		70 - 81	Loam
	Politberia	0 - 8	Sandy loam
		9 - 33	Clay loam
	Mira	0 - 36	Clay
		37 - 64	Loam

Contd....

Table 3.1 (Contd.)

Block	Village Name	Depth(cm)	Soil type
Nakashipara	Rajpur	0 - 36	Clay loam
		37 - 66	Clay
	Bandakhola	0 - 25	Clay
		26 - 41	Sandy clay
	Dhaparia	0 - 33	Sandy clay loom
		34 - 53	Clay loam
Chapra	Dompukur	0 - 122	Silty loam
	Bagberia	0 - 30	Loam
		31 - 91	Sandy loam
	Kaling	0 - 15	Sandy clay loam
		16 - 91	Sandy loam
Krishnagar	Satkulia	0 - 61	Loam
		62 - 91	Sandy loam
	Hatisala	0 - 91	Clay loam
	Kulgachhi	0 - 51	Clay
		52 - 76	Silty clay loam
	Bahadurpur	0 - 51	Clay loam
		52 - 71	Loam
	Char-mahatpur	0 - 20	Clay loam
		21 - 53	Loamy sand
	Sujanpara	0 - 48	Sandy loam
49 - 122		Silty clay loam	
Nabadwip	Gangaprasad	0 - 53	Silty loam
		54 - 64	Sandy loam
Hanskhali	Purba Simulia	0 - 15	Sandy loam
		16 - 38	Clay loam
	Bagula	0 - 15	Loamy sand
		16 - 106	Sandy clay loam
	Omerpur	0 - 15	Clay loam
		16 - 48	Clay

Contd....

Table 3.1 (Contd.)

Block	Village Name	Depth(cm)	Soil type
Santipur	Kudampur	0 - 81	Silty loam
		82 - 122	Loam
	Chandkuri	0 - 79	Silty clay loam
		82 - 117	Clay
	Madhya Sreerampur	0 - 48	Sandy loam
		49 - 63	Sandy
Ranaghat	Habibpur	0 - 25	Silty Clay
		26 - 89	Clay loam
	Sreedharpur	0 - 25	Clay loam
		26 - 63	Clay
	Birnagar	0 - 38	Clay loam
		39 - 122	Sandy loam
	Hizuli	0 - 38	Sandy clay loam
		39 - 74	Clay loam
	Char Naapara	0 - 94	Loamy sand
		95 - 122	Sandy
Chakdah	Charjirat	0 - 30	Sandy loam
		31 - 51	Sandy
	Muratipur	0 - 30	Clay
		31 - 122	Clay loam
	Itapukuria	0 - 61	Clay
		62 - 76	Loam
	Darabpur	0 - 30	Loam
		31 - 61	Silty loam
Haringhata	Satsimula	0 - 15	Silty clay loam
		16 - 38	Clay
	Uttar Rajpur	0 - 15	Loam
		16 - 66	Silty clay
	Jhikra	0 - 33	Sandy loam
		34 - 56	Loam

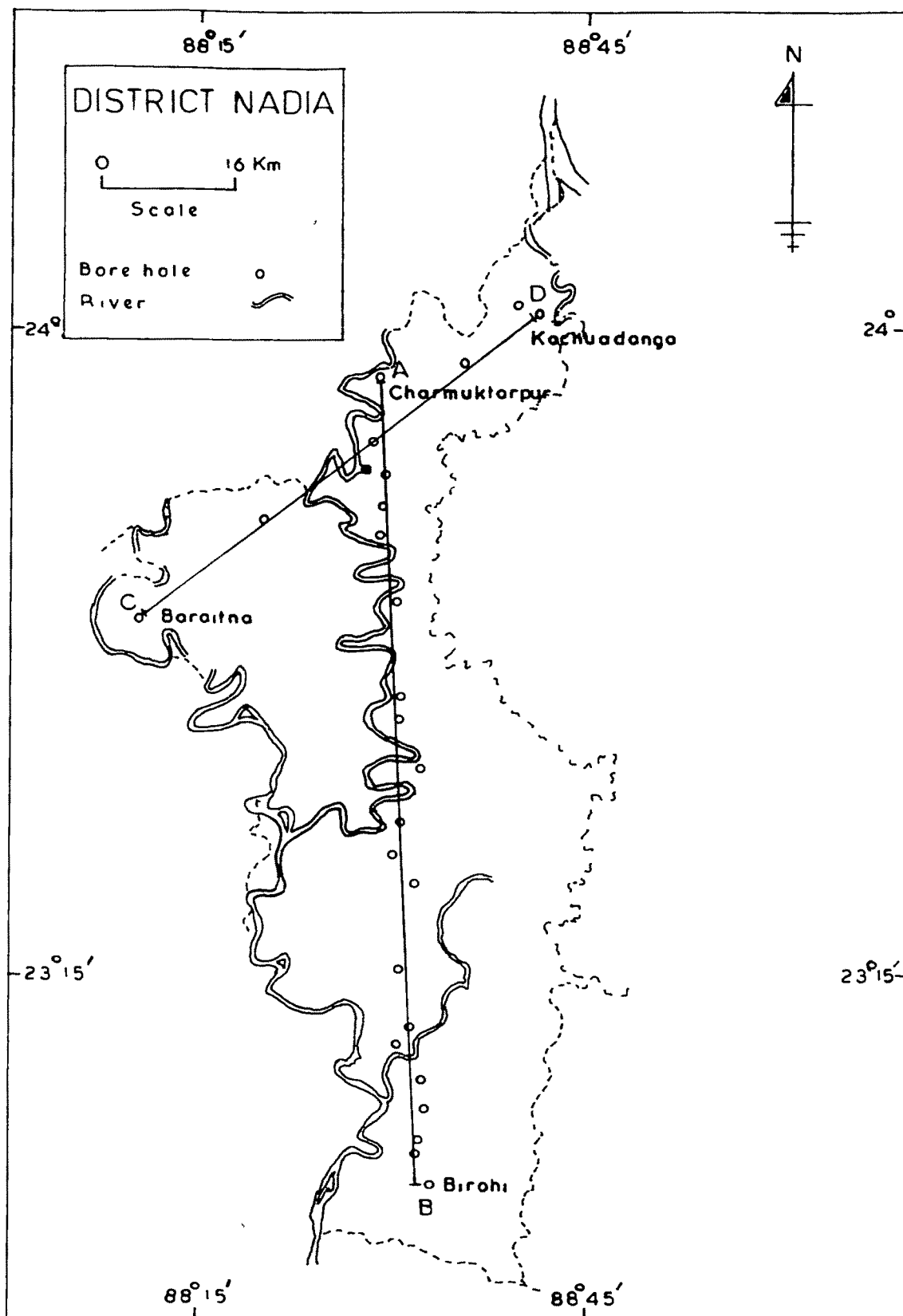


**FIG 32 LOCATION OF 25 BORE HOLES OF DEEP TUBE WELL
IN NADIA DISTRICT**

SOURCE GROUND WATER RESOURCES OF NADIA DISTRICT (1986)

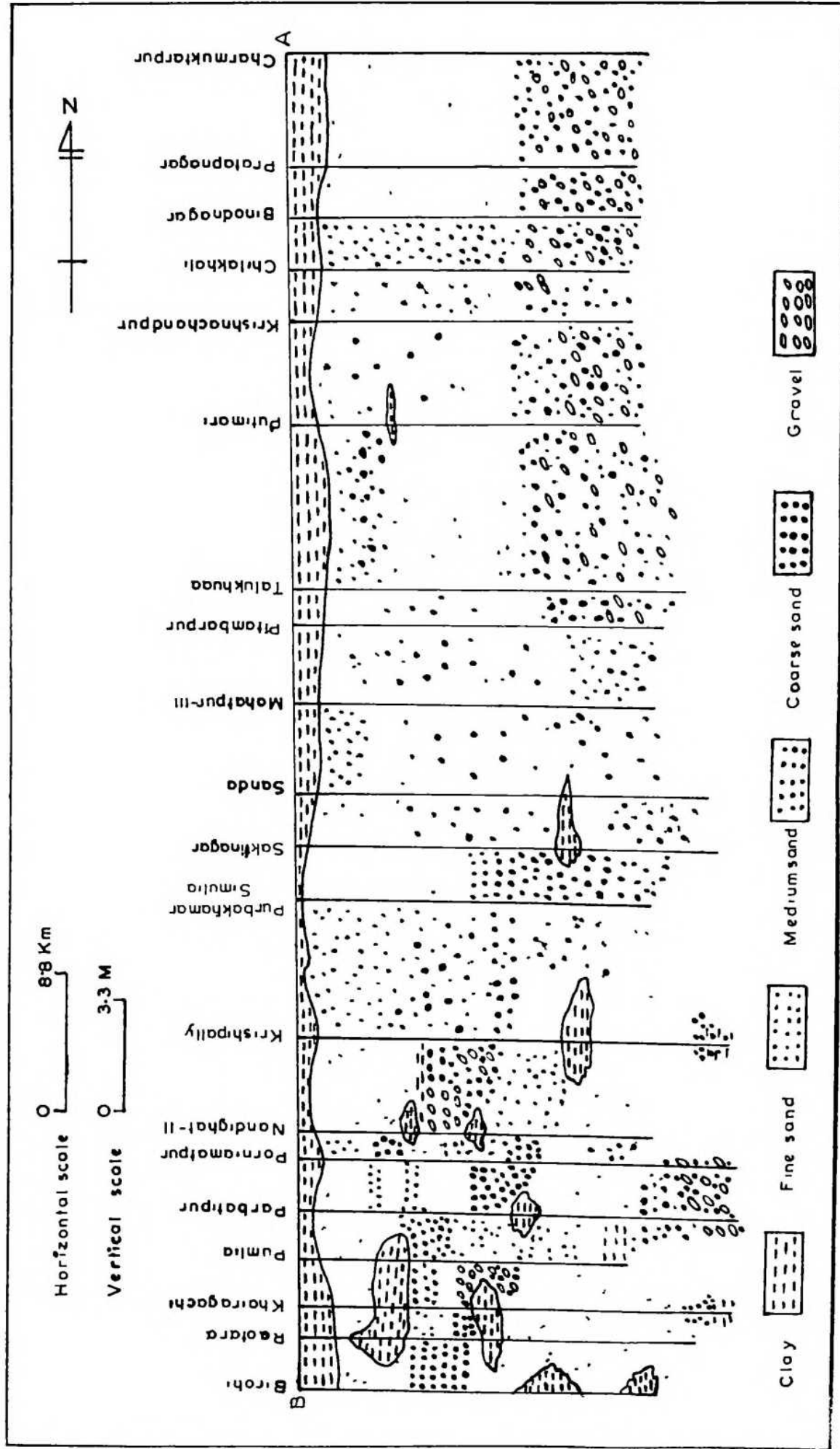


Fig 3.3 Sub surface details of bore holes along the line A B of fig 3.2
SOURCE GROUND WATER RESOURCES OF NADIA DISTRICT (1986)

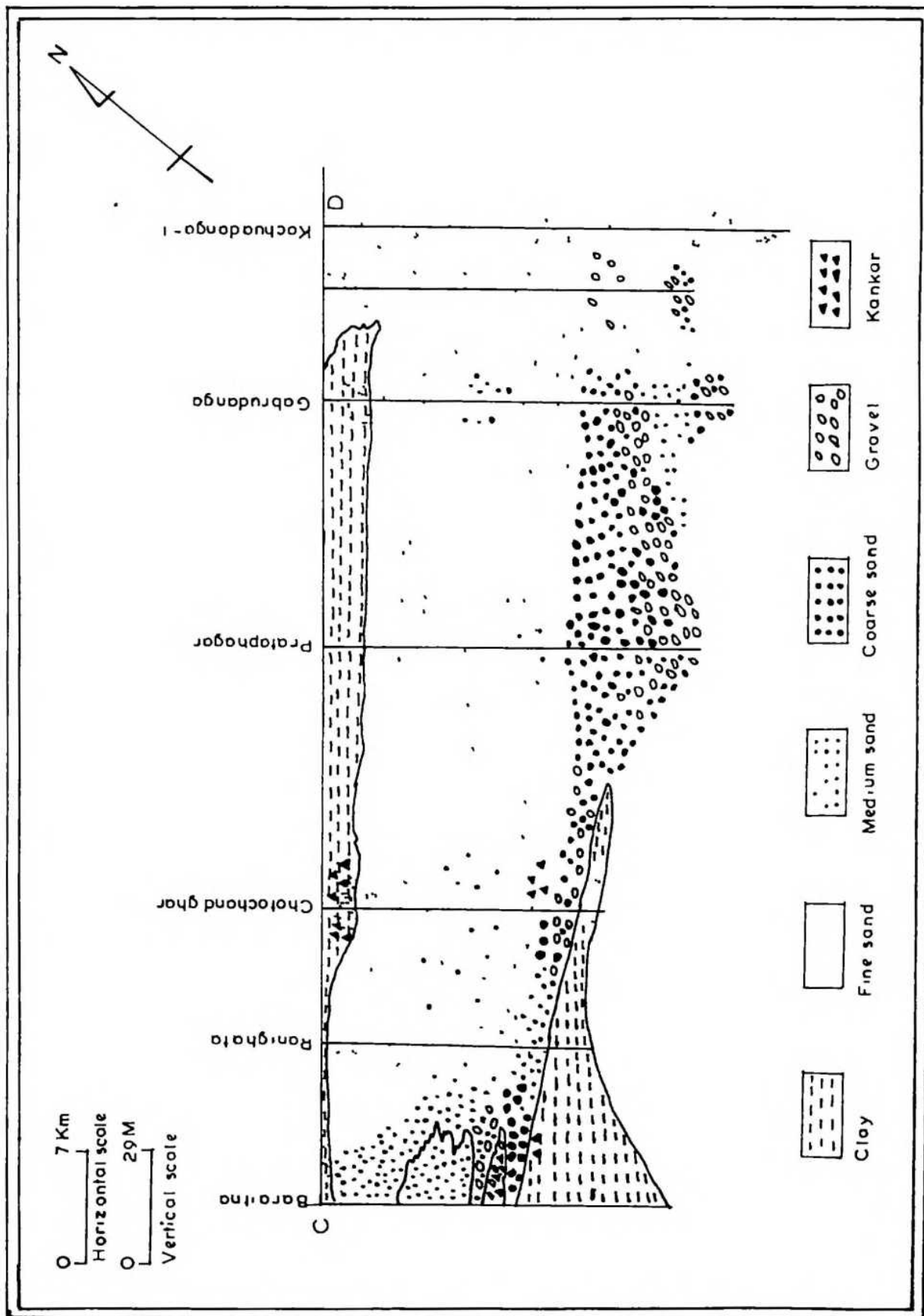


Fig 3.4 Sub-surface details of bore holes along the line C D of fig 3.2

SOURCE GROUND WATER RESOURCES OF NADIA DISTRICT (1986)

deposits having undeveloped profiles and underlain by unconsolidated materials. These profiles showed no accumulation of clay or lime in the sub-soil resulting from the weathering and downward movement of water from the surface horizon. Deposition of alluvium, having different textures in various layers in an unsystematic manner, was evident.

b. Ganga flat lands . those lands were formed from soils of the young alluvial fans, old flood plains or other secondary deposits having somewhat developed profiles underlain by unconsolidated materials. These profiles showed slight compaction and slight accumulation of clay in the subsoils as a result of leaching from the surface horizon.

c. Ganga low lands . those lands consisted of the soils from the lower plains, depressions and left river beds having a good accumulation of clay in the surface soils and underlain by unconsolidated materials of more often riverine profile, clay-pan soils are relatively impervious with regard to the downward movement of water. Water moved through big cracks in the soil.

3.4 Drainage system

The study area happened to be an extensive alluvial plain intersected by four rivers (Bhagirathi, Churni, Ichhamati and Jalangi), numerous abandoned river courses, minor streams (Jamuna, Mathabhanga, Bhairavi) and lakes (popularly known as bills in Bengali), which served as the passage of runoff from rainfall and over-irrigation. The river Bhagirathi (i.e., Ganga) followed a meandering course entering the district in the north and leaving it in the south. The high ridges observed in some places were subjected to impact of monsoon floods, which got eroded by slip erosion. The plains got submerged by the floods during monsoon. During the floods, the banks of the river were subjected to severe impact resulting in a swing of the river either towards the right or towards the left against the natural course. Often the river beds

got choked as a result of the deposition of sand and silt. This resulted change in their course forcing their ways through new areas. The lower part of the Bhagirathi, upto Nabadwip, was subjected to daily rise and fall of water levels due to tides.

The river Ichhamati forms the Eastern boundary. The Churni happened to be an important tributary of the Ichhamati and flew to the south. All the rivers were off-shoots of the Padma and had attained almost base level of erosion.

Other rivers included Bhairabi, Mathabhanga and Jumuna. There were numerous perennial streams flowing over the district (Fig. 3.1).

3.5 Climate

The district experienced extreme climate. the summer was hot and humid and the winter was cold. The temperature rose to maximum during the months of April and May while the minimum was recorded during December and January. The South-West monsoon usually borke in the month of early June and continued upto October.

The mean annual atmospheric temperature of the district was recorded to be 26°C and ranged between 20.8°C and 31.5°C, the mean minimum atmospheric temperature of the district varied from 11°C in January to 26°C in June and mean maximum from 25°C in December to 36°C in May. The average humidity was noted to be 79 per cent.

An isohyetal map (on the basis of average rainfall for the period of 1976-85) of Nadia district were shown in Fig. 3.5.

3.6 Irrigation system

No major irrigation project was in operation in the district of Nadia and therefore, all efforts were made to exploit ground water for the purpose of irrigation. Ground water was the principal source of irrigation and ground water

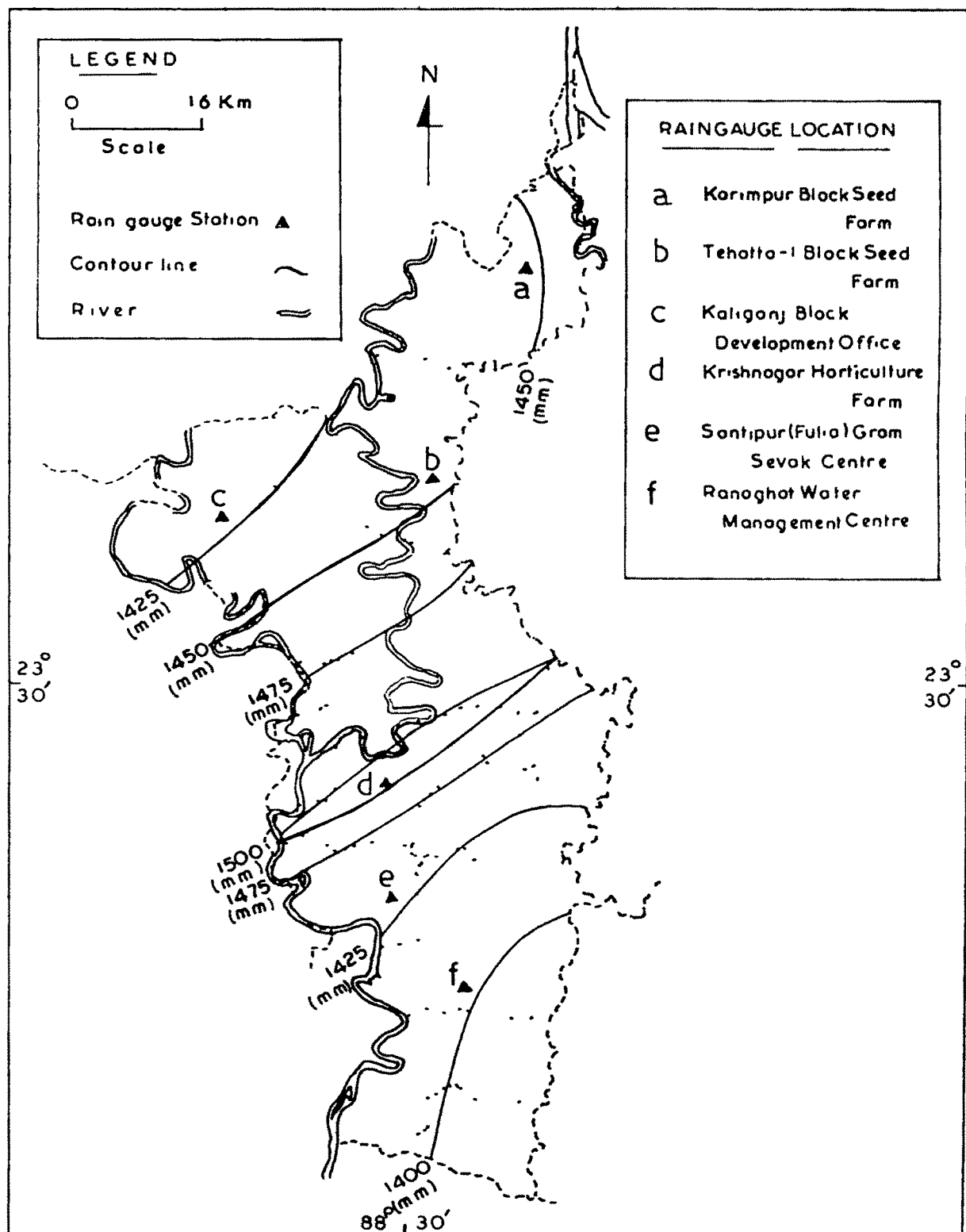


Fig 3.5 Isohyetal map (on the basis of average rainfall data for the period of 1976-85) of district Nadia, West Bengal

accounted for nearly 85 per cent of the total area commanded by means of shallow and deep tube wells. Abundant supplies of ground water within the shallow depth and low pumping heads made ground water cynosure of all farmers. Table 3.2 indicates the total extraction of ground water from different sources for irrigation purposes in Nadia district for the year 1983-84. This gave an idea about the pressure created by the agriculture sector on ground water reservoir.

Table 3.2 Surface and ground water exploitation in the year 1983-84 in Nadia district (conjunctive use)

Sources	Number of installation	Per unit * discharge $10^3 \text{ m}^3/\text{year}$	Total extraction $10^3 \text{ m}^3/\text{year}$
Deep tube well	603	403.8	243491.4
Shallow tube well	28873	27.0	779571.0
Dug well	2	52.9	105.8
River lift scheme	319	230.4	73497.6
Surface Irrigation Scheme (Pond etc.)	198	230.4	45619.2
Total			1142285.0

* Source: Ray(1986)

Of the total exploitation, ground water contributed the major part, i.e., 89 per cent of the total exploitation.

3.7 Land use pattern

Like other districts of West Bengal, Nadia is also a predominantly agricultural district. The total geographical area is about 3866.74 sq km. The district is in progress towards attaining self-sufficiency in food production with cropping intensity as high as 198 per cent. previously, Jute, autumn paddy, winter paddy, vegetables and pulses happened to be the main crops, however, of late, a number of crops have been introduced in the crop rotation, notably wheat,

potato and mustard. Crops like groundnut, sweet potato, water melon and spices are also gaining importance. There are some areas which are occupied by orchards and plantation crops as well. But the area occupied by forests is not significant. Table 3.3 illustrates the distribution of land use in the various blocks of the district in 1976.

3.8 Ground water condition and its fluctuation

In Nadia district, ground water occurred under unconfined conditions. Confining bed, like clay, was either absent or when present occurred only as isolated patches (perched aquifer).

The huge thickness of the alluvium with excellent components of the aquifer material and vast exposed recharge area rendered the district as one of the finest well field of the state. The deep tube wells were capable of yielding $180 \text{ m}^3/\text{hour}$, whereas the shallow tube wells recorded a discharge to the tune of $30 \text{ m}^3/\text{hour}$ at a drawdown not exceeding 4.5 m. Transmissibility values ranged from as high as $30849 \text{ m}^2/\text{day}$ in Ranaghat block to as low as $1487 \text{ m}^2/\text{day}$ in Nabadwip block. However, transmissibility in the district, in general, was deemed to be high. Storage co-efficient values did not indicate confined conditions. Those values rather lay in between 0.57×10^{-3} to 6.0×10^{-3} (Mishra, 1983).

The area surrounding Kalyani recorded the depth of water table in about 4 m below the surface of the soil. The water table near Ranaghat occurred at a depth of 5.7 m below the ground level. In the area around Hanskhali, the depth of water table was found to range between 4 to 4.5 m below the ground level. The shallowest water table recorded around Mira and Debagram under Kaliganj block and Jagadanandapur under Nakashipara block (2.3 m to 3.5 m below the ground level). The ground water level was found to be situated beyond 6 m from the surface of the soil at Shikarpur under Karimpur block, in Tehatta block, Krishnagar Horticultural Farm in Krishnagar- I block and Banpur in Krishnaganj block. Like

Table 3.3 Blockwise land use pattern in Nadia District in 1976

Block	Geographical area (Sq. Km.)	Cultivated area (Sq. Km.)	Orchards (Sq. Km.)	Forest (Sq. Km.)	River, Canal, tank, road etc. (Sq. Km.)	Cultivable waste (Sq. Km.)	Non-cultivable waste (Sq. Km.)
Karimpur	445.54	317.85	8.86	Nil	0.94	NA	NA
Kaliganj	320.78	189.69	4.85	NA	57.56	NA	65.36
Tehatta-I	249.47	191.81	12.66	NA	0.17	0.56	41.89
Tehatta-II	172.43	149.76	1.37	NA	NA	NA	NA
Chapra	306.50	209.72	7.13	2.15	84.05	NA	NA
Krishnagar-I	254.65	182.00	NA	NA	NA	NA	NA
Krishnagar-II	133.71	102.00	1.44	1.66	25.31	1.66	0.07
Nabadwip	103.46	81.73	NA	NA	NA	NA	NA
Krishnaganj	151.39	98.00	NA	NA	NA	NA	NA
Haskhali	254.72	176.05	2.71	0.63	20.60	NA	NA
Santipur	193.23	138.26	2.00	1.35	8.43	NA	43.23
Ranaghat-I	154.70	103.18	0.34	1.18	NA	NA	NA
Ranaghat-II	274.90	172.08	0.53	1.82	0.91	NA	96.47
Nakashipara	360.22	229.20	1.92	3.09	67.36	NA	49.60
Chakdaha	331.69	220.00	8.06	NA	95.98	95.98	NA
Haringhata	168.35	123.02	NA	NA	NA	NA	NA

Source . Nadia District Census Report 1976,

NA : Not available

surface water, ground water too, flew from North to South following the general surface slope of the land mass except near the main rivers which generally used to receive effluent recharge from the ground water body.

During the last one decade, utilisation of ground water had sharply increased. The ground water resources of the district was required to be developed in a planned manner. In that context, State Water Investigation Directorate ventured upon an ambitious scheme and installing gradually a number of piezometers since 1976 at different locations throughout the district and since then, the depth of water table has been recorded for 6 to 9 times in a year in the first week of the months. The data on monthly water table depth along with the rainfall received in the respective months are presented in Tables 3.4 to 3.9.

3.9 Collection of data

Available monthly rainfall data (Tables 3.4 to 3.9) for six raingauge stations of Nadia district, viz, Ranaghat Water Management Centre, Santipur Gram Shevak Training Centre, Krishnagar Horticultural Farm, Kaliganj Block Development Office, Tehatta Block Seed Farm and Karimpur Block Seed Farm, were collected from Meteorology Department, Writers' Buildings, Calcutta, West Bengal, for the period between 1976 to 1985.

The corresponding data of ground water table in 32 piezometers scattered randomly throughout the district (Fig. 3.6) and the reduced levels (RL) of the piezometric sites were collected from the State Water Investigation Directorate, Sech Bhavan (Third floor), Bidhan Nagar, Calcutta.

Different borehole log charts were collected from Central Ground Water Board, Park Street, Calcutta.

3.10 Analysis of data

The data thus obtained were processed in a tabular form (Table 3.10), graphically (Figs. 3.7, 4.1, 5.1 and 5.2) and statistically (Eqs 3.1 and 3.2, Eqs 4.1 through 4.12).

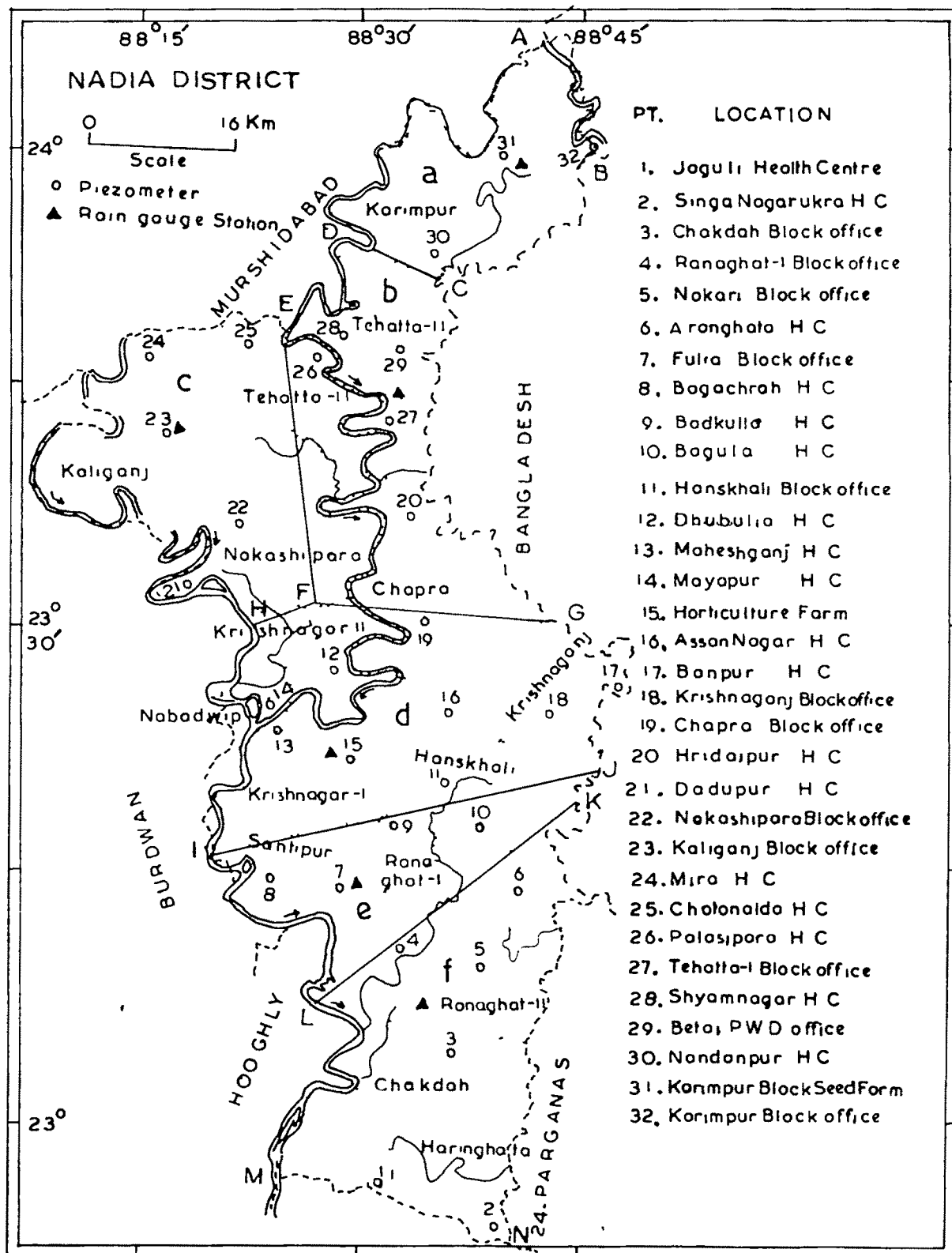


Fig 3.6 THE MAP OF NADIA DISTRICT SHOWING THE LOCATIONS OF THIRTYTWO PIEZOMETERS AND SIX THISSION POLYGON AREA INFLUENCED BY RAIN GAUGE STATION

Table 3.4 Monthly rainfall of Water Management Research Centre, Ranaghat for the year 1978-85 and the monthly piezometric data from six sites within the area of influence of the said station (determined by Thiessen polygon method, KLMN from Fig. 3.6)

Month	Rainfall (mm)	Water table depth with reference to mean sea level					
		PT-1	PT-2	PT-3	PT-4	PT-5	PT-6
1978-79							
June	100.4	3.96	NA	2.89	3.5	2.89	NA
July	279.5	4.18	NA	3.05	3.5	2.98	NA
August	241.0	6.17	NA	3.59	3.98	3.51	NA
September	612.2	7.04	NA	4.79	4.84	4.12	NA
October	38.0	6.82*	NA	5.22*	5.32*	4.7*	NA
November	0	6.51	NA	4.69	5.67	4.93	NA
December	10.5	4.87	NA	4.66	4.9	4.44	NA
January	14.0	5.06	NA	2.98	4.47	3.95	NA
February	30.0	4.64	NA	2.80	4.21	3.67	NA
March	16.0	3.72	NA	2.19	3.83	3.27	NA
April	3.0	3.54	NA	1.45	3.64	3.27	NA
May	27.0	2.91	NA	1.65	2.89	2.28	2.48
1979-80							
June	186.8	3.4*	-0.06	2.2*	2.76*	2.7*	2.2*
July	432.0	4.3*	0.72*	2.6*	3.63*	3.24*	2.8*
August	179.0	5.2*	1.54*	3.3*	4.03*	3.5*	3.6*
September	245.0	5.72	2.1	3.91	4.39	3.77	4.42
October	60.0	6.21	2.42	4.70	4.82	3.95	4.53
November	3.0	5.28	1.93	5.04	5.0	3.85	4.0
December	27.6	4.82	1.4*	4.49	3.72	3.56	3.73
January	0	4.33	1.05	2.03	3.68	3.58	3.96
February	63.0	3.98	0.8	2.93	3.48	2.91	3.23
March	35.0	3.76	0.46	1.41	3.18	2.6	2.7
April	11.0	3.38*	0.26	1.46	2.92*	2.4*	2.4*
May	58.8	3.24	0.11	1.59	2.87	2.27	2.54

Table contd...

Table 3.4 (Contd..)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)					
		PT-1	PT-2	PT-3	PT-4	PT-5	PT-6
1980-81							
June	264.0	3.41	0.09	2.55	3.06	2.31	2.69
July	378.0	4.47*	0.6*	3.10*	3.56*	2.7*	3.15*
August	501.0	5.85	1.56	4.02	3.89	3.27	3.77
September	89.0	7.08	2.94	5.75	5.18	5.06	5.95
October	91.0	6.6	2.59	4.46	5.21	3.77	5.43
November	0	6.18	2.43	3.72	5.02	4.56	5.09
December	0	5.52	1.72	3.99	4.55	4.11	4.3
January	1.4	4.91	1.08	3.27	4.06	3.68	3.86
February	106.6	4.98	1.04	2.78	3.95	3.49	3.49
March	150.2	5.22*	0.69*	2.98	3.85*	3.2*	3.26*
April	198.0	5.39*	0.4*	3.49*	3.94*	3.3*	3.3*
May	265.1	5.6	1.0	4.27	4.02	3.36	3.75
1981-82							
June	127.5	6.13	1.5	4.56	4.04	3.43	3.65
July	634.4	6.46*	1.92*	5.17*	4.38	3.7*	4.0
August	230.1	6.72	2.32	5.57	4.98	4.1	5.15
September	168.9	7.15	3.55	5.96	5.58	5.22	6.05
October	7.0	6.46	2.45	5.49	5.13	4.83	5.18
November	0	5.93	2.15	4.79	4.76	4.31	4.4
December	104.0	6.13	2.2	4.19	4.61	4.13	4.22
January	0	5.17	1.48	2.71	4.06	2.41	3.55
February	12.2	5.02	1.32	2.26	3.87	3.21	3.28
March	34.1	4.93	1.17	2.17	3.76	3.24	3.15
April	142.2	4.25	0.71	2.04	3.54	3.0	2.9
May	65.9	3.81	0.40	2.79	3.46	2.86	2.97

Table contd...

Table 3.4 (Contd..)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)					
		PT-1	PT-2	PT-3	PT-4	PT-5	PT-6
1982-83							
June	159.9	3.76	0.3	2.76	3.49	2.8	2.87
July	157.3	3.69	0.37	2.92	3.52	2.9	2.81
August	307.9	3.61	0.65	2.33	3.46	2.91	3.3
September	65.6	4.33	1.26	2.61	3.96	3.46	3.93
October	41.6	4.81	1.42	1.60	3.83	3.26	3.4
November	12.8	4.26	0.87	1.52	3.71	3.0	2.93
December	0	4.02	0.71	1.44	3.63	2.84	2.93
January	4.2	4.43	0.30	1.24	3.31	2.21	2.68
February	29.5	3.23	0.07	0.84	3.11	2.26	2.49
March	52.7	2.96	-0.25	0.72	3.02	2.01	2.3
April	56.4	2.58	-0.68	0.42	2.69	1.82	2.1
May	291.9	3.07	-0.28	1.59	2.81	1.86	2.21
1983-84							
June	106.8	2.89	-0.68	1.76	NA	1.88	2.12
July	154.9	3.63*	-0.4*	2.07*	NA	2.0*	2.3*
August	329.0	4.28	-0.03	1.92	NA	2.08	2.63
September	131.6	4.7*	0.43*	2.23*	NA	2.7*	3.2*
October	188.8	5.08*	0.79*	1.89*	NA	2.8*	3.8*
November	0	5.38	1.07	1.79	NA	2.38	3.58
December	16.9	4.92*	0.82*	2.22	NA	1.6*	3.1*
January	49.6	4.0	0.5	1.67	NA	1.25	2.93
February	0	3.43*	0.12*	1.02*	NA	1.1*	2.4*
March	0	2.84*	-0.34*	1.23*	NA	1.2*	2.1*
April	56.6	2.36	-0.75	0.54	NA	1.45	1.89
May	141.0	2.9*	-0.4*	0.76*	NA	1.7*	2.0*

Table contd...

Table 3.4 (Contd..)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)					
		PT-1	PT-2	PT-3	PT-4	PT-5	PT-6
1984-85							
June	471.2	3.84	-0.13	1.92	NA	2.05	3.11
July	146.4	5.95	1.30	3.28	NA	2.4	3.6
August	201.7	6.51*	2.25*	4.25*	NA	3.1*	4.2*
September	152.4	6.91	2.53*	4.81	NA	3.98*	4.8*
October	42.5	6.62*	2.38*	3.96*	NA	4.36	5.11
November	0	6.21	2.01	2.92	NA	3.9*	4.7*
December	0	5.23	1.35	NA	NA	3.26	4.2*
January	32.4	4.42*	0.92*	NA	NA	NA	3.67
February	2.0	3.78*	0.5*	NA	NA	NA	3.24*
March	0	3.25	-0.05	NA	NA	NA	2.8*
April	22.4	2.9*	-0.23*	NA	NA	2.48	2.53
May	79.4	2.67	-0.39	1.82	NA	2.36	2.57

* Extrapolated/interpolated from the depth Vs month plots on squared paper

NA = Not available.

Table 3.5 Monthly piezometric data from four sites within the area of influence (IJKL as determined by Thiessen polygon method and shown in Fig. 3.6) for the year 1978-85 of the raingauge stationed at Santipur (Fulia) Gram Shevak Centre and also the monthly rainfall of the said Station

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)			
		PT-7	PT-8	PT-9	PT-10
1978-79					
June	162.0	2.99	NA	NA	NA
July	162.4	2.97	NA	NA	NA
August	189.0	3.09	NA	NA	NA
September	827.0	3.95	NA	NA	NA
October	66.2	5.1*	NA	NA	NA
November	0	5.66	NA	NA	NA
December	5.3	4.95	NA	NA	NA
January	31.0	4.17	NA	NA	NA
February	31.2	3.99	NA	NA	NA
March	11.0	3.85	NA	NA	NA
April	14.8	3.62	NA	2.2	0.92
May	135.2	2.52	3.41	2.0	0.65
1979-80					
June	160.0	2.7*	3.48*	2.1*	0.9*
July	426.4	3.3*	4.03*	2.6*	1.56*
August	123.0	3.8*	4.56*	3.0*	2.48*
September	237.0	5.15	5.02	3.24	3.07
October	61.2	4.2	5.15	3.63	3.54
November	4.6	3.97	6.3	3.38	2.74
December	30.4	3.8	5.2*	3.23	2.7
January	10.0	3.38	4.08	2.85	2.17
February	83.6	3.13	3.85	2.87	2.28
March	19.4	2.85	3.54*	2.51	1.85
April	10.2	2.6*	3.38*	2.16*	1.6*
May	212.6	2.53	3.4	2.19	1.42

Table contd...

Table 3.5 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)			
		PT-7	PT-8	PT-9	PT-10
1980-81					
June	216.0	2.57	3.48	2.2	1.49
July	378.4	2.9*	4.12*	2.5*	1.92*
August	281.4	3.26	4.84	2.92	2.63
September	119.4	4.26	5.84	4.06	4.6
October	93.0	4.51	5.37	4.28	4.27
November	0	4.24	5.1	4.21	4.19
December	0	4.05	4.62	3.85	2.42
January	8.0	3.79	4.37	3.59	2.92
February	111.2	3.54	4.06	3.29	2.76
March	94.4	3.28*	3.86*	2.9*	2.4*
April	207.0	3.3*	3.84	2.6*	2.3*
May	190.2	3.4	4.01	3.11	2.47
1981-82					
June	139.4	3.41	4.15	3.15	3.07
July	519.6	3.98*	4.5*	3.3*	3.6*
August	224.4	4.78	4.92	3.51	4.08
September	200.8	5.33	5.76	5.39	4.72
October	0	4.91	5.05	4.44	4.13
November	0	4.57	4.72	4.01	4.42
December	75.2	4.28	4.54	3.51	3.29
January	0	3.92	4.21	3.44	2.66
February	19.6	3.66	4.07	3.08	2.34
March	53.4	3.44	4.0	3.04	2.02
April	86.0	3.19	3.26	2.76	1.92
May	83.5	2.96	3.76	2.45	1.68

Table contd...

Table 3.5 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)			
		PT-7	PT-8	PT-9	PT-10
1882-83					
June	152.5	2.91	3.81	2.39	1.65
July	121.5	2.96	3.68	2.42	1.62
August	247.1	2.79	3.77	2.19	1.62
September	99.8	3.14	4.47	2.84	2.75
October	60.6	3.04	4.39	2.89	2.56
November	17.4	2.84	4.03	2.84	2.36
December	0	2.82	3.84	2.82	2.22
January	1.4	2.68	3.7	2.47	1.82
February	18.2	2.48	3.5	2.27	1.57
March	57.0	2.27	3.31	2.18	1.37
April	92.2	1.99	3.26	1.79	1.09
May	247.4	2.14	3.46	1.83	1.23
1983-84					
June	132.8	2.25	3.72	2.06	1.33
July	84.0	2.2*	3.9*	2.0*	1.42*
August	283.8	2.26	4.12	2.09	1.55
September	146.4	2.6*	4.6*	2.63*	2.35
October	108.2	3.0*	5.2*	3.2*	3.6
November	0	2.79	4.99	2.91	2.82
December	16.0	2.72*	4.6*	2.7*	2.48*
January	39.2	2.62	4.21	2.63	2.22
February	0	2.1*	3.7*	2.2*	1.7*
March	0	1.9*	3.4*	1.8*	1.0*
April	110.4	1.89	3.5	1.64	0.29
May	136.6	2.0*	3.6*	1.8*	1.2*

Table contd...

Table 3.5 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sealevel(m)			
		PT-7	PT-8	PT-9	PT-10
1984-85					
June	502.2	2.26	4.06	2.1	2.47
July	360.2	2.7	5.17	3.12	2.37
August	361.6	3.5*	5.96*	4.3*	NA
September	158.0	5.0*	7.02	5.71	NA
October	64.4	5.14	6.06	4.67*	NA
November	0	4.8*	5.3*	3.93	NA
December	0	4.4*	4.87*	3.79	NA
January	14.6	4.04	4.69	3.3*	2.02
February	6.4	3.36*	4.4*	2.9*	NA
March	0	3.12	4.07	2.56	0.28
April	20.6	2.9*	3.62	2.29	0.42
May	113.8	2.74	3.89	2.4	0.42

* Extrapolated/interpolated from the depth Vs month plots on squared paper

NA = Not available.

Table 3.6 Monthly rainfall of Krishnagar Horticultural Farm for the year 1978-85 and the monthly piezometric data from nine sites within the area of influence of the said station (determined by Thiessen ploygon method, GFHLJ from Fig. 3.6)

Month	Rainfall (mm)	Water table depth with reference to mean sea level (m)									
		PI-11	PI-12	PI-13	PI-14	PI-15	PI-16	PI-17	PI-18	PI-19	
1978-'79											
June	180.6	3.23	4.92	5.254	NA	5.624	NA	NA	NA	4.94	
July	259.8	3.62	4.77	5.854	NA	5.884	NA	NA	NA	5.34	
August	219.2	5.13	5.06	6.824	NA	7.084	NA	NA	NA	6.69	
September	786.6	6.81	5.80	7.704	NA	7.524	NA	NA	NA	8.02	
October	64.5	7.1 *	7.2 *	8.1 *	NA	8.1 *	NA	NA	NA	8.5 *	
November	0	6.97	7.87	8.324	NA	8.374	NA	NA	NA	7.7	
December	0	4.67	7.24	7.314	NA	7.514	NA	NA	NA	6.53	
January	37.8	4.88	6.74	6.174	NA	6.574	NA	NA	NA	5.28	
February	44.2	4.39	6.29	5.794	NA	6.564	NA	NA	NA	5.98	
March	0	2.99	5.85	5.534	NA	6.184	5.35	NA	NA	5.16	
April	3.8	2.72	5.46	5.294	7.38	5.724	4.76	NA	NA	4.86	
May	68.0	2.0	5.1 *	4.774	NA	5.154	4.42 *	NA	NA	4.7 *	
1979-'80											
June	207.5	1.8 *	4.8 *	5.0 *	NA	5.3 *	5.03 *	NA	NA	5.0 *	
July	322.9	2.02 *	5.1 *	5.7 *	NA	5.9 *	6.0 *	NA	NA	5.4 *	
August	269.8	2.25 *	5.7 *	6.9 *	NA	6.3 *	6.7 *	NA	NA	6.0 *	
September	126.3	2.4	6.14	7.704	6.42	6.734	7.31	8.38	NA	7.12	
October	128.8	4.9	6.59	6.964	6.62	7.314	7.6	8.57	NA	7.09	
November	35.0	3.91	6.50	6.194	6.86	6.574	7.0	7.85	NA	6.22	
December	2.5	3.34	6.33	5.874	NA	6.324	6.5 *	7.41	NA	5.71	
January	7.6	3.92	5.83	5.484	5.87	5.714	6.1 *	6.72	7.41	5.1 *	
February	59.9	2.85	5.46	4.774	5.3	5.334	5.67	6.45	6.75	4.7 *	
March	55.1	2.43	5.12	4.344	5.07	4.984	5.06	6.14	6.62	4.36	
April	20.3	2.24 *	4.8 *	4.2 *	NA	4.8 *	4.85	NA	NA	4.2 *	
May	186.5	2.21	4.68	4.064	4.14	4.674	4.71	5.66	NA	3.99	

Table contd....

Table 3.6 (contd.)

Month	Rainfall (mm)	Water table depth with reference to mean sea level (m)									
		PT-11	PT-12	PT-13	PT-14	PT-15	PT-16	PT-17	PT-18	PT-19	
1980-'81											
June	380.8	2.92	4.51	4.544	5.164	5.014	5.92	6.01	6.15*	4.11	
July	334.3	3.7*	4.8*	5.4*	6.5*	5.6*	6.4*	6.5*	6.6*	4.8*	
August	326.1	4.6	5.40	6.584	7.684	6.314	6.94	6.97	7.4	5.59	
September	77.5	6.48	6.03	7.784	8.294	7.644	8.39	8.76	9.04	7.15	
October	83.1	6.0	6.53	7.344	7.784	7.414	8.23	10.16	8.75	8.14	
November	0	5.44	6.75	6.994	7.714	7.364	7.54	8.19	7.9	7.67	
December	0	3.48	6.53	6.344	6.844	6.654	7.29	8.0	7.31	6.55	
January	18.8	3.66	6.23	5.824	6.194	6.184	6.8	7.36	7.48	5.89	
February	76.2	3.4	5.90	5.554	5.844	5.964	6.26	6.95	7.19	5.48	
March	47.5	3.0*	5.3*	5.3*	5.2*	5.5*	5.7*	6.5*	6.8*	5.24*	
April	131.8	2.82*	5.1*	5.0*	5.0*	5.2*	5.5*	6.2*	6.84	4.96*	
May	260.9	3.41	5.15	4.964	5.364	5.364	5.94	6.32	6.31	4.76	
1981-'82											
June	53.3	4.13	4.99	5.394	5.564	5.764	6.55	6.90	6.65	4.99	
July	266.4	4.6*	5.12*	5.9*	6.1*	6.1*	7.1*	7.4*	7.4*	5.42*	
August	234.9	5.23	5.31	6.214	6.664	6.934	7.66	7.99	8.22	6.03	
September	222.2	6.35	5.73	7.594	7.914	8.114	8.59	9.08	10.44	7.74	
October	0	4.95	6.08	6.514	6.554	7.194	7.69	8.47	10.34	7.26	
November	0	4.20	5.93	6.164	6.514	6.844	7.09	7.67	8.56	6.29	
December	85.9	4.30	5.85	5.864	6.264	6.514	7.05	7.28	8.01	5.92	
January	5.0	3.08	5.53	5.544	5.824	6.194	6.19	6.88	7.16	5.39	
February	15.5	3.01	5.25	5.134	5.454	5.644	5.54	6.62	6.99	5.09	
March	111.3	2.87	5.18	5.094	5.444	5.564	5.39	6.39	6.80	4.89	
April	105.9	2.13	4.93	4.914	5.224	5.104	5.29	NA	6.66	4.62	
May	45.2	2.9	4.61	4.982	5.394	5.124	5.40	NA	7.01	4.44	

43

Table contd....

Table 3.6 (contd...)

Month	Rainfall (mm)	Water table depth with reference to mean sea level (m)									
		PT-11	PT-12	PT-13	PT-14	PT-15	PT-16	PT-17	PT-18	PT-19	
1982-'83											
June	115.8	2.78	4.52	5.114	5.524	5.104	5.19	NA	7.42	4.86	
July	66.8	2.60	4.45	5.114	5.484	4.944	5.13	NA	8.1*	4.56	
August	283.9	2.50	4.40	5.364	6.264	5.024	5.05	NA	9.3*	4.78	
September	106.9	5.25	4.59	6.514	6.854	5.984	6.87	NA	10.46	5.91	
October	28.5	4.06	4.76	6.004	6.534	5.664	6.47	NA	8.91	6.24	
November	28.0	3.45	4.75	5.584	6.264	5.464	6.09	NA	7.96	5.56	
December	0	2.95	4.75	5.414	5.944	5.304	5.99	NA	7.51	5.17	
January	0	2.71	4.58	5.174	5.564	5.034	5.36	NA	6.84	4.95	
February	43.4	2.4	4.43	4.884	5.304	4.704	4.96	NA	6.66	4.59	
March	96.5	2.34	4.28	4.834	5.244	4.684	4.86	NA	6.43	4.61	
April	68.2	2.13	4.03	4.094	4.684	4.554	4.51	NA	6.30	3.99	
May	339.5	2.52	4.18	4.604	4.844	4.714	4.84	NA	6.66	4.04	
1983-'84											
June	57.5	2.70	4.53	4.964	5.604	4.844	5.01	NA	6.56	4.28	
July	173.0	3.2*	4.9*	5.8*	6.4*	5.3*	5.5*	NA	5.61	4.84*	
August	335.8	3.53	5.38	6.394	6.954	5.924	5.89	NA	5.50	6.10	
September	83.5	4.3*	6.2*	6.8*	7.4*	6.3*	6.6*	NA	6.23	6.6*	
October	169.9	5.2*	6.8*	6.6*	7.6*	6.8*	7.8*	NA	8.05	7.6*	
November	0	4.67	6.51	6.434	7.064	6.714	7.57	NA	7.40	7.76	
December	13.0	3.4	6.38*	6.1*	6.82*	6.2*	6.9*	NA	7.16	7.3*	
January	2.5	4.28	6.18	5.764	6.494	5.884	6.37	NA	7.34	6.7	
February	0	3.6*	5.7*	5.4*	6.1*	5.4*	5.6*	NA	6.7*	6.2*	
March	0	2.7*	5.4*	4.9*	5.7*	4.9*	5.0*	NA	6.5*	5.6*	
April	83.5	2.3	5.03	4.734	5.114	4.744	4.39	NA	6.52	5.31	
May	138.8	3.4*	5.35*	4.4*	5.9*	5.1*	5.1*	NA	6.36	5.3*	

Table contd.....

Table 3.6 (contd...)

Month	Rainfall (mm)	Water table depth with reference to mean sea level (m)									
		PT-11	PT-12	PT-13	PT-14	PT-15	PT-16	PT-17	PT-18	PT-19	
1984-'85											
June	486.7	4.22	6.03	5.374	7.184	5.684	6.63	NA	6.49	5.46	
July	318.6	5.03	5.61	6.654	6.8*	6.334	7.69	NA	6.8*	6.53	
August	349.4	5.5*	6.0*	7.6*	6.7*	7.1*	8.4*	NA	7.03	7.5*	
September	219.7	6.05*	6.7*	8.344	6.9*	9.194	9.01	NA	7.8*	9.53	
October	65.1	5.62	7.3*	7.124	7.214	8.434	8.2	NA	8.71*	8.6*	
November	0	5.0*	7.69	6.54*	6.8*	7.6*	7.8*	NA	8.65	7.65	
December	0	3.9*	7.1*	6.1*	6.3*	7.2*	7.5*	NA	8.0*	6.71	
January	0	3.27	6.66	6.024	5.914	6.854	6.52	7.55	7.54	NA	
February	9.3	2.87*	6.2*	5.5*	5.6*	5.9*	5.8*	NA	7.1*	NA	
March	11.2	2.42*	5.8*	4.754	5.124	5.164	5.23	6.1	6.71	NA	
April	3.8	2.1	5.45	4.6*	4.9*	5.03*	4.53	6.1	6.21	5.35	
May	83.3	2.35	4.88	4.44	4.794	4.944	4.82	6.0	6.16*	4.85	

* Extrapolated/interpolated from the depth Vs month plots on squared paper

NA = not available.

Table 3.7 Monthly rainfall of Block Development Office, Kaliganj for the year 1978-85 and the monthly piezometric data from five sites within the area of influence of the said station (determined by Thiessen polygon method, EFG from Fig. 3.6)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-21	PT-22	PT-23	PT-24	PT-24
1978-79						
June	230.1	NA	9.68	8.37	NA	NA
July	167.2	NA	9.87	10.09	NA	NA
August	258.6	NA	10.9	10.50	NA	NA
September	552.5	NA	11.81	11.84	NA	NA
October	124.7	NA	11.9*	11.9*	NA	NA
November	5.4	NA	11.76	11.64	NA	NA
December	0	NA	11.23	10.98	NA	NA
January	13.2	NA	10.84	10.34	NA	NA
February	46.9	NA	10.59	10.06	NA	NA
March	10.2	NA	10.2	9.56	NA	NA
April	10.0	NA	9.86	9.12	10.17	7.92
May	35.2	NA	9.2*	8.9*	NA	NA
1979-80						
June	254.8	NA	8.7*	8.5*	9.7*	7.8*
July	262.7	NA	8.98*	9.3*	10.23*	8.2*
August	212.6	NA	9.8*	10.2*	11.0*	8.9*
September	202.6	6.51	11.5	10.99	12.078	9.545
October	43.4	7.59	11.53	11.04	12.528	10.945
November	29.8	5.76	10.94	10.28	12.088	10.205
December	20.0	5.76	10.71	10.30	11.978	9.915
January	28.2	5.22	10.15	9.48	11.508	9.265
February	1.8	4.96	9.83	9.15	11.148	8.945
March	67.8	4.8	9.62	9.07	10.858	8.775
April	17.2	NA	9.5*	8.7*	10.5*	8.3*
May	110.6	4.51	9.77	8.56	10.39	8.015

Table contd...

Table 3.7 (Contd....)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-21	PT-22	PT-23	PT-24	PT-25
1980- 81						
June	350.6	4.55	9.11	8.57	10.378	8.205
July	407.4	4.9*	9.9*	9.9*	11.2*	9.0*
August	384.4	6.51	10.9	11.60	12.82	11.065
September	245.7	7.52	11.89	12.56	13.348	11.915
October	162.0	7.4	11.49	12.17	12.948	11.315
November	0	6.72	11.65	12.07	12.928	10.975
December	0	6.32	11.11	11.22	12.388	10.335
January	20.8	5.8*	10.68	10.66	12.028	9.895
February	98.8	5.47	9.42	10.23	11.778	9.835
March	65.0	5.2*	9.2*	9.6*	11.6*	9.5*
April	194.0	5.0*	9.18*	9.7*	11.4*	9.54*
May	119.4	5.4	10.32	10.76	12.058	10.045
1981- 82						
June	97.4	5.4	10.82	10.60	11.96	10.685
July	350.8	5.5	11.2*	10.65	12.3*	10.7*
August	118.2	5.73	11.15	10.94	12.26	10.405
September	381.8	6.02	11.67	12.31	12.78	11.265
October	0	6.38	11.43	11.61	12.37	10.568
November	0	5.9	10.84	10.91	11.83	9.915
December	61.4	5.7	10.67	10.73	11.83	10.035
January	2.8	5.46	10.29	10.04	11.46	9.345
February	4.2	5.37	9.95	9.78	11.26	8.965
March	64.8	5.18	9.89	9.69	11.11	8.635
April	32.2	5.05	9.66	9.31	10.85	8.685
May	33.0	4.8	9.44	8.93	10.46	8.215

Table contd.....

Table 3.7 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-21	PT-22	PT-23	PT-24	PT-25
1992-83						
June	157.8	4.81	9.3	8.87	10.42	8.125
July	159.4	4.96	9.35	8.99	10.76	8.455
August	285.6	4.88	9.81	8.98	11.75	8.435
September	84.8	5.0	10.04	10.24	11.35	10.765
October	1.6	5.5	9.68	9.57	11.07	10.445
November	44.8	5.31	9.39	9.06	10.68	9.645
December	19.4	5.1	9.29	8.97	NA	9.515
January	3.6	4.99	9.06	8.69	NA	8.995
February	31.6	4.87	8.97	8.39	NA	8.695
March	49.8	4.76	8.81	8.3	NA	8.505
April	19.2	4.47	8.53	7.86	NA	7.855
May	210.2	4.62	8.59	8.16	NA	8.295
1983-84						
June	167.8	4.93	8.8	8.46	NA	8.765
July	196.0	5.5*	9.0*	8.9*	NA	9.7*
August	374.2	6.14	9.12	10.14	NA	10.995
September	111.0	6.56*	9.4*	10.54*	NA	10.9*
October	289.6	6.5*	9.6*	10.7*	NA	10.8*
November	0	6.14	9.84	10.43	NA	10.495
December	0	5.9*	9.53*	10.0*	NA	10.0*
January	4.9	5.6	9.11	9.80*	NA	9.755
February	1.2	5.1*	8.2*	9.94*	NA	9.0*
March	3.0	4.53*	7.8*	8.9*	NA	8.6*
April	23.6	3.89	7.49	8.46	10.32	8.275
May	96.4	3.66	7.45*	8.2*	NA	8.1*

Table contd...

Table 3.7 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-21	PT-22	PT-23	PT-24	PT-25
1984-85						
June	404.9	NA	8.61	9.08	10.828	8.795
July	508.9	NA	9.03	9.72	11.778	10.465
August	358.7	NA	10.6*	10.9*	12.4*	11.05*
September	224.5	NA	11.99	12.01	12.838	11.615
October	83.0	NA	11.65*	11.5*	12.54*	11.4*
November	0	NA	11.41	10.87	12.208	10.385
December	0	NA	10.9*	10.4*	11.7*	9.7*
January	10.0	5.53	10.61	9.96	11.558	9.265
February	10.3	NA	10.3*	9.54*	11.2*	8.7*
March	3.8	NA	9.9*	9.1*	10.9*	8.4*
April	3.0	4.93	9.58	8.72	10.498	8.095
May	106.3	4.63	9.14	8.22	10.04	7.445

* Extrapolated/interpolated from the depth Vs
month plots on square paper

NA = Not available.

Table 3.8 Monthly piezometric data from five sites within the area of influence (BCEFG as determined by Thiessen polygon method and shown in Fig. 3.6) for the year 1978-85 of the raingauge stationed at Block Seed Farm, Tehatta and also the monthly rainfall of the said station

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-20	PT-26	PT-27	PT-28	PT-29
1978-78						
June	264.0	NA	6.2	2.46	NA	NA
July	124.0	NA	7.64	4.33	NA	NA
August	234.0	NA	10.31	6.47	NA	NA
September	438.5	NA	11.74	7.57	NA	NA
October	144.5	NA	10.2*	6.5	NA	NA
November	1.5	NA	9.01	5.0	NA	NA
December	0	NA	7.12	3.67	NA	NA
January	1	NA	6.59	3.13	NA	NA
February	43.0	NA	6.52	2.9	NA	NA
March	0	NA	5.32	2.64	NA	NA
April	35.7	NA	6.15	2.37	NA	7.79
May	31.5	3.36	5.9*	2.32	3.0	NA
1979-80						
June	231.6	2.9*	6.1*	2.2	2.9*	7.78*
July	337.5	3.5*	7.1*	2.65	3.9*	8.9*
August	232.0	4.9*	8.7*	3.7	5.5*	9.5*
September	216.0	5.93	9.78	6.2	6.37	10.52
October	50.0	6.69	7.03	5.2	6.13	10.45
November	30.5	5.73	7.43	4.75	5.23	9.93
December	14.5	5.39	6.69	3.25	4.5	9.51
January	17.0	4.37	6.4*	2.74	3.81	8.98
February	18.7	4.02	6.07	2.5	3.64	8.69
March	41.5	4.02	5.99	2.36	3.47	8.4
April	7.5	3.6*	5.8*	2.1	3.2*	8.24*
May	180.5	3.5	5.72	2.08	3.02	8.82

Table contd...

Table 3.8 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-20	PT-26	PT-27	PT-28	PT-29
1980-81						
June	304.5	4.07	5.84	2.19	4.28	NA
July	305.5	NA	7.7*	3.9*	5.0*	NA
August	332.0	7.58	10.24	6.38	5.97	NA
September	82.5	8.13	11.83	7.46	7.98	NA
October	68.7	7.76	11.69	6.9*	7.73	NA
November	0.6	NA	9.86	6.26	7.05	NA
December	0	NA	7.51	3.97	5.48	NA
January	22.0	NA	6.76	3.6	4.71	NA
February	85.0	NA	6.53	2.88	4.27	NA
March	62.5	NA	6.3*	2.5*	4.0*	NA
April	152.5	NA	6.35*	2.3*	3.9*	NA
May	228.0	NA	6.76	3.02	3.9	NA
1981-82						
June	182.6	NA	8.91	3.66	4.65	NA
July	317.0	NA	9.5	4.1*	5.4*	NA
August	326.4	NA	10.0	4.77	6.6	NA
September	220.0	NA	11.36	7.17	7.8	NA
October	0	NA	9.19	5.73	6.62	NA
November	0	NA	7.11	3.93	5.2	NA
December	0	NA	6.73	3.4	5.03	NA
January	1	NA	6.26	2.85	4.1	NA
February	5.5	NA	6.18	2.63	3.7	NA
March	77.6	NA	6.18	2.56	3.62	NA
April	86.3	4.1	6.05	2.37	4.5	10.45
May	163.8	4.05	5.89	2.19	3.27	10.45

Table contd...

Table 3.8 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-20	PT-26	Pt-27	Pt-28	PT-29
1982-83						
June	199.4	3.99	5.86	2.18	3.22	10.47
July	59.9	4.05	7.02	2.42	3.02	10.88
August	169.2	4.0	7.01	2.41	2.9	10.82
September	122.9	6.52	10.41	6.44	5.73	11.16
October	19.2	6.4	9.27	5.62	6.25	11.22
November	37.4	5.15	7.06	3.65	4.95	10.72
December	0	5.0	6.56	3.08	4.34	10.56
January	4	4.27	6.29	2.63	3.93	10.15
February	28.2	3.96	6.11	2.34	3.56	10.0
March	49.8	3.85	5.99	2.23	3.44	9.93
April	54.4	3.33	5.73	2.0	3.17	9.64
May	336.4	3.5	6.47	2.08	3.28	9.73
1983-84						
June	114.8	4.74	5.82	2.28	2.96	10.64
July	159.0	5.7*	7.0*	3.1*	3.5*	10.8*
August	333.3	6.85	8.59	5.37	4.38	10.93
September	109.7	6.68*	9.5*	5.5*	4.87*	11.2*
October	179.1	6.6*	10.2*	5.4*	5.4*	11.5*
November	0	6.53	9.39	4.97	5.88	11.43
December	17.3	5.7*	8.4*	4.0*	5.1*	10.93*
January	4	5.11	6.56	3.05	4.33	10.75
February	3	4.6*	6.2*	2.6*	3.9*	10.3*
March	0	4.0*	6.02*	2.3*	3.6*	9.92*
April	23.6	3.63	5.89	2.12	3.3	9.66
May	114.8	3.92	5.7*	2.5*	3.32*	9.5*

Table contd...

Table 3.8 (Contd...)

Month	Rainfall (mm)	Water table depth with respect to mean sea level(m)				
		PT-20	PT-26	PT-27	PT-28	Pt-29
1984-85						
June	405.2	5.58	5.96	2.84	3.37	10.48
July	304.3	6.44	7.03	4.09	3.77	10.8*
August	417.0	7.2*	8.0	6.02*	5.0*	11.1*
September	324.8	7.91	9.3*	7.47	7.83	11.4*
October	126.0	6.8*	9.2*	7.1*	6.5*	11.7*
November	0	6.25	7.86	4.65	5.8	12.01
December	0	5.0	7.6*	3.15	4.27	11.03
January	0.4	4.6*	7.23	2.84*	4.06*	10.52*
February	0	4.15*	6.8*	2.7*	3.8*	10.2*
March	0	3.94*	6.4*	2.4*	3.54*	10.04*
April	99.5	3.7	6.07	2.22	3.41	9.85
May	178.6	3.61	5.81	2.07	3.11	9.71

* Extrapolated/interpolated from the depth versus month plots on squared paper

NA = Not available

Table 3.9 Monthly Rainfall data of Block Seed Farm, Karimpur for the year 1978-85 and the monthly piezometric data from three sites within the area of influence of the said station (determined by Thiessen polygon method, ABCD from Fig. 3.6)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)		
		PT-30	PT-31	PT-32
1978-79				
June	245.2	NA	NA	7.804
July	200.6	NA	NA	8.044
August	294.4	NA	NA	9.894
September	374.8	NA	NA	11.404
October	120.8	NA	NA	12.3*
November	1.0	NA	NA	12.224
December	0	NA	NA	10.154
January	12.6	NA	NA	9.414
February	39.8	NA	NA	8.164
March	5.8	NA	NA	7.864
April	50.6	7.39	12.0	7.804
May	7.8	NA	NA	7.4*
1979-80				
June	227.8	6.95*	11.6*	6.9*
July	285.2	7.8*	12.0*	7.0*
August	338.5	8.70*	12.84*	7.7*
September	282.6	9.72	14.259	8.554
October	67.2	9.79	14.299	8.734
November	31.6	9.20	13.669	8.004
December	1.0	8.84	13.379	7.894
January	24.8	8.40	12.929	7.854
February	3.0	8.14	12.87	7.774
March	57.0	7.91	12.689	7.644
April	1.6	7.6*	12.3*	7.4*
May	205.4	7.59	12.229	7.374

Table contd...

Table 3.9 (Contd...)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)		
		PT-30	PT-31	PT-32
1980-81				
June	294.4	8.44	12.609	7.814
July	133.2	8.8*	13.0*	8.0*
August	289.4	9.2	13.629	9.734
September	222.2	9.6	15.559	12.664
October	171.4	9.81	14.8	9.934
November	0	9.66	14.329	9.094
December	110.1	8.93	13.409	8.444
January	28.8	8.68	13.15	8.174
February	111.6	8.49	13.219	8.174
March	71.8	8.3*	13.0*	7.9*
April	148.4	8.6*	12.96	7.7*
May	230.4	9.03	13.18	8.114
1981-82				
June	257.8	9.18	13.369	8.444
July	369.7	9.52*	13.7*	9.4*
August	304.8	10.13	14.139	10.344
September	240.1	10.63	15.029	11.044
October	0	9.57	13.999	8.844
November	0	8.95	13.29	8.294
December	0	9.02	13.429	8.014
January	0	8.49	12.629	7.794
February	10.5	8.3	12.89	7.784
March	133.5	8.22	12.89	7.694
April	63.4	8.07	12.749	7.644
May	109.6	8.03	12.709	7.444

Table contd...

Table 3.9 (Contd...)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)		
		PT-30	PT-31	PT-32
1982-83				
June	129.7	8.03	12.55	6.894
July	164.1	8.74	12.98	7.464
August	236.4	8.53	12.94	7.534
September	30.2	8.9*	14.53	10.954
October	0	9.20	13.699	9.814
November	102.3	9.15	12.98	7.994
December	0.4	8.55	12.979	7.784
January	12.0	8.20	12.76	7.694
February	25.9	7.92	12.56	7.654
March	10.5	7.56	12.48	7.544
April	48.2	7.38	12.26	7.544
May	326.4	7.55	12.30	7.714
1983-84				
June	61.3	8.03	12.25	7.404
July	162.5	8.58*	12.6*	8.05*
August	318.0	9.08	13.17	8.674
September	207.6	9.2*	14.3*	9.7*
October	197.2	9.2*	14.1*	10.3*
November	0	9.06	13.49	8.514
December	15.5	8.7*	13.16*	8.15*
January	0	8.36	12.79	7.844
February	0	8.1*	12.6*	7.7*
March	0	7.6*	12.3*	7.65*
April	8.2	7.46*	12.13	7.524
May	201.4	7.3*	12.0*	7.4*

Table contd...

Table 3.9 (Contd...)

Month	Rainfall (mm)	Water table depth with reference to mean sea level(m)		
		PT-30	PT-31	PT-32
1984-85				
June	372.6	8.59	12.59	7.454
July	373.0	NA	13.409	7.714
August	407.8	NA	13.2*	8.2*
September	239.0	NA	15.369	8.9*
October	9.4	NA	13.409	9.81*
November	0	9.07	13.41	8.514
December	0	8.30	12.86	7.174
January	0	NA	12.5*	6.9*
February	9.0	NA	12.3*	9.7*
March	5.6	NA	12.2*	6.4*
April	37.2	7.46	12.309	7.624
May	117.8	7.44	12.109	7.9*

* Extrapolated/interpolated from the depth versus month plots on squared paper

NA = Not available.

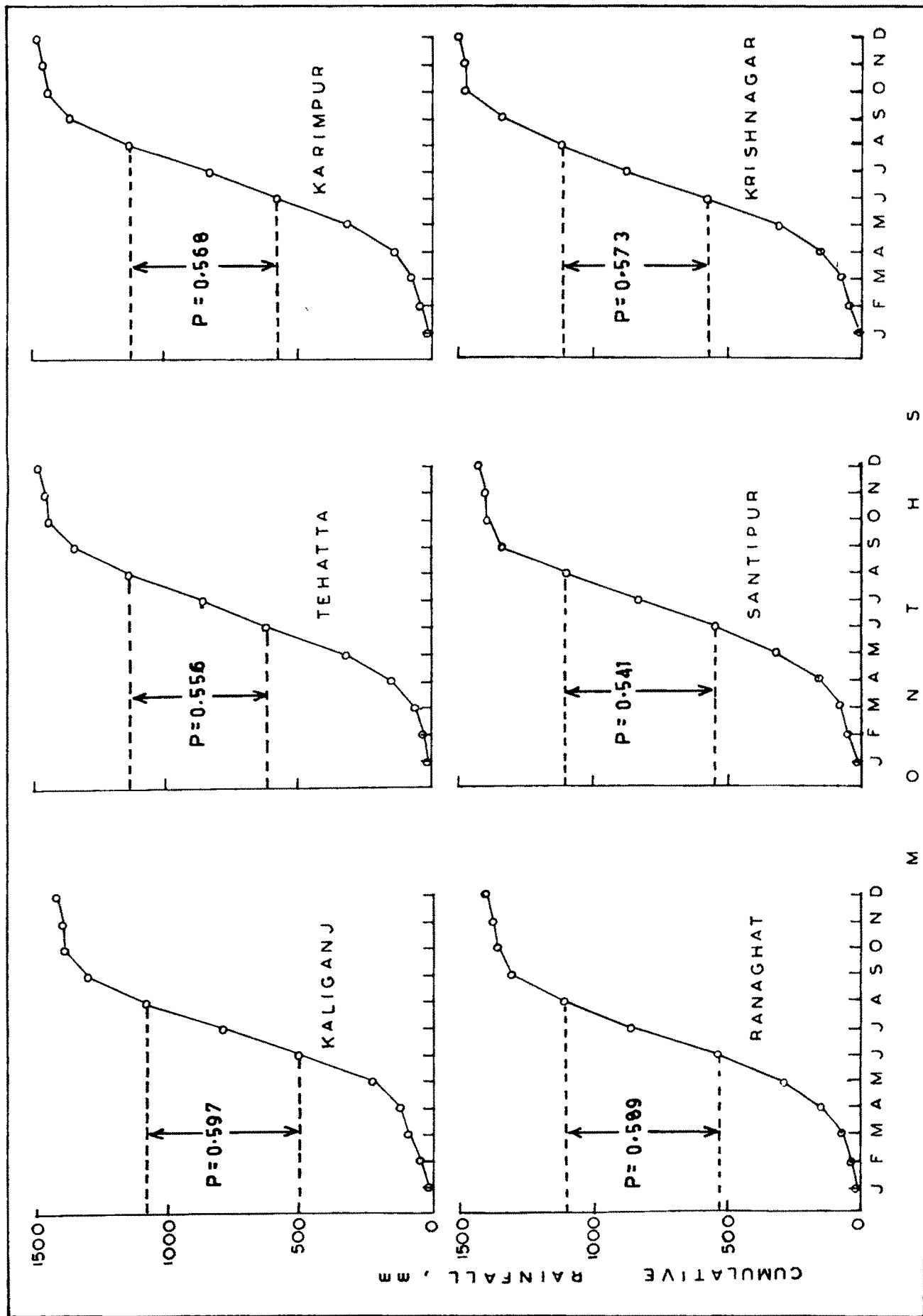


FIG 37 MONTHLY AVERAGE CUMULATIVE RAINFALL FOR THE PERIOD OF 1976 - 85 AT SIX RAIN GAUGE

STATIONS IN NADIA DISTRICT. $P = (\text{Rainfall in June} + \text{July} + \text{August}) / \text{Annual Rainfall}$

Table 3.10 Annual rainfall (mm) for the period 1976 to 1985 at six raingauge station in Nadia District

Year	Ranaghat Water Mana- gement Research Centre	Santipur (Fulia) Gram Sevak Centre	Krishnagar Horticultural Farm	Kaliganj Block Deve- lopment Office	Tehatta Block Seed Farm	Karimpur Block Seed Farm	Average
1976	-	1467.0	-	1096.9	-	1357.1	1307.00
1977	1729.1	1655.5	2020.8	2012.7	2023.3	1901.1	1890.41
1978	1475.2	1627.3	1766.8	1573.1	1525.2	1554.3	1586.98
1979	1223.4	1265.8	1246.6	1141.4	1223.3	1350.5	1241.83
1980	1490.8	1424.0	1531.2	1776.1	1359.0	1512.5	1515.60
1981	1993.2	1770.2	1487.9	1507.6	1596.0	1763.4	1686.38
1982	999.5	941.4	912.8	890.4	942.2	980.1	944.40
1983	1362.7	1187.4	1380.3	1453.0	1386.0	1385.4	1359.13
1984	1261.4	1732.6	1664.3	1708.6	1722.7	1510.6	1600.03
1985	1107.6	1262.6	1574.4	1045.3	-	-	1247.47
Average	1404.76	1433.38	1509.45	1420.91	1472.21	1479.44	1453.29

The annual rainfall (Table 3.10) were used to study the significant lag period, i.e., renewal period of six rainguage stations with the help of auto-regression and auto -correlation methods. The auto-correlation was a special case of correlation in which the relationship was studied not between two or more different variables, but between the successive values of the same variable. The formula used for calculation of auto-correlation coefficient (r) of different orders is given below:

$$r = \frac{N \sum R_t R_{t-n} - \sum R_t \sum R_{t-n}}{\sqrt{[N \sum R_t^2 - (\sum R_t)^2] [N \sum R_{t-n}^2 - (\sum R_{t-n})^2]}} \dots\dots\dots(3.1)$$

Where, R_t = total annual rainfall of t th year (mm)

n = rank of the year

N = number of observation year

The generalised form of auto-regression equation is

$$R_t = A + B R_{t-n} \dots\dots\dots(3.2)$$

Where A and B are empirical constants.

If n = 1, then it is the first order auto-regressive process

n = 2, then it is the second order auto-regressive process

n = n, then it is the n th order auto-regressive process.

The water table depth data sets were processed graphically (not shown here). Afterwards, they were processed in a mini computer (FX 750 P Casio) following the least squares method and two parametric polynomial equations were established. They were then tested statistically.

RESULTS

4. RESULTS

4.1 General

The data obtained from the study area (Nadia district) were analysed to find out the nature of significant lag period (i.e., return period) of annual rainfall and to develop some predictive models which are presented and discussed in this chapter along with their results.

4.2 Study of recurrence interval of annual rainfall

The annual rainfall data of different locations of Nadia district were analysed by which an approximate time interval of the occurrence of nearly the same amount of annual rainfall could be achieved. The data (Table 3.10) on sequence of annual rainfall were analysed by the method of auto-regression and auto-correlation (vide Eqs 3.1 and 3.2).

Based on the values of auto-correlation coefficient of different orders, a particular auto-correlation coefficient which was found to be most significant for all the six rain-gauge stations was chosen. The auto-regression equation of different orders for different rain-gauge stations and their respective correlation coefficient values were presented in the Table 4.1.

4.3 Prediction of monthly variation in water table depths with reference to rainfall and time

Several attempts were made to examine the feasibility of any workable relation between daily or monthly rainfall versus depth of ground water in various permutations and combinations. Groups of dependent and independent variables were made in various combinations and tried for a functional relation. Out of those attempts, the following model seemed to be a reasonably acceptable one.

$$\frac{D}{R_c} = A + B_1 t_1 + B_2 t_1^2 + B_3 t_1^3 + B_4 t_1^4 + B_5 t_1^5 \quad \dots\dots(4.1)$$

Table 4.1 The auto-regression equation of different order for different raingauge station and their correlation coefficient

Raingauge station	Equation*	Correlation (r)
Karimpur	$R_2 = 1818.780 - 0.2196 R_1$	-0.223
	$R_3 = 1856.190 - 0.2820 R_1$	-0.352
	$R_4 = 410.415 + 0.6399 R_1$	0.547
	$R_5 = 626.005 + 0.5240 R_1$	0.409
Tehatta	$R_2 = 1459.470 - 0.0460 R_1$	-0.059
	$R_3 = 1959.650 - 0.4070 R_1$	-0.541
	$R_4 = 804.334 + 0.3862 R_1$	0.395
	$R_5 = 1211.613 + 0.1305 R_1$	0.133
Kaliganj	$R_2 = 2001.610 - 0.3728 R_1$	-0.366
	$R_3 = 2171.126 - 0.5478 R_1$	-0.631
	$R_4 = 329.451 + 0.7217 R_1$	0.855
	$R_5 = 1564.163 - 0.1102 R_1$	-0.109
Krishnagar	$R_2 = 1517.015 - 0.0242 R_1$	-0.025
	$R_3 = 1899.583 - 0.3382 R_1$	-0.475
	$R_4 = 1206.925 + 0.1460 R_1$	0.211
	$R_5 = 1753.750 - 0.2171 R_1$	-0.217
Santipur	$R_2 = 1628.619 - 0.1722 R_1$	-0.171
	$R_3 = 2140.605 - 0.5215 R_1$	-0.493
	$R_4 = 335.894 + 0.7125 R_1$	0.668
	$R_5 = 1490.278 - 0.0677 R_1$	-0.038
Ranaghat	$R_2 = 1612.293 - 0.1720 R_1$	-0.174
	$R_3 = 1634.195 - 0.1947 R_1$	-0.194
	$R_4 = 909.726 + 0.3094 R_1$	0.309
	$R_5 = 1177.293 + 0.1059 R_1$	0.079

* Eq (3.2)

Where, D = depth of ground water table with respect to mean sea level(m)

R_c = monthly cumulative rainfall, starting from June and ending in the month of May in the next year (m)

t = concerned month, values are June=1, July=2, ..., May=12
 $i = 1$ to 12

A, B_1 to B_5 are empirical constants. Those constants were evaluated with the help of least squares method.

The data on depth of ground water table for all the twelve months were not available as the depth of water table in some months were not recorded which were, in turn, generated following the graphical method and were considered along with the observed data sets.

As the reference levels of all piezometric sites were not uniform (Table 4.2) the observed water table values were converted with respect to mean sea level (MSL) to obtain the reduced levels of water table.

The area of influence of each raingauge was determined following Thiessen polygon method. Data from each piezometer were processed considering the rainfall data from the same Thiessen polygon. The influencing area of six raingauge stations are depicted in Table 4.3.

The water table depths of each month of each piezometric site were evaluated using the Eq (4.1). The relationship was compared by using the following statistical formula

$$r^2 = \frac{\sum (D_{obs} - D_{est})^2}{\sum D_{obs}^2} \quad \dots (4.2)$$

Where, $S_T = \sum D_{obs}^2 - \frac{(\sum D_{obs})^2}{N}$

$$S_E = \sum (D_{obs} - D_{est})^2$$

and, D_{obs} = observed water table depths (m)

D_{est} = estimated water table depths (m).

After determining the coefficient of determination (r^2) of each piezometric site for different years (1978-85), the value $r^2 < 0.30$ were considered in the Tables 4.4 to 4.10. The values of constant terms A, B_1 to B_5 of the Eq (4.1) along with the coefficient of determination (r^2) values

Table 4.2 Elevations of thirty two piezometric points on the ground surface with reference to mean sea level

Piezo- tube No.	Block	Location of Piezometer	Reduced level, m
PT-1	Haringhata	Jaguli Health Centre	8.835
PT-2	Haringhata	Singa Nagarukra H.C.	5.045
PT-3	Chakdah	Block Office at Chakdah	8.917
PT-4	Ranaghat -I	Block Office at Habibpur	8.540
PT-5	Ranaghat-II	Block Office at Nokari	5.956
PT-6	Ranaghat-II	Aranghata Primary H.C.	8.091
PT-7	Santipur	Block Office at Fulia	7.640
PT-8	Santipur	Bagachra Health Centre	8.700
PT-9	Hanskhali	Badkulla Health Centre	7.443
PT-10	Hanskhali	Bagula Primary H.C.	5.775
PT-11	Hanskhali	Block Office	7.985
PT-12	Krishnagar-II	Dhubulia Health Centre	9.459
PT-13	Nabadwip	Mahesgunj Health Centre	8.994
PT-14	Nabadwip	Mayapur Health Centre	8.844
PT-15	Krishnagar-I	Horticulture Farm	12.364
PT-16	Krishnagar-I	Assannagar Health Centre	9.489
PT-17	Krishnaganj	Banipur H.C. (Mitlari)	13.405
PT-18	Krishnaganj	Block Office at Krishnaganj	12.160
PT-19	Chapra	Block Office at Chapra	10.239
PT-20	Chapra	Hridaypur Health Centre	8.454
PT-21	Nakashipara	Dadupur Health Centre	8.698
PT-22	Nakashipara	Block Office at Jaganandapur	12.159
PT-23	Kaliganj	Block Office at Debagram	12.609
PT-24	Kaliganj	Mira Health Centre	14.358
PT-25	Tehatta-II	Chotonaldah Health Centre	11.965
PT-26	Tehatta-II	Tehatta Sub Health Centre	11.860
PT-27	Tehatta-I	Block Office	8.619
PT-28	Tehatta-I	Shyamnagar Health Centre	9.550
PT-29	Tehatta-I	Betai (PWD Office)	13.225
PT-30	Karimpur	Nandanpur Health Centre	12.484
PT-31	Karimpur	Block Seed Farm	16.089
PT-32	Karimpur	Block Office	14.974

for various piezometers are presented year wise in Tables 4.4 to 4.10. A sample test of procedure for prediction of monthly variation in water table depth for the year 1984-85 for PT 12 is shown in Appendix-I.

Table 4.3 The influencing area of 32 piezometers of six raingauge stations situated in Nadia district

Name of raingauge station	Thiessen* Polygon area	Name of area	Piezometer situated
Ranaghat Water Management Research Centre	KLMN	a	PT - 1 to 6
Santipur (Fulia) Gram Shevak Training Centre	IJKL	b	PT - 7 to 10
Krishnagar Horticultural Farm	HFGJI	c	PT - 11 to 19
Kaliganj Block Development Office	EFH	d	PT - 21 to 25
Tehatta Block Seed Farm	CDEFG	e	PT - 20 and PT - 26 to 29
Karimpur Block Seed Farm	ABCD	f	PT - 30 to 32

* Area shown in Fig 3.6

As the above mentioned model was not found to be applicable for the low rainfall year besides some other factors, another attempt was made for such failure cases. The model obtained was .

$$\frac{D}{R_c} = A + B_1 t_1^{-0.5} + B_2 t_1^{-1} + B_3 t_1^{-1.5} + B_4 t_1^{-2} \quad \dots (4.3)$$

The significance of the symbols used here was the same as that of Eq (4.1).

The values of constant terms A, B_1 to B_4 of the Eq (4.3) along with coefficient of determination values (which were evaluated with the help of Eq(4.2)), are presented in Table 4.11.

Table 4.4 The values of A, B₁, B₂, B₃, B₄ and B₅ of the Eq (4.1) and their coefficient of determination values for the year 1978-'79

Piezometer Number	A	B ₁	B ₂	B ₃	B ₄	B ₅	r ²
PT-1	91.769185	-73.89494	23.95676	-3.65487	0.26242	-0.007149	0.738
PT-3	69.24633	-56.87426	18.43649	-2.78344	0.19672	-0.005266	0.831
PT-4	84.95220	-70.35819	22.79842	-3.44777	0.24513	-0.006619	0.327
PT-5	69.97270	-57.89943	18.84375	-2.86512	0.20490	-0.005567	0.657
PT-7	36.02042	-23.21704	6.46404	-0.87103	0.05664	-0.001430	0.876
PT-11	34.39450	-22.89429	7.02683	-1.04484	0.07368	-0.001980	0.941
PT-12	57.74040	-41.51706	12.36224	-1.74470	0.11707	-0.003012	0.881
PT-13	56.66090	-37.14250	10.65685	-1.48982	0.10017	-0.002594	0.984
PT-15	61.75920	-41.47517	12.01270	-1.68910	0.11426	-0.002980	0.721
PT-19	52.21540	-33.62748	9.50638	-1.30171	0.08519	-0.002139	0.851
PT-22	69.69454	-34.32761	7.41575	-0.76680	0.03758	-0.000696	0.829
PT-23	52.52960	-17.51414	1.52770	0.17421	-0.03246	0.001270	0.802
PT-26	23.78680	2.13928	-3.05479	0.61611	-0.04920	0.001409	0.977
PT-27	1.06410	12.79010	-5.31710	0.84907	-0.06052	0.001611	0.963
PT-32	58.37410	-35.65144	10.41004	-1.47628	0.09956	-0.002563	0.985

Table 4.5 The values of A, B₁, B₂, B₃, B₄ and B₅ of the Eq (4.1) and their coefficient of determination values for the year 1979-'80

Piezometer Number	A	B ₁	B ₂	B ₃	B ₄	B ₅	r ²
PT-1	40.31771	-31.62177	10.68077	-1.67688	0.12243	-0.00337	0.878
PT-2	- 2.65323	2.48353	-0.53601	0.03177	0.00005	-0.00004	0.935
PT-3	28.5441	-24.15736	8.45684	-1.33102	0.09554	-0.00256	0.929
PT-4	32.8323	-25.59337	8.53776	-1.32217	0.09532	-0.00259	0.863
PT-5	32.2041	-24.98839	8.09728	-1.21965	0.08587	-0.00229	0.791
PT-6	25.4845	-19.65037	6.58670	-1.01547	0.07248	-0.00195	0.841
PT-7	38.6645	-31.39163	10.72252	-1.69801	0.12498	-0.00346	0.642
PT-8	52.0812	-43.29890	14.67023	-2.28192	0.16456	-0.00447	0.791
PT-9	30.0241	-24.11053	8.07028	-1.24935	0.09010	-0.00245	0.699
PT-10	11.6786	- 9.19351	3.51529	-0.60017	0.04629	-0.00132	0.941
PT-11	20.3932	-16.36211	5.39415	-0.77982	0.05094	-0.00124	0.926
PT-12	50.1106	-37.72678	12.14694	-1.82880	0.12922	-0.00347	0.814
PT-13	48.2866	-33.78440	10.62828	-1.59872	0.11363	-0.00307	0.860
PT-15	56.7001	-43.99679	14.68740	-2.29073	0.16658	-0.00457	0.838
PT-16	49.9259	-35.78929	11.43737	-1.72766	0.12268	-0.00331	0.908
PT-19	52.5713	-40.23944	13.35272	-2.07865	0.15124	-0.00415	0.857
PT-20	26.58753	-20.53220	7.40446	-1.21780	0.09169	-0.002576	0.931
PT-22	67.43225	-46.22081	14.65180	-2.20016	0.15571	-0.00419	0.874
PT-23	52.6918	-40.18041	12.26036	-1.80226	0.12604	-0.00337	0.923
PT-24	73.5727	-48.72363	14.95892	-2.18773	0.15178	-0.00403	0.895
PT-25	60.5354	-41.32143	13.00878	-1.93625	0.13593	-0.00363	0.928
PT-26	51.0354	-34.68826	11.06867	-1.71016	0.12528	-0.00348	0.780
PT-27	21.4132	-18.05207	7.06972	-1.23664	0.09721	-0.00281	0.920
PT-28	24.04271	-16.86279	6.05720	-1.01880	0.07864	-0.00226	0.963
PT-29	71.08361	-52.7488	17.21579	-2.64117	0.19015	-0.00518	0.633
PT-30	60.44134	-40.73628	12.29155	-1.78366	0.12359	-0.00328	0.940
PT-31	104.8572	-73.71488	22.45973	-3.27402	0.22779	-0.00608	0.702
PT-32	62.6745	-44.43359	13.63897	-1.99992	0.13977	-0.00374	0.509

Table 4.6 The values of A, B₁, B₂, B₃, B₄ and B₅ of the Eq (4.1) and their coefficient of determination values for the year 1980-'81

Piezometer Number	A	B ₁	B ₂	B ₃	B ₄	B ₅	r ²
PT-1	25.94908	-18.35477	6.13185	-0.96169	0.07031	-0.00194	0.914
PT-2	0.32636	- 0.56368	0.71015	-0.16657	0.01434	-0.00042	0.710
PT-3	15.6586	-14.8186	4.77033	-0.75108	0.05476	-0.00149	0.827
PT-4	25.3174	-19.19618	6.32858	-0.96521	0.06851	-0.00184	0.901
PT-5	18.6441	-13.96177	4.64020	-0.70782	0.05001	-0.00133	0.793
PT-6	22.7218	-17.94419	6.25501	-0.99374	0.07246	-0.00198	0.888
PT-7	26.7491	-21.09552	7.08168	-1.08786	0.07741	-0.00208	0.708
PT-8	34.4236	-25.93661	8.58144	-1.32224	0.09492	-0.00257	0.765
PT-9	22.9773	-18.24810	6.17504	-0.94488	0.06645	-0.00175	0.899
PT-10	16.4836	-14.51424	5.64493	-0.96656	0.07446	-0.00212	0.852
PT-11	14.5768	-10.36358	4.04774	-0.70879	0.05544	-0.00159	0.928
PT-12	22.7747	-15.09751	4.75998	-0.68683	0.04599	-0.00117	0.987
PT-13	21.5219	-13.62622	4.63743	-0.73809	0.05434	-0.00150	0.961
PT-14	22.5895	-12.36693	3.81605	-0.56445	0.03891	-0.00101	0.983
PT-15	24.8893	-16.43224	5.41279	-0.82811	0.05882	-0.00158	0.945
PT-16	29.6904	-19.71923	6.37812	-0.96165	0.06740	-0.00178	0.877
PT-18	31.1444	-21.18099	7.09549	-0.11547	0.08198	-0.00228	0.861
PT-19	21.5909	-15.63468	5.68707	-0.92914	0.06904	-0.00191	0.989
PT-21	25.45135	-17.65579	5.78007	-0.88972	0.06385	-0.00173	0.775
PT-22	50.21544	-33.00558	9.82680	-1.38671	0.09224	-0.00233	0.855
PT-23	45.3286	-28.49168	8.48302	-1.20795	0.08131	-0.00208	0.905
PT-24	57.0073	-37.51384	11.25243	-1.61298	0.10987	-0.00286	0.589
PT-25	44.2582	-28.81109	8.82962	-1.29875	0.09064	-0.00241	0.789
PT-26	34.8873	-22.84734	8.33239	-1.48118	0.10978	-0.00314	0.977
PT-27	9.9904	- 4.77692	2.32875	-0.47040	0.03933	-0.00116	0.987
PT-28	28.9291	-21.50465	7.76416	-1.28124	0.09633	-0.00269	0.956
PT-30	43.23408	-17.14995	3.12866	-0.25078	0.00688	-0.00003	0.609
PT-31	65.4782	-27.42115	5.66594	-0.58373	0.02908	-0.00056	0.793
PT-32	39.2454	-16.34548	4.04135	-0.55928	0.03929	-0.00108	0.883

Table 4.7 The values of A, B₁, B₂, B₃, B₄ and B₅ of the Eq (4.1) and their coefficient of determination values for the year 1881-82

Piezometer Number	A	B ₁	B ₂	B ₃	B ₄	B ₅	r ²
PT-2	-1.35191	3.45734	-1.03844	0.13636	-0.00858	0.00021	0.419
PT-10	55.5858	-47.82280	16.24567	-2.55094	0.18637	0.00513	0.285
PT-26	106.62495	-80.47180	25.53284	-3.86706	0.27756	0.00758	0.568
PT-27	44.88498	-35.52738	12.16647	-1.85638	0.14637	0.00411	0.786
PT-28	55.25134	-42.02891	13.93918	-2.19354	0.16206	0.00452	0.863
PT-32	65.02134	-44.38618	12.48340	-1.97572	0.13837	0.00371	0.588

Table 4.8 The values of A , B_1 , B_2 , B_3 , B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1982-83

Piezometer Number	A	B_1	B_2	B_3	B_4	B_5	r^2
PT-1	48.86089	-34.15860	10.16527	-1.41329	0.09222	-0.00229	0.862
PT-2	4.29218	- 3.75716	1.55497	-0.26579	0.01937	-0.00050	0.970
PT-3	31.7188	-18.36522	4.42891	-0.45262	0.01659	-0.00004	0.734
PT-4	44.4997	-30.43259	8.98437	-1.26247	0.08446	-0.00217	0.838
PT-5	35.7509	-24.64195	7.46408	-1.08031	0.07415	-0.00195	0.927
PT-6	35.3591	-25.21437	7.76429	-1.14419	0.08001	-0.00214	0.864
PT-7	35.5404	-21.29752	5.59533	-0.70539	0.04255	-0.00099	0.878
PT-8	48.6891	-31.63439	9.151883	-1.27588	0.08519	-0.00219	0.787
PT-9	30.5241	-19.54916	5.50651	-0.73549	0.04662	-0.00114	0.879
PT-10	22.3609	-15.89130	5.08340	-0.75864	0.05267	-0.00138	0.913
PT-11	48.1700	-32.31556	9.74789	-1.40133	0.09484	-0.00244	0.747
PT-12	69.6297	-37.31148	8.15850	-0.79606	0.03308	-0.00042	0.314
PT-13	78.1727	-42.03514	9.69486	-1.04886	0.05243	-0.00097	0.417
PT-14	84.1451	-45.18357	10.50609	-1.15714	0.05973	-0.00116	0.661
PT-15	80.61789	-45.71188	11.07653	-1.27463	0.06942	-0.00144	0.484
PT-16	82.7595	-47.84483	12.05320	-1.44699	0.08224	-0.00179	0.435
PT-18	104.2372	-47.44657	9.14569	-0.78383	0.02616	-0.00014	0.749
PT-19	79.7695	-48.56115	12.89778	-1.64777	0.10092	-0.00239	0.648
PT-20	33.5599	-18.20123	5.80793	-0.90516	0.08608	-0.00183	0.906
PT-21	62.06998	-42.30366	12.46506	-1.74951	0.11713	-0.00302	0.486
PT-22	118.97723	-80.77452	23.86082	-3.38481	0.23006	-0.00602	0.583
PT-23	114.4645	-78.59558	23.50154	-3.36454	0.22993	-0.00601	0.664
PT-25	106.2386	-74.47701	22.96159	-3.35815	0.23264	-0.00616	0.694
PT-26	37.5977	- 9.03105	1.59064	-0.20875	0.01639	-0.00053	0.866
PT-27	21.77635	-16.81553	7.37245	-1.39265	0.11484	-0.00343	0.877
PT-28	32.73998	-23.70956	8.74680	-1.46329	0.11127	-0.00315	0.804
PT-30	131.65586	-95.53094	29.92117	-4.45839	0.31534	-0.00853	0.609

Table 4.9 The values of A, B₁, B₂, B₃, B₄ and B₅ of the Eq (4.1) and their coefficient of determination values for the year 1983-84

Piezometer Number	A	B ₁	B ₂	B ₃	B ₄	B ₅	r ²
PT-1	53.81807	-35.50253	10.08244	-1.36207	0.08686	-0.00211	0.919
PT-2	-15.41617	12.3306	- 3.71972	0.55699	-0.04103	0.00117	0.989
PT-3	32.6172	-20.95246	- 5.43581	-0.65344	0.03579	-0.00071	0.936
PT-5	39.3795	-30.03817	9.59276	-1.45986	0.10469	-0.00284	0.924
PT-6	43.1952	-31.90906	9.86165	-1.43831	0.09887	-0.00258	0.954
PT-7	31.3491	-18.25663	4.58913	-0.54485	0.03024	-0.00063	0.866
PT-8	49.7241	-27.0054	6.45515	-0.73147	0.03854	-0.00075	0.813
PT-9	29.3254	-17.78104	4.71779	-0.59010	0.03452	-0.00076	0.923
PT-10	18.9918	-11.69481	3.28055	-0.40967	0.02204	-0.00039	0.944
PT-20	80.78497	-52.39223	14.72982	-2.01118	0.13182	-0.00333	0.974
PT-21	56.47498	-35.96865	10.07302	-1.37424	0.09045	-0.00230	0.915
PT-22	106.62406	-72.36639	20.74588	-2.86190	0.18944	-0.00483	0.771
PT-23	99.7245	-66.11236	19.01505	-2.65389	0.17866	-0.00465	0.657
PT-25	100.3600	-63.79039	17.77686	-2.42444	0.16023	-0.00410	0.856
PT-26	103.5704	-71.73125	21.86200	-3.21227	0.22446	-0.00598	0.975
PT-27	35.9050	-22.02282	6.76894	-1.02567	0.07335	-0.00198	0.988
PT-28	53.10452	-36.99884	11.18579	-1.60567	0.10900	-0.00282	0.978
PT-29	199.07129	-143.6684	42.61174	-6.04903	0.41098	-0.01073	0.666

Table 4.10 The values of A , B_1, B_2, B_3, B_4 and B_5 of the Eq (4.1) and their coefficient of determination values for the year 1984- 85

Piezometer Number	A	B_1	B_2	B_3	B_4	B_5	r^2
PT-1	5.29637	4.82264	-2.08739	0.34791	-0.02664	0.00077	0.985
PT-2	-4.97004	6.40124	-1.91015	0.25956	-0.01731	0.00045	0.997
PT-5	7.07470	-4.24897	1.88731	-0.35166	0.02828	-0.00082	0.995
PT-6	8.8174	-2.98689	0.95942	-0.14757	0.00996	-0.00024	0.995
PT-7	8.6068	-6.12075	2.37223	-0.39921	0.030003	-0.00083	0.967
PT-8	11.8614	-5.12626	1.50867	-0.22945	0.01666	-0.00046	0.964
PT-9	5.9697	-2.92773	1.35651	-0.27899	0.02489	-0.00080	0.793
PT-11	13.5650	-6.50119	1.88065	-0.27741	0.01926	-0.00050	0.996
PT-12	24.0469	-15.99642	5.01023	-0.73165	0.05017	-0.00131	0.995
PT-13	15.1714	-5.11645	1.05715	-0.11502	0.00616	-0.00013	0.861
PT-14	27.3844	-16.93486	4.94967	-0.69537	0.04652	-0.00119	0.993
PT-15	19.0599	-11.00382	3.46515	-0.52138	0.03655	-0.00097	0.967
PT-16	20.7086	-9.03644	2.18974	-0.25960	0.01423	-0.00028	0.995
PT-18	23.9609	-14.27024	4.24808	-0.59476	0.03114	-0.00098	0.985
PT-19	19.04971	-11.12397	3.92179	-0.66384	0.05162	-0.00149	0.984
PT-20	22.21863	-10.96141	2.87798	-0.39662	0.02704	-0.00072	0.993
PT-22	43.80498	-31.83808	10.47785	-1.61485	0.11684	-0.00321	0.807
PT-23	45.5477	-32.42717	10.49037	-1.60308	0.11540	-0.00315	0.844
PT-24	53.5123	-37.00270	11.54556	-1.71543	0.12107	-0.00327	0.760
PT-25	41.9591	-27.94712	8.76265	-1.31956	0.09429	-0.00257	0.962
PT-26	23.6591	-11.66255	3.11194	-0.42310	0.02830	-0.00074	0.980
PT-27	9.5255	-3.90056	1.59114	-0.32829	0.02931	-0.00093	0.981
PT-28	15.27408	-10.21394	3.76967	-0.65299	0.05162	-0.00151	0.945
PT-31	58.3886	-32.17114	8.59317	-1.13634	0.07367	-0.00187	0.955

Table 4.11 Statistically obtained values of A , B_1 , B_2 , B_3 and B_4 of the Eq (4.3) along with r^2 for different years

Piezometer	A	B_1	B_2	B_3	B_4	r^2
1981-'82						
PT-1	-8.54588	25.2728	145.3711	-434.0476	320.0244	0.942
PT-2	-5.49047	9.0799	90.3872	-223.0499	140.8397	0.924
PT-3	16.93251	-180.9913	687.3698	-1004.3219	516.7777	0.912
PT-5	6.13689	-81.5531	382.9063	-627.7872	347.2031	0.834
PT-6	13.50490	-147.1995	586.4646	-879.9750	455.8332	0.982
PT-7	-0.88881	-18.7032	189.5578	-369.0992	223.5941	0.991
PT-8	2.212518	-38.0095	239.3134	-431.9218	258.1756	0.930
PT-9	-3.72289	-0.1276	142.5434	-323.7109	207.5475	0.881
PT-10	2.02485	-50.4604	275.9329	-458.7562	253.2829	0.995
PT-11	3.33443	-77.8285	437.7280	-786.6093	500.8663	0.932
PT-12	-49.03809	363.6985	-803.5766	618.4508	35.9135	0.885
PT-13	-22.13792	141.6420	-163.8008	-136.4902	281.9171	0.935
PT-14	-14.2920	88.8544	-35.2890	-270.9995	336.0403	0.727
PT-15	-23.3804	137.0381	-97.5190	-277.1543	369.0847	0.972
PT-16	-25.15741	149.9698	-128.4861	-252.5628	379.1295	0.965
PT-18	-23.56895	127.0989	-4.4737	-460.1142	485.8369	0.852
PT-19	-27.18531	162.5027	-174.0182	-164.2492	296.5783	0.935
PT-21	22.5736	186.4140	659.5749	-945.6791	505.3749	0.063
PT-22	55.59101	-439.8178	1447.5735	-1977.6609	1025.3805	0.050
PT-23	58.07097	-480.4074	1616.5428	-2231.3891	1145.9825	0.491
PT-24	60.80568	-475.7936	1560.2116	-2132.1412	1109.6634	0.090
PT-25	48.95453	-400.8949	1356.0628	-1888.5822	994.1427	0.525
PT-30	-27.16608	239.4042	-613.7553	683.0740	-245.9518	0.931
PT-31	-46.83730	424.4084	-1137.3466	1298.1902	-486.5575	0.836
1982-'83						
PT-29	-172.72475	1397.7746	-3804.9157	4401.0518	-1759.2586	0.186
PT-31	-203.04526	1667.1823	-4519.7465	5210.3988	-2058.0062	0.040
PT-32	-88.6170	692.6811	-1722.7218	1851.8591	-680.0142	0.020
1983-'84						
PT-11	-67.75002	532.65871	-1402.1792	1542.6751	-558.4364	0.649
PT-12	-93.31235	764.4745	-2068.1395	2311.3267	-837.2969	0.834
PT-13	-91.72840	749.5092	-2046.2064	2328.5755	-853.8124	0.845
PT-14	-92.69531	767.8396	-2104.0963	2391.9716	-865.5482	0.761
PT-15	-87.73086	713.6966	-1919.1197	2134.7959	-757.3897	0.863
PT-16	-126.34301	1002.6953	-2674.9316	2963.8846	-1078.1612	0.844
PT-18	-112.92768	921.4406	-2451.2191	2625.2761	-868.4719	0.754
PT-19	-103.88506	827.6192	-2179.0842	2381.7235	-851.9333	0.972
PT-30	-100.32910	380.5917	-2556.6675	3062.7632	-1156.3609	0.859
PT-31	-127.28693	1143.4515	-3326.7821	3965.1194	-1654.6502	0.462
PT-32	-69.43193	622.4424	-1799.6550	2153.2142	-785.7761	0.733
1984-'85						
PT-29	-46.76814	420.2490	-1204.6973	1477.0181	-619.9375	0.881

4.4 Prediction of average position of water table depths for separate piezometer with reference to time and average rainfall

The water table depth (D) and rainfall (R) data were averaged over seven years' (1978-79 to 1984-85) with a view to develop a model. The model was :

$$\frac{D}{R_c} = A + B_1 t_i + B_2 t_i^2 + B_3 t_i^3 + B_4 t_i^4 + B_5 t_i^5 \quad \dots\dots (4.4)$$

Where, D = depth of ground water table (average of 7 years), with reference to mean sea level for any piezometer (m)

R_c = seven years' average monthly cumulative rainfall, starting from June and ending in May of the subsequent year (cm)

t = concerned month, values are june = 1, July = 2, ..., May = 12

i = 1 to 12

A, B_1 to B_5 are empirical constants.

Using least squares method, those constants were determined and depicted in Table 4.12 along with the coefficient of determination (r^2) value as described in Eq (4.2)

✓ 4.5 Prediction of monthly variation in water table depths with reference to time (month)

Another simple model was evaluated considering the only parameter as time. This model was a cubic equation of time and given below :

$$D = A + B_1 t_i + B_2 t_i^2 + B_3 t_i^3 \quad \dots\dots (4.5)$$

Where, D = depth of ground water table with reference to mean sea level (m)

t = concerned month, values are June = 1, July = 2, ..., May = 12

i = 1 to 12

Table 4.12 Best fit values of A , B_1 , B_2 , B_3 , B_4 and B_5 of the Eq(4.4) along with their r^2 for thirty two piezometers

Piezometer	A	B_1	B_2	B_3	B_4	B_5	r^2
PT-1	0.39577	-0.28193	0.089731	-0.013501	9.5361×10^{-4}	-2.5537×10^{-5}	0.951
PT-2	0.00345	0.004853	0.000981	-0.0004495	4.2245×10^{-5}	-1.2132×10^{-6}	0.994
PT-3	0.24327	-0.15081	0.040449	-0.0048886	2.5516×10^{-4}	-4.4683×10^{-6}	0.670
PT-4	0.30186	-0.17770	0.0412017	-0.00361808	6.6668×10^{-5}	3.1485×10^{-6}	0.769
PT-5	0.27995	-0.215524	0.0716331	-0.011093	8.0067×10^{-4}	-2.1804×10^{-5}	0.930
PT-6	0.29186	-0.218581	0.0720003	-0.01108	7.9491×10^{-4}	-2.1521×10^{-5}	0.910
PT-7	0.27318	-0.2023	0.0646944	-0.0097945	6.9501×10^{-4}	-1.8712×10^{-5}	0.953
PT-8	0.36886	-0.26011	0.081546	-0.0121422	8.5268×10^{-4}	-2.2765×10^{-5}	0.917
PT-9	0.22713	-0.16216	0.052079	-0.0078583	5.5498×10^{-4}	-1.4847×10^{-5}	0.939
PT-10	0.18568	-0.14056	0.047756	-0.00747074	5.3813×10^{-4}	-1.4536×10^{-5}	0.965
PT-11	0.29218	-0.201238	0.0641186	-0.00967691	6.8247×10^{-4}	-1.8175×10^{-5}	0.961
PT-12	0.47704	-0.33533	0.10171	-0.014555	9.8616×10^{-4}	-2.5575×10^{-5}	0.964
PT-13	0.46013	-0.29859	0.088874	-0.012789	8.7769×10^{-4}	-2.3076×10^{-5}	0.960
PT-14	0.53891	-0.3584	0.106121	-0.0151534	1.0342×10^{-3}	-2.7102×10^{-5}	0.962
PT-15	0.50391	-0.34413	0.10476	-0.015213	1.0467×10^{-3}	-2.7498×10^{-5}	0.950
PT-16	0.53041	-0.3524	0.10468	-0.0148859	1.0049×10^{-3}	-2.5942×10^{-5}	0.971
PT-17	0.613318	-0.421288	0.12886	-0.0188435	1.3073×10^{-3}	-3.4643×10^{-5}	0.928
PT-18	0.642545	-0.450725	0.13925	-0.0205165	1.4335×10^{-3}	-3.8235×10^{-5}	0.893
PT-19	0.456545	-0.317338	0.100205	-0.01504088	1.0645×10^{-3}	-2.8657×10^{-5}	0.962
PT-20	0.31349	-0.18956	0.058293	-0.008787	6.2766×10^{-4}	-1.7034×10^{-5}	0.990
PT-21	0.41586	-0.28718	0.08831	-0.012972	9.0402×10^{-4}	-2.4057×10^{-5}	0.877
PT-22	0.78918	-0.54476	0.16595	-0.0239118	1.6492×10^{-3}	-4.3552×10^{-5}	0.712
PT-23	0.74330	-0.50357	0.15225	-0.0221006	1.5296×10^{-3}	-4.0516×10^{-5}	0.820
PT-24	0.80427	-0.464358	0.11116	-0.0115928	4.8833×10^{-4}	-5.0999×10^{-6}	0.621
PT-25	0.726772	-0.490796	0.147679	-0.021349	1.4717×10^{-3}	-3.8876×10^{-5}	0.868
PT-26	0.45650	-0.26317	0.078349	-0.0116932	8.3843×10^{-4}	-2.2982×10^{-5}	0.979
PT-27	0.173136	-0.10019	0.037055	-0.0065924	5.2941×10^{-4}	-1.5582×10^{-5}	0.984
PT-28	0.27627	-0.183212	0.0614435	-0.0098382	7.3360×10^{-4}	-2.0559×10^{-5}	0.944
PT-29	0.76845	-0.4847	0.137978	-0.0190083	1.2603×10^{-3}	-3.2324×10^{-5}	0.950
PT-30	0.686727	-0.43385	0.123233	-0.0170239	1.1339×10^{-3}	-2.9214×10^{-5}	0.959
PT-31	1.05936	-0.682039	0.19657	-0.027551	1.8629×10^{-3}	-4.8689×10^{-5}	0.836
PT-32	0.643636	-0.42337	0.12781	-0.01872	1.31051×10^{-3}	-3.5134×10^{-5}	0.924

A, B_1 , B_2 and B_3 were the empirical constants and were determined with the help of least squares method. The estimated water table depths of each piezometer of each month were determined using the Eq (4.5) and tested statistically by Eq (4.2) for obtaining coefficient of determination (r^2) values. The values of A, B_1 , B_2 and B_3 of the Eq (4.5) along with coefficient of determination (r^2) for various piezometers for different years are presented in tables 4.13 to 4.19.

From this model [Eq (4.5)] the minimum and maximum water table depths as well as corresponding time (month) can be predicted. The time when maximum and minimum depths of water table are likely to occur can be predicted by differentiating the Eq (4.5) and equating to zero with respect to time. Thus,

$$\left| \begin{aligned} d(D)/dt &= (A + B_1 t + B_2 t^2 + B_3 t^3) \quad || \text{ } \end{aligned} \right|$$

$$d^2(D)/dt^2 = B_1 + 2B_2 t + 3B_3 t^2 \quad \dots\dots (4.6)$$

Equating $d^2 D/dt^2 = 0$ and solving for t, the time (beginning from June), were determined for maximum and minimum water table position (vide Appendix - II). The time period when the water table will reach maximum and minimum heights with respect to mean sea level for each piezometer and concerned year are also shown in Tables 4.13 to 4.19. -

4.6 Prediction of ground water recharge during July-August-September

Considering Δd as the average recharge during the period July-August-September (this is actual measurable recharge plus $0.85 \times 1/3$ discharge during remaining nine months) and R as the total rainfall during July-August-September over the area under consideration, i.e., Thiessen polygon (Vide Fig. 3.6). The models obtained are as follows :

$$\Delta d = 0.10096 R^{0.6963} \quad (\text{for Thiessen Polygon a}) \dots\dots (4.7)$$

Table 4.13 The values of A , B_1 , B_2 , B_3 of the Eq (4.5) for different piezometers for the year 1978-79 and the time for minimum and maximum water table depth

Piezometer	A	B_1	B_2	B_3	r^2	t_{min}^*	t_{max}^*
PT-3	0.5824242	2.0402892	-0.2981102	0.011111	0.935	13.3	4.6
PT-4	2.1272727	1.1028538	-0.1176474	0.0025758	0.923	24.7	5.8
PT-5	1.7362626	0.9572026	-0.0927067	0.0015126	0.900	34.8	6.1
PT-7	1.7759596	0.8238887	-0.0452825	-0.0015255	0.867	12.0	6.8
PT-11	-0.090404	3.1114728	-0.4403674	0.016295	0.939	13.2	4.8
PT-12	3.4795	0.930495	-0.050416	-0.001524	0.869	13.0	7.0
PT-13	2.7411717	2.4311297	-0.350444	0.0135126	0.951	12.5	4.8
PT-15	3.6454141	1.832954	-0.2399328	0.0081435	0.946	14.4	5.2
PT-19	2.0060606	2.804127	-0.4125708	0.0164491	0.942	11.9	4.7
PT-22	7.9552525	1.6057406	-0.2074115	0.0068946	0.961	14.8	5.2
PT-23	5.992404	2.7070951	-0.3899877	0.0154043	0.983	11.9	4.9
PT-26	1.7260	5.03287	-0.870087	0.040363	0.945	10.3	4.0
PT-27	-1.28828	4.47354	-0.766533	0.035196	0.908	10.5	4.0
PT-32	3.516545	3.905437	-0.579139	0.023354	0.923	11.8	4.7

* Time begins from June and fractional value indicates the fraction of month (Vide Appendix - II)

Table 4.14 The values of A , B_1 , B_2 , B_3 of the Eq. (4.5) for different piezometers for the year 1979-80 and the time for minimum and maximum water table depth

Piezometer	A	B_1	B_2	B_3	r^2	t_{min}^*	t_{max}^*
PT-3	-0.3439394	2.3151526	-0.340368	0.0132207	0.876	4.7	12.5
PT-4	1.2569697	1.6456571	-0.2455628	0.0099689	0.83	11.7	4.7
PT-5	1.7840404	0.9860097	-0.1380941	0.0048938	0.982	14.0	4.8
PT-6	0.4658586	1.769941	-0.2487285	0.0095558	0.960	12.3	4.9
PT-7	1.1523232	1.6665927	-0.2590238	0.0108405	0.931	11.4	4.5
PT-8	1.6117172	1.7908956	-0.2592352	0.0101023	0.888	12.3	4.8
PT-9	1.1232323	1.0330212	-0.1408819	0.0051412	0.976	13.1	5.1
PT-10	-0.7985859	1.7866243	-0.2516961	0.0098847	0.957	11.9	5.0
PT-11	0.1621212	1.212151	-0.1004662	0.0008353	0.783	12.5	6.5
PT-12	3.44930	1.257194	-0.161993	0.005405	0.965	13.1	5.2
PT-13	2.870101	2.3482206	-0.3900495	0.0169513	0.974	11.2	4.1
PT-14	2.5919192	2.9297231	-0.4749806	0.0208254	0.992	10.9	4.3
PT-15	2.9487879	2.2835263	-0.3576797	0.0149479	0.827	11.5	4.4
PT-16	3.0880808	2.1182499	-0.3212282	0.0129927	0.989	11.9	4.5
PT-19	2.983333	2.0121773	-0.3259074	0.0138034	0.959	11.5	4.2
PT-20	-0.0191919	2.8578553	-0.4188955	0.0171186	0.943	11.4	4.8
PT-22	6.2286869	2.2895664	-0.3333694	0.0138708	0.906	11.0	4.9
PT-23	6.5178283	2.1263916	-0.3225545	0.0133383	0.972	11.5	4.6
PT-24	7.741919	1.876061	-0.244654	0.008842	0.962	13.0	5.4
PT-25	5.86298	1.765723	-0.223478	0.007559	0.887	14.2	5.5
PT-26	4.1220	2.50346	-0.440835	0.020483	0.864	12.4	3.9
PT-27	-1.0396	3.188139	-0.513354	0.022539	0.896	10.8	4.3
PT-28	0.100101	3.075062	-0.494656	0.021728	0.962	10.8	4.3
PT-29	5.253333	2.529953	-0.395393	0.017382	0.955	10.5	4.6
PT-30	9.5440404	1.987733	-0.280217	0.0111176	0.923	11.7	5.1
PT-31	9.544798	1.987162	-0.2801602	0.011116	0.924	11.7	5.1
PT-32	5.527576	1.28918	-0.18539	0.007667	0.875	11.0	5.1

* Time begins from June and fractional value indicates the fraction of month (Vide Appendix - II)

Table 4.15 The values of A, B₁, B₂, B₃ of the Eq. (4.5) for different piezometers for the year 1980-81 and the time for minimum and maximum water table depth

Piezometer	A	B ₁	B ₂	B ₃	r ²	t _{min} [*]	t _{max} [*]
PT-3	0.0588889	2.6377219	-0.4584954	0.0223608	0.824	9.5	4.1
PT-4	1.2448485	1.7710695	-0.2639227	0.0113015	0.908	10.6	4.9
PT-5	0.5129293	1.7372032	-0.247139	0.0101567	0.851	11.1	5.1
PT-6	-0.1068687	2.6786055	-0.4177944	0.018402	0.888	10.5	4.6
PT-7	1.0805051	1.3907702	-0.1917810	0.007612	0.925	11.5	5.3
PT-8	1.6537374	1.9455596	-0.3098807	0.0136972	0.959	10.6	4.4
PT-9	0.4507071	1.5856823	-0.2166422	0.0084214	0.913	11.8	5.3
PT-10	-0.9958586	2.4002756	-0.3623105	0.0155491	0.844	10.7	4.8
PT-11	-0.2039394	3.2139055	-0.5340393	0.0242929	0.908	10.4	4.2
PT-12	3.06060	1.278932	-0.144767	0.004246	0.947	12.7	6.0
PT-13	2.0773737	2.6185976	-0.4014091	0.0169909	0.918	11.1	4.6
PT-14	2.5919192	2.9297231	-0.4749806	0.0208254	0.992	10.9	4.3
PT-15	2.8307071	2.1611178	-0.318850	0.0129738	0.954	11.5	4.8
PT-16	3.6621212	2.1974731	-0.3420646	0.0144483	0.941	11.3	4.5
PT-18	4.1661616	1.9940706	-0.2922866	0.0118713	0.886	11.6	4.8
PT-19	1.0563636	2.9396454	-0.4198651	0.0167133	0.939	11.7	4.9
PT-21	1.8351515	2.6817893	-0.4161322	0.0180925	0.944	10.7	4.6
PT-22	6.2738384	2.8634403	-0.4597364	0.020553	0.939	10.5	4.4
PT-23	5.0800505	3.7500169	-0.5970832	0.0269022	0.980	10.3	4.5
PT-24	7.915455	2.649231	-0.41468	0.018522	0.968	10.3	4.6
PT-25	5.220758	3.181219	-0.503651	0.022718	0.948	10.2	4.6
PT-26	0.4320	5.939446	-1.006994	0.04659	0.951	10.3	4.1
PT-27	-2.5491	5.21628	-0.871878	0.039744	0.972	10.4	4.2
PT-28	0.772828	3.496569	-0.569221	0.025026	0.937	10.9	4.3
PT-30	10.3285859	2.2696111	-0.3679543	0.0166071	0.858	10.4	4.4
PT-31	10.3284344	2.2692831	-0.3678885	0.0166044	0.858	10.4	4.4
PT-32	4.639344	3.256527	-0.555631	0.025842	0.799	10.2	4.1

* Time begins from June and fractional value indicates the fraction of month (Vide Appendix - II)

Table 4.16 The values of A, B₁, B₂, B₃ of the Eq (4.5) for different piezometers for the year 1981-82 and the time for minimum and maximum water table depth

Piezometer	A	B ₁	B ₂	B ₃	r ²	t _{min} [*]	t _{max} [*]
PT-3	2.8331313	1.9829361	-0.4037435	0.0198006	0.974	10.4	3.2
PT-4	2.8104040	1.3169055	-0.2179093	0.0094276	0.967	11.3	4.1
PT-5	1.8073737	1.6394191	-0.281534	0.0127998	0.848	10.6	4.0
PT-6	1.7945465	2.0558993	-0.3563592	0.0161797	0.955	10.7	3.9
PT-7	2.0338384	1.5406231	-0.2427633	0.0101334	0.975	11.6	4.3
PT-8	3.0089899	1.2313052	-0.2062732	0.0090184	0.927	11.2	4.1
PT-9	1.6969697	1.3872589	-0.2166767	0.0089316	0.849	11.8	4.4
PT-10	1.473333	1.7070907	-0.2922061	0.012661	0.974	11.4	3.9
PT-11	2.3626263	1.9906708	-0.3717677	0.017445	0.946	10.6	3.6
PT-12	4.2882	0.616896	-0.070244	0.001741	0.949	15.0	5.5
PT-13	3.9125051	1.6061544	-0.2734573	0.0122997	0.918	10.8	4.0
PT-14	4.4406869	1.3442647	-0.2305452	0.0104582	0.766	10.6	4.0
PT-15	4.0378586	1.779416	-0.2861191	0.0121339	0.943	11.5	4.3
PT-16	4.7787879	1.9276102	-0.3428405	0.0155633	0.972	10.9	3.8
PT-18	3.310202	3.3801419	-0.5574287	0.025180	0.902	10.5	4.2
PT-19	2.8475758	2.1487588	-0.3421195	0.0145765	0.920	11.3	4.3
PT-21	4.6993939	0.6617471	-0.0980936	0.0036558	0.942	13.4	4.5
PT-22	10.1054546	0.8304479	-0.531069	0.006655	0.979	11.8	3.5
PT-23	9.251616	2.2933418	-0.2172147	0.009006	0.933	12.1	3.9
PT-24	11.486121	0.601495	-0.109728	0.004441	0.972	12.9	3.5
PT-25	10.124596	0.567284	-0.123989	0.00538	0.967	12.6	2.7
PT-26	7.39730	2.039141	-0.454286	0.023147	0.927	10.2	2.8
PT-27	1.114949	2.69899	-0.486536	0.022633	0.890	10.6	3.7
PT-28	2.361111	2.642992	-0.475336	0.022185	0.908	10.5	3.8
PT-30	12.32717171	1.2275906	-0.231398	0.0111046	0.882	10.3	3.5
PT-31	12.3225556	1.2309514	-0.2319516	0.0111296	0.883	10.3	3.6
PT-32	7.300182	1.746477	-0.345468	0.017007	0.870	10.2	3.3

* Time beging form June and fractional value indicates the fraction of month (Vide Appendix - II)

Table 4.17 The values of A, B₁, B₂, B₃ of the Eq (4.5) for different piezometers for the year 1982-83 and the time for minimum and maximum water table depth

Piezometer	A	B ₁	B ₂	B ₃	r ²	t _{min} [*]	t _{max} [*]
PT-3	1.5329293	0.9479391	-0.1665895	0.0068933	0.608	12.4	3.7
PT-4	2.9759596	0.4494914	-0.0719408	0.0027169	0.944	13.6	4.0
PT-5	2.0617172	0.714840	-0.1267827	0.0054636	0.958	11.7	3.7
PT-6	1.9818182	0.8611189	-0.1495455	0.0066084	0.922	11.2	3.9
PT-7	2.6337374	0.2462772	-0.0432773	0.0015411	0.955	15.2	3.5
PT-8	3.010404	0.6686171	-0.1123748	0.0049288	0.864	11.1	4.0
PT-9	1.9216162	0.3462101	-0.0397741	0.0007757	0.886	29.0	5.1
PT-10	0.602222	0.8721136	-0.1276196	0.0048588	0.872	12.8	4.6
PT-11	0.7741414	1.6849143	-0.2683594	0.0115747	0.734	11.0	4.4
PT-12	4.26070	0.152564	-0.014315	-0.00003	0.864	12.0	5.2
PT-13	3.9480404	1.0653854	-0.1710262	0.0071316	0.885	11.7	4.2
PT-14	4.2519798	1.199292	-0.1907132	0.0078736	0.947	11.8	4.3
PT-15	4.2200606	0.7196198	-0.1166817	0.0049573	0.850	11.4	4.2
PT-16	3.6087879	1.3230231	-0.2022761	0.0082673	0.823	11.8	4.5
PT-18	5.108888	2.638656	-0.4844145	0.0230601	0.943	10.3	3.7
PT-19	3.5969697	0.9725436	-0.1385598	0.0049806	0.853	13.8	4.7
PT-20	1.754444	1.9549532	-0.2986158	0.01225858	0.824	11.7	4.5
PT-21	4.3980808	0.366475	-0.0486908	0.0015708	0.853	15.7	4.9
PT-22	8.6746465	0.6632986	-0.1168387	0.0060842	0.962	11.5	3.7
PT-23	7.8362727	0.9996687	-0.1715784	0.0074942	0.891	11.3	3.9
PT-25	6.062374	1.885268	-0.276829	0.011156	0.843	11.7	4.8
PT-26	2.6860	3.406043	-0.587650	0.027589	0.826	10.1	4.0
PT-27	-1.08560	3.01994	-0.485354	0.021373	0.769	10.7	4.3
PT-28	0.661818	2.066775	-0.299181	0.012016	0.746	11.6	4.9
PT-29	9.880101	0.798588	-0.142178	0.006273	0.975	11.4	3.7
PT-30	11.4219192	1.2113488	-0.2012593	0.008907	0.829	10.9	4.1
PT-31	11.4213434	1.2112772	-0.2012606	0.0089074	0.829	10.9	4.1
PT-32	4.300061	2.607861	-0.426614	0.019539	0.719	10.2	4.3

* Time -begins from June and fractional value indicates the fraction of month (Vide Appendix - II)

Table 4.18 The values of A , B_1 , B_2 , B_3 of the Eq (4.5) for different piezometers for the year 1983-'84 and the time for minimum and maximum water table depth

Piezometer	A	B_1	B_2	B_3	r^2	t_{min}^*	t_{max}^*
PT-3	0.9680808	0.7754377	-0.1353341	0.0054053	0.873	13.0	3.7
PT-5	0.6112121	1.2353003	-0.2331885	0.0115113	0.896	9.9	3.6
PT-6	0.7516162	1.2151528	-0.168920	0.0062536	0.919	13.0	4.9
PT-7	1.5428283	0.5485317	-0.075510	0.0026483	0.842	14.1	4.9
PT-8	2.3132323	1.2533259	-0.1879199	0.0075887	0.892	11.8	4.6
PT-9	1.1365657	0.7086434	-0.0896964	0.0028024	0.859	16.1	5.2
PT-10	-0.4324242	1.4521417	-0.1997619	0.0071873	0.838	13.6	4.9
PT-11	0.769899	1.8316815	-0.2730064	0.0112795	0.823	11.4	4.7
PT-12	2.931616	1.461648	-0.186702	0.006661	0.934	11.0	5.6
PT-13	3.6596768	1.5169594	-0.2283938	0.0089591	0.996	12.4	4.5
PT-14	3.9173535	1.8253851	-0.2880464	0.0123261	0.968	11.1	4.4
PT-15	3.1469495	1.6479185	-0.2421201	0.0097283	0.951	11.8	4.8
PT-16	2.7502020	2.0385884	-0.2842618	0.0105996	0.902	12.9	4.9
PT-18	4.9588889	0.9228268	-0.1042297	0.0029902	0.608	17.2	5.9
PT-19	1.9058586	2.2137636	-0.2761910	0.0094626	0.957	13.0	5.6
PT-20	2.7546465	2.2640678	-0.3756499	0.0162031	0.992	11.3	4.1
PT-21	3.6731313	1.3561463	-0.1944378	0.0067353	0.994	14.6	4.6
PT-22	7.8046465	0.8787398	-0.1228427	0.0037788	0.951	17.1	4.5
PT-23	6.8923535	1.5973448	-0.2081788	0.0098230	0.997	14.6	5.2
PT-25	6.990859	2.066836	-0.324955	0.013396	0.989	11.8	4.3
PT-26	1.93540	4.009017	-0.636358	0.027445	0.962	11.0	4.4
PT-27	-1.005556	3.497041	-0.575374	0.025720	0.949	10.6	4.2
PT-28	0.879394	1.984841	-0.272214	0.010218	0.943	12.6	5.1
PT-29	9.830404	0.74037	-0.107125	0.00353	0.972	15.8	4.4
PT-30	10.6029293	1.6427476	-0.2529232	0.0105063	0.939	11.5	4.5
PT-32	5.353616	2.166935	-0.364774	0.015820	0.881	10.6	4.2

*Time begins from June and fractional value indicates the fraction of month (Vide Appendix -II)

Table 4.19 The values of A , B_1 , B_2 , B_3 of the Eq (4.5) for different piezometers for the year 1984-'85 and the time for minimum and maximum water table depth

Piezometer	A	B_1	B_2	B_3	r^2	t_{min}^*	t_{max}^*
PT-5	0.3740099	1.6134352	-0.2253219	0.0087153	0.934	12.1	5.0
PT-6	1.3343434	1.7709187	-0.712426	0.0109622	0.977	12.0	4.5
PT-7	-0.059596	2.177370	-0.2991231	0.0113857	0.944	12.3	5.1
PT-8	2.1553535	2.2900181	-0.3851842	0.0172585	0.950	10.7	4.1
PT-9	-0.5322727	2.8986772	-0.4732867	0.0212179	0.943	10.3	4.3
PT-11	2.2784849	2.2015207	-0.4059657	0.0185975	0.993	10.9	3.6
PT-12	4.910101	0.689972	-0.051984	-0.000580	0.900	12.0	6.0
PT-13	3.5909899	2.2792216	-0.3853661	0.0168762	0.961	11.2	4.0
PT-14	6.6346263	0.3410551	-0.0742132	0.0026711	0.968	15.8	2.7
PT-15	2.9253333	2.7506148	-0.4258894	0.0175237	0.946	11.7	4.4
PT-16	4.6154546	2.3239877	-0.396022	0.0169114	0.992	11.7	3.9
PT-18	4.8937374	1.387804	-0.1732773	0.0053989	0.920	16.0	5.3
PT-19	2.4270496	3.2585519	-0.5296036	0.0230653	0.936	11.0	4.2
PT-20	3.739798	2.2223889	-0.4136652	0.0190974	0.974	10.8	3.5
PT-22	6.1509091	2.4062138	-0.3284715	0.0124476	0.949	12.4	5.2
PT-23	6.9388788	2.2646496	-0.344568	0.0138186	0.968	12.1	4.5
PT-24	9.583010	1.544242	-0.23697	0.009380	0.983	12.4	4.4
PT-25	6.881162	2.476789	-0.412232	0.017670	0.981	11.5	4.1
PT-26	3.54040	2.661071	-0.411995	0.01726	0.956	11.4	4.5
PT-27	-0.995152	4.303515	-0.748423	0.034565	0.860	10.5	3.9
PT-28	0.005859	3.326992	-0.534932	0.023437	0.874	10.8	4.3
PT-29	9.199697	1.235965	-0.191432	0.007638	0.937	12.3	4.3
PT-30	10.9793939	1.9673915	-0.3537779	0.0166628	0.890	10.3	3.8
PT-32	4.910303	2.565308	-0.475964	0.023693	0.883	9.6	3.8

* Time begins from June and fractional value indicates the fraction of month (Vide Appendix -II)

$$\Delta d = 0.012296 R^{1.1981} \text{ (for Thiessen Polygon b).... (4.8)}$$

$$\Delta d = 0.04384 R^{0.94269} \text{ (for Thiessen Polygon c).... (4.9)}$$

$$\Delta d = 0.04135 R^{0.9457} \text{ (for Thiessen Polygon d).... (4.10)}$$

$$\Delta d = 0.12146 R^{0.84275} \text{ (for Thiessen Polygon e).... (4.11)}$$

$$\Delta d = 0.014605 R^{0.88165} \text{ (for Thiessen Polygon f).... (4.12)}$$

Where, Δd = average recharge during July-August-September, (m)

R = total rainfall of those months over the polygon,
(cm)

The Δd (actual) versus R (actual) and Δd (estimated) versus R (actual) are plotted and shown in Fig. 4.1 for each of the six polygons. The correlation coefficients (r^2) are shown in the respective figures. The details of the procedure following which Eqs (4.7) through (4.12) were obtained may be glanced in Appendix III.

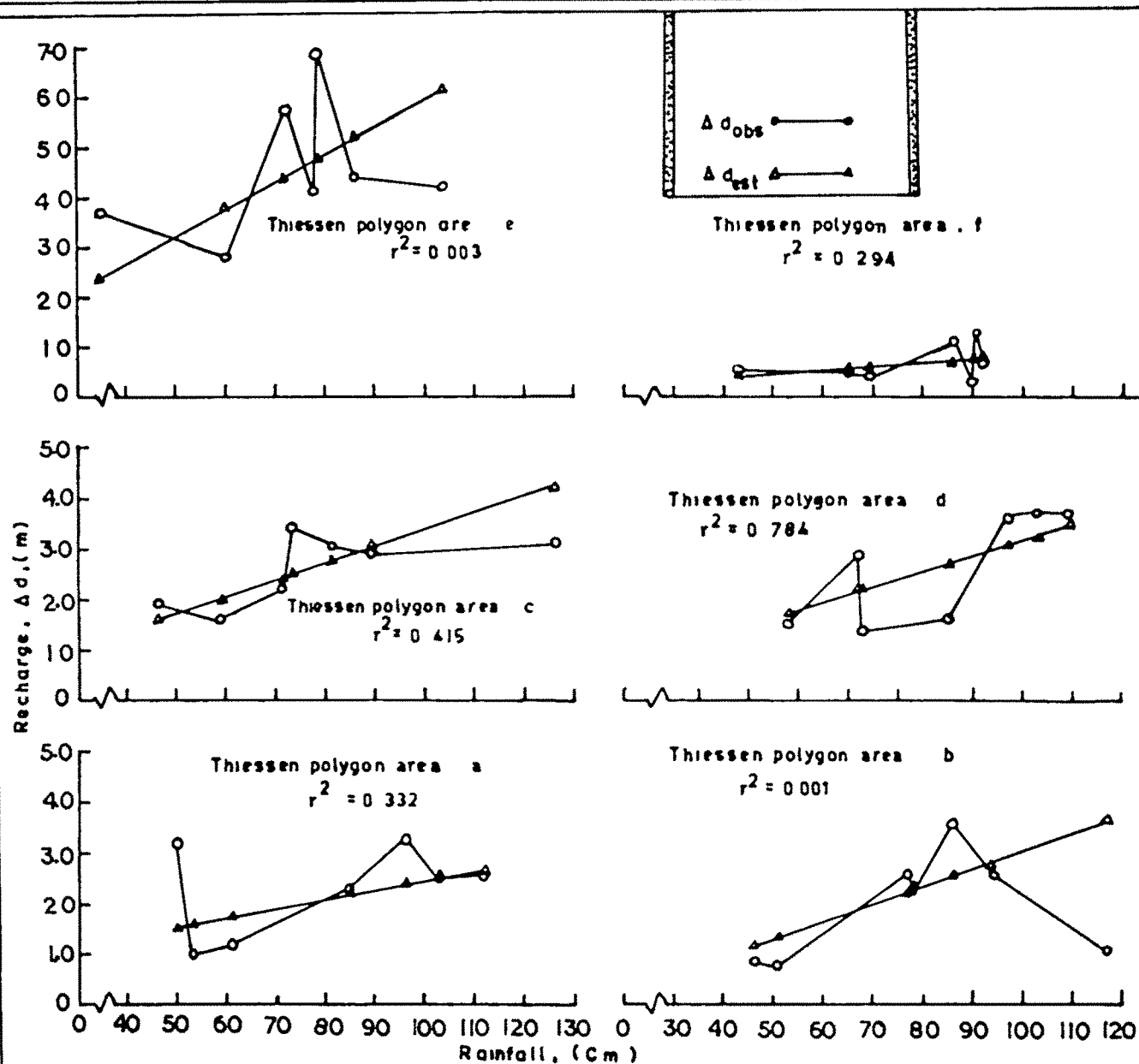


Fig 4.1 Comparison between actual recharge and estimated recharge using Eqs (4.7) to (4.12)

DISCUSSION

5. DISCUSSION

In order to get the general idea about the significant renewal period of a particular rainfall (annual), auto-regressive model was used (Eq. 3.2). Based on the results of correlation (r), the proper time interval at which the particular amount of annual rainfall could be correlated was noted. Upto fifth order auto-regression equations, for each raingauge station, were done and presented in Table 4.1. This table reveals that the 4th order auto-correlation (r) values are to some extent higher than the others. Though the correlation coefficient values are not so high in few cases, yet it can be said that the return period of annual rainfall follows approximately a sequence at an interval of four years. It also reveals that, only fourth order auto-correlation (r) values are all positive and others are negatively correlated. The nature of the rainfall, changes in cyclic order, causes this phenomenon.

The average annual rainfall of the district for 10 years (1976-1985) was 1453.29 mm. Out of the total precipitation, as much as 56.8 per cent was received during the months of June-July-August (Fig 3.7). The annual rainfall, received at various stations, was in the range of 890.4 mm to 2023.3 mm during the study period (1976-1985). From Table 3.10 it is apparent that the highest amount of rainfall was received in the station located at Tehatta Block Seed Farm during the year 1977 while the lowest receipt was recorded at Kaliganj Block Development Office during the year 1982. However, the annual average rainfall was maximum (1509.45 mm) at Krishnagar Horticultural Farm and minimum (1404.45 mm) in Ranaghat Water Management Centre. The annual rainfall for whole of Nadia district was maximum (1890.41 mm) in the year 1977 and minimum (944.4 mm) in the year 1982. It is observed that the year 1982 was the low rainfall year. In that year, the total annual rainfall was 64.9 per cent (approximately) of annual average (1453.29 mm) of the district. On the other hand, the annual

rainfall, received in 1977, was 130.7 per cent of the annual average of the district.

The central part of the district received higher rainfall compared with the Southern and Northern parts as evidenced from isohy²atal map of this district (Fig 3.5). The Tropic of Cancer passes through the middle of this district (Krishnagar area). This might be the reason for receiving higher rainfall in the central part of the district.

The monthly fluctuation of water table of each piezometer is expressed by the Eq (4.1). The values of coefficient for each piezometric sites for different years are available in Tables 4.4 to 4.10. Each alternate term of the Eq (4.1) is negative save at 8 cases, namely, PT 23, 26, 27 for the year 1978-1979; PT 2 for the year 1979-1980, 1981-1982, 1983-1984 and 1984-1985, PT 29 for the year 1982-1983 out of 185.

The computed values of water table depths using Eq (4.1) are very close to the observed values in most of the cases, as is evidenced from coefficient of determination (r^2) values, delineated in Tables 4.4 to 4.10. On the basis of the values of coefficient of determination, three classes are made and delineated in the table 5.1. This table reveals that 39 cases out of 285 are fallen in the low r^2 value classes (i.e., $r^2 < 0.30$). These 39 cases are in the year 1981-1982 (number of piezometers are 25), 1982-1983 (number of piezometers are 3), 1983-1984 (number of piezometers are 11) and in the year 1984-1985, one piezometer only. In 145 cases, out of 185, the estimated water table depth values (D_{est}) are nearer to observed water table depths (D_{obs}).

Few sample plots of observed water table depths (D_{obs}) and estimated water table depths (D_{obs}^{est}) against time is displayed in Fig 5.1. This figure reveals that in the years 1978-1979, 1979-1980, 1980-1981, 1982-1983, 1984-1985 for PT 12 and the year 1978-1979 for PT 7, the estimated values of water table depth (D_{est}) are very close to the observed values (D_{obs}) when working with the Eq (4.1). In

Table 5.1 Piezometer situated in different Coefficient of determination classes in different year

Year	Name of Piezometer		
	Coefficient of determination class		
	Low (0.03)	Medium (0.31 - 0.70)	High (0.71 - 0.99)
1978-'79	-	PT-4,5	PT- 1,2,3,7,11,12, 13,15,19,22,23, 26,27,32
1979-'80	-	PT-7,9,29,31,32	PT- 1,2,3,4,5,6,8, 10,11,12,13,15, 16,19,20,22,23, 24,25,27,28,30
1980-'81	-	PT-24,30	PT- 1,2,3,4,5,6,7,8, 9,10,11,12,13, 14,15,16,18,19, 21,22,23,25,26, 27,28,31,32
1981-'82	PT-1,3,4,5,6, 7,8,9,10,11, 12,13,14,15, 16,18,19,21, 22,23,24,25, 30,31	PT-2,26,32	PT- 27,28
1982-'83	PT-29,31,32	PT-12,13,14,15, 16,19,21,22, 23,25,30	PT- 1,2,3,4,5,6,7, 8,9,10,11,18, 20,26,27,28
1983-'84	PT-11,12,13, 14,15,18, 19,30,31, 32	PT-23,29	PT- 1,2,3,5,6,7, 8,9,10,20,21, 22,25,26,27,28
1984-'85	PT-29	-	PT- 1,2,5,6,7,8,9, 11,12,13,14,15, 16,18,19,20,22, 23,24,25,26,27, 28,31

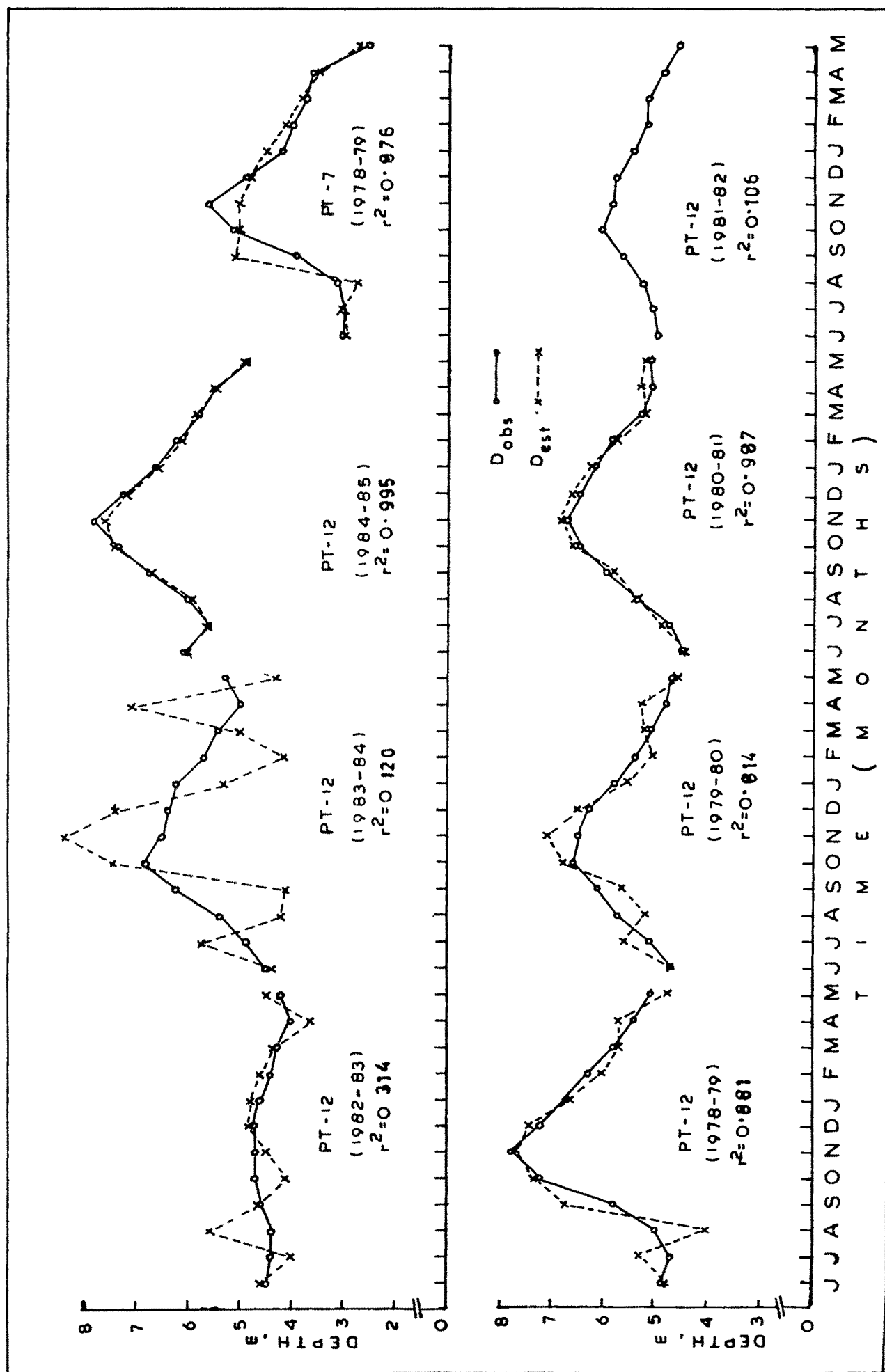


FIG 51 SAMPLE PLOT OF DEPTH VERSUS TIME FOR EIGHT CASES (VIDE Eq 41)

the year 1981-1982 and 1983-1984 for PT 12, D_{obs} values differed greatly to the D_{est} values. But Eq (4.3) gives good results for these two cases (it gave higher r^2 value, i.e., 0.885 and 0.834, respectively, vide Table 4.11). Scrutinising this figure, it is also observed that in the year 1982-1983, the average ground water table position was lowest from ground surface throughout the year. As the year 1982 happened to be the low rainfall year (Table 3.11), the water table did not rise in that year.

The 39 cases in which r^2 ranges in between 0-0.30, the generated values of water table depths deviate too much from observed water table depths.

The causes of failure of Eq (4.1) in 39 cases might be due to the following reason(s) .

a) Infiltration rate varies from place to place due to the different textural classes of the soil surface (clay, sand, etc.) as evidenced from Table 3.2) resulting variation in the recharge. The borehole log-charts (Fig 3.3 and 3.4) also indicate the subsurface horizontal/lateral as well as vertical movement of ground water. The model (Eq 4.1) established herein has not accommodated all these parameters and therefore, the deviations are observed.

b) Each piezometric data were processed corresponding to the raingauge (data) situated within the same Thiessen Polygon. But the availability of water in the aquifer below, may also depend on rainfall in the surrounding areas. This has not been taken into consideration.

c) Withdrawl of ground water by deep and shallow tube wells has been ignored.

d) The period(s) in which failures occur is not a normal period(s) from the point of view of yearly average rainfall.

e) The assumption for Eq (4.1) that "monsoon breaks towards the month of June" - do not hold good for these cases.

The 39 cases out of a total of 185, the above model (Eq 4.1) is not universal one (vide low coefficient of determi-

nation values < 0.30), because of one reason or the other. An attempt was, therefore, made to find out a separate but suitable model for those cases. In this model, the monthly fluctuation of water table of each piezometer is expressed by the Eq (4.3). The values of r^2 (coefficient of determination) for each piezometric site for different years are available in the Table 4.11.

The generated values of water table depths using Eq (4.3) are very close to the observed values. In most of the cases r^2 (coefficient of determination) is high (evidence from Table 4.11). From this table, it is revealed that out of 39 cases the number of unsuccessful cases to be only 7 as observed from the values of r^2 . The seven cases are concentrated in Kaliganj (area EFH in Fig 3.6) for 1981-1982 (low rainfall year compared with the other years) and Karimpur (area ABCD in Fig 3.6) for 1982-1983.

With a view to general prediction of the average water table height for a particular piezometric site, the particular amount of rainfall Eq (4.4) can be used. By using the Eq (4.1), water table height can be predicted only for that particular year. Occurrence of rainfall is highly irregular in nature. On the other hand, it is very difficult to predict the actual amount of ground water extracted and the extent of water actually recharged from the surrounding areas by sub-surface flow. Therefore, the consideration of average water table depth with respect to average rainfall is better for such type of prediction purposes (Eq 4.4).

The coefficients of the Eq (4.4) are shown in Table 4.12. The water table depth of each piezometer was determined using Eq (4.4) and was compared with the observed values (average). The coefficient of determination (r^2) are also shown in Table 4.12.

It is evident from the Table 4.12 that the alternate coefficients of Eq (4.4) are negative except in PT 2. By scrutinizing the data set for PT 2, it is noted that very often

the positions of water table heights were below the mean sea level. This might be the reason for its failure.

For all cases (except two), the r^2 value lies in between 0.80 to 0.99. It can, therefore, be safely said that the model is good.

A simple model of depth versus time (Eq 4.5) has been evaluated. This is more or less successful in almost all cases (Tables 4.13 to 4.19), which is apparent from the high values of r^2 .

The symbol $t_{\min}$ and $t_{\max}$ correspond to the time of occurrences of maximum and minimum ground water depths obtained from $d^2D/dt^2 = 0$ (vide Eq 4.6). The values, thus, evaluated are shown in Tables 4.13 to 4.19. For example, in PT 3, the water table was in upper limit on 18th September 1978 and on 6th June 1979 (vide appendix II) the lower limit.

The signs of numerical values (obtained by least squares method) of A of the Eq (4.5) are mostly positive except in 16 cases. Similarly, signs in the all cases of B_1 are positive and signs with all B_2 are negative. Like the sign of A, the sign of B_3 also differs in four cases (negative) and the rests are positive. The PT 12 in the year 1978-1979, 1982-1983, 1984-1985 and PT 7 in the year 1978-1979 yield negative value of B_3 . The values of $t_{\min}$ for these four cases are determined graphically (vide Fig 5.2).

The recharge in ground water takes place mainly in july, August and September, i.e., during rainy season. An occasional recharge during pre-monsoon period (April, May and June) is not considered here for modelling because the sum total of discharge during October to June and occasional recharge during April, May and June is adjusted in such a fashion that the height of ground water falls down. Hence, the resultant effect is discharge which takes place during the period between October to June. Afterwards main recharge takes place, however, the discharge during July to September

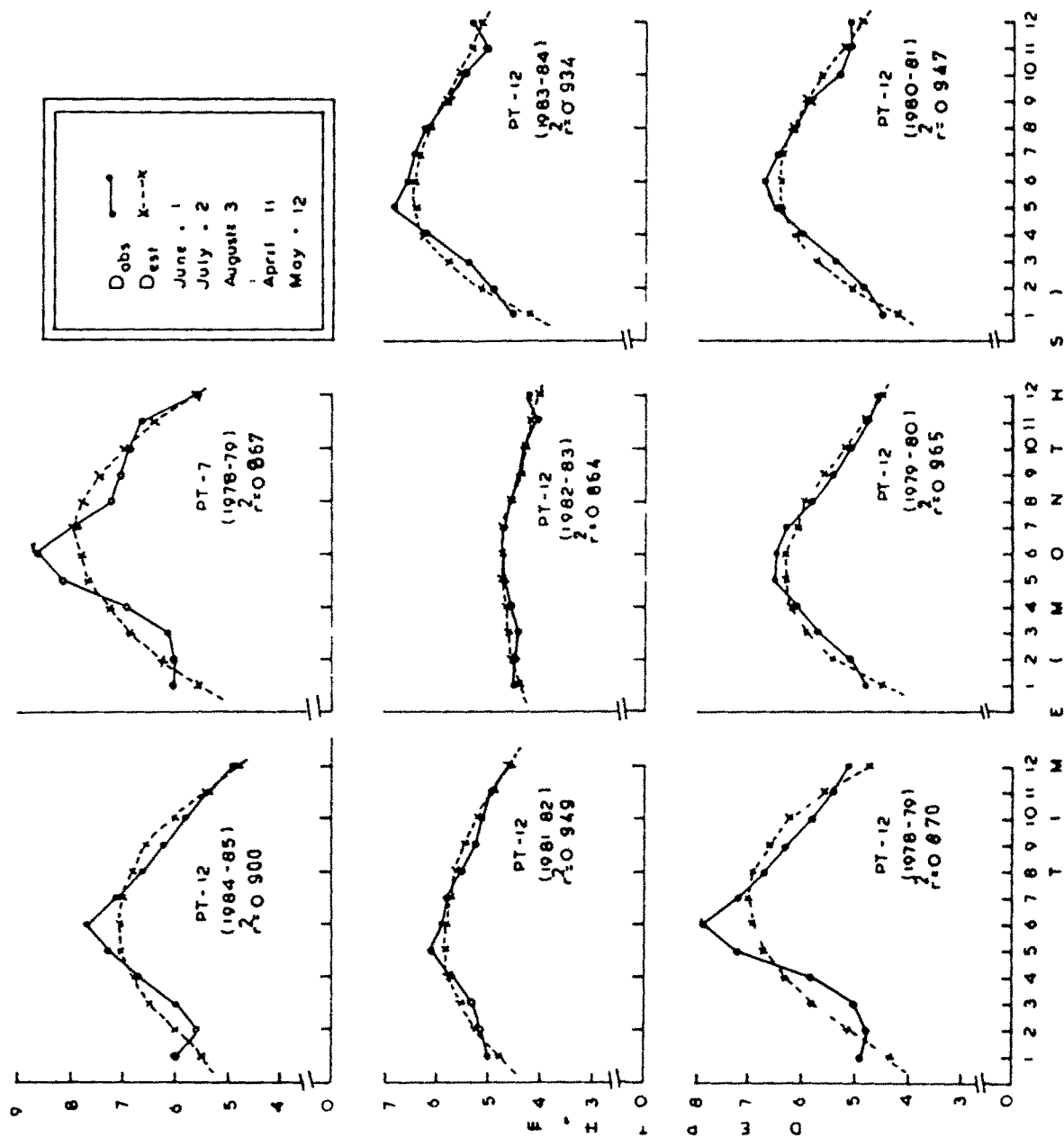


FIG 5.2 SAMPLE PLOT OF DEPTH VERSUS TIME FOR EIGHT CASES (VIDE Eq 4.5)

could not be isolated from recharge. Hence 85 per cent of 1/3rd of the total discharge during October to June is considered as discharge for the period between July to September and is added with the rise in height of water table for that period to obtain Δd value of each year for the purpose of modelling (Eqs 4.7 to 4.12)

The aquifer has porosity in which the recharge takes place. Hence the rise and fall in water table in the aquifer is not same as that of rise and fall in water level in a surface pond. It is much less. The problem was such that Δd value obtained in 1979 might not hold the same volume of water within the same Δd value obtained in 1980 as aquifer porosity changed tremendously due to the disturbances and shocks in it. Thus, $\Delta d = 40.6$ cm in one year and $\Delta d = 40.6$ cm in the other year does not convey the same message. This is the main limitation in handling such cases. This is also the main reason due to which the statistical r^2 , i.e., coefficient of determination value is so less in the present models. Moreover, a certain percentage of rainfall during October to June will also get recharged slowly which may ultimately take place in July, August and September and could not be separated out in this case. This is another reason of having low value.

The models (Eqs 4.7 to 4.12) may fail in other areas or in the same areas for coming years in view of non-availability of the records on discharge in each season.

Only two parametric value (data), namely, total rainfall and water table depths are available. The fluctuations of ground water table depend on many variables including rainfall. Thus, an attempt to establish model(s) of water table depths solely on rainfall (total) is destined to failure even to guesstimate the situations on many occasions. But some how, if these could be arrived at, it will be of immense help to the users. That is the reason why such attempts have been made in this study knowing fully apriori the limitations of such attempts.

SUMMARY AND CONCLUSION

6. SUMMARY AND CONCLUSION

Water is one of the most essential and important resources for the progress of modern human society. Ground water is one of the earth's widely distributed resources of the world and contributes significantly in the developmental plans of most of the countries. This is particularly true because ground water is a replenishable resource and it is a dynamic object. Any inefficient management of this resource may lead to serious threat in future. Hence, it is very essential to make a detailed study of ground water resources of a region before exploitation of this resource. One important feature of ground water, which needs detailed study, is the fluctuation of water table. This fluctuation depends on quite a good number of hydrologic, geomorphic and meteorologic variables. Mathematical modelling in this line has been introduced but these also miserably fail to express the real world situation in most of the places. The main object of the present work was to establish empirical models for prediction of monthly variations in water table depth with reference to rainfall and/or time.

From a review of the vast literatures available on this subject, it is observed that the water table which forms the upper surface of the saturated zone of the underground, fluctuates from day to day, season to season and year to year. A large number of factors (i.e., season, rainfall, drainage, evaporation, stream flow, ocean tide, soil etc.) are responsible for the fluctuation of this water table. But it is difficult to assess the combined resultant effect of all these variables. Thus, scientists are compelled to study the individual effect of one or two important but easily measurable variables on the fluctuations of water table. Rainfall is one of the most important parameters and source of all water supplies in the earth. The occurrence of rainfall is highly irregular in nature and does not follow a specific pattern. But with the introduction of cumulative monthly

rainfall, a conceptual parameter, the capacity to manage it either mathematically or graphically has gained importance.

Nadia district (West Bengal) was selected for the present study. The work was carried out in the above mentioned directions.

The information on the topography, soils, climate, irrigation, drainage system, land use pattern, ground water conditions and its fluctuations of the study area were obtained. Monthly rainfall data for a period of 10 years (1976-1985) for six raingauge stations (Karimpur Block Seed Farm, Tehatta Block Seed Farm, Kaliganj Block Development Office, Krishnagar Horticultural Farm, Santipur (Fulia) Gram Shevak Training Centre, Ranaghat Water Management Research Centre) of Nadia district were collected.

To find out recurrence interval of annual rainfall auto-correlation coefficients were done. The influence of rainfall on fluctuations of water tables and the recharge were expressed through managable empirical equations.

The data of ground water table in 32 piezometric sites scattered randomly throughout the district and the reduced levels of the piezometric sites were collected and attempt was made to find out suitable workable relation between monthly depth of ground water versus cumulative rainfall and time. The resonably acceptable models are as follows :

$$\frac{D}{R_c} = A + B_1 t_1 + B_2 t_1^2 + B_3 t_1^3 + B_4 t_1^4 + B_5 t_1^5 \quad \dots\dots (4.1)$$

Where, D = depth of ground water table with respect to mean sea level, (m).

R_c = monthly cumulative rainfall, starting from June and ending in the month of May in the next year, (m)

t = concerned month, values are June = 1, July =2, .
..... , May = 12

$i = 1 \text{ to } 12$

$A, B_1 \text{ to } B_5$ are empirical constants and coefficients.

In 39 cases out of total 185 the above model fails because of one reason or the other. For those particular cases the following model is suggested.

$$\frac{D}{R_c} = A + B_1 t_i^{-0.5} + B_2 t_i^{-1} + B_3 t_i^{-1.5} + B_4 t_i^{-2} \quad \dots\dots (4.3)$$

With the same significance of the symbols as in Eq (4.1)

In both the cases (Eqs 4.1 and 4.3), the constant terms, i.e., A, B_1, B_2, B_3 and B_4 were determined from the field data following least squares method.

These two models (Eqs 4.1 and 4.3) explain almost all the cases. The introduction of the term R_c (monthly cumulative rainfall) has enabled us to achieve this success.

To get further better results ($r^2 = 0.80 \text{ to } 0.99$), average ground water depths on the basis of average rainfall, the following model may be used :

$$\frac{D}{R_c} = A + B_1 t_i + B_2 t_i^2 + B_3 t_i^3 + B_4 t_i^4 + B_5 t_i^5 \quad \dots\dots (4.4)$$

Where, D = average depth of ground water table, with reference to mean sea level for any piezometer (m)

R_c = average monthly cumulative rainfall, starting from June and ending in May of the subsequent year (cm)

t = concerned month, values are June = 1, July = 2, ..., May = 12

$i = 1 \text{ to } 12$

$A, B_1 \text{ to } B_5$ are empirical constants.

But a fourth model alone can explain all the cases, this is given below :

$$\frac{D}{R_c} = A + B_1 t_1 + B_2 t_1^2 + B_3 t_1^3 \quad \dots\dots (4.5)$$

Where, D = depth of ground water table with reference to mean sea level (m)

t = concerned month, values as June = 1, July = 2, ..., May = 12

$i = 1$ to 12

A, B_1 to B_3 are the empirical constants and coefficients obtained by fitting the field data (least squares method). The time when the maximum and minimum water table depths reached, were obtained by solving

$$\frac{d^2 D}{dt^2} = 0 = B_1 + 2B_2 t + 3B_3 t^2 \quad \dots\dots (4.6)$$

Using these models the data (water table depths) were generated for the respective piezometric sites and compared with the observed values (vide Figs. 5.1 and 5.2 for few sample cases). It was observed that in most of the cases as the values of coefficient of determination (r^2), they are very close to the observed values.

Fluctuations of water table heights without any knowledge of recharge/discharge will loose its significance. Hence, model for recharge is suggested herein :

$$\Delta d = a R^b \quad \dots\dots (a.1)$$

Where, Δd = average recharge during the period July-August-September (m)

R = total rainfall during July-August-September over the area under a Thiessen polygon (cm)

a, b are empirical constants.

Because of non-availability of discharge data, model of discharge pattern could not be presented in this study.

From the present study, the following major conclusions may be drawn :

- i) The return period of annual rainfall follows approximately a sequence of an interval of four years.
- ii) A good correlation exists between monthly cumulative rainfall and ground water table depth (vide Eqs. 4.1 and 4.3)
- iii) On the basis of average rainfall, the average water table depth can be predicted (Eq 4.4) within its influencing area.
- iv) Time alone can tell the positions of water tables (Eq 4.5).
- v) The time corresponding to upper and lower limits of water tables may be obtained from Eq (4.6).
- vi) Recharge of ground water for the period July, August and September can be predicted by the model (Eqs 4.7 to 4.12) on the basis of rainfall within the influencing area of each raingauge station.

FUTURE SCOPE OF RESEARCH

7. FUTURE SCOPE OF RESEARCH

The present study reveals that the water table fluctuation is a complicated hydrological process which is resulted from several hydrological factors. The importance of these factors are likely to differ from season to season and place to place. In the present study, only rainfall has been taken into consideration as an excitation factor. The effect of other factors have been incorporated in the model. However, some important aspects on which further studies beyond the present investigation can be undertaken are as follows :

The model established in the present study can be improved by the use of other hydrological/meteorological parameters.

Mathematical models, similar to the present investigation can also be established for varying soil textures as well as for different climatic regions of the country and a study can be made as to which factors are predominant for a particular region. The ultimate aim should be to develop suitable model for different regions of the country.

The validity of the models need to be demonstrated by carrying out tests against future data for a considerable period of time.

Lastly, the influence of ground water table towards raising of crops through capillarity different periods of the year can also be studied.

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* Original not seen

APPENDIX - I

Prediction of monthly variation in water table depths with reference to rainfall and time for the year 1984-'85 for PT-12

PART- 1				PART- 2		
Month	Value of month t	Rainfall, R (m)	Water table depth, D _{obs} (m)	Cumulative rainfall, R _c (m)	D _{obs} /R _c	Estimated* water table depth, D _{est} (m)
June	1	0.4867	6.03	0.4867	12.38	6.02
July	2	0.3186	5.61	0.8053	6.96	5.63
August	3	0.3494	6.00	1.1547	5.19	5.94
September	4	0.2197	6.70	1.3744	4.87	6.73
October	5	0.0651	7.30	1.4395	5.07	7.37
November	6	0	7.69	1.4393	5.34	7.52
December	7	0	7.10	1.4395	4.93	7.24
January	8	0	6.66	1.4395	4.63	6.67
February	9	0.0093	6.20	1.4488	4.28	6.15
March	10	0.0112	5.80	1.4600	3.97	5.81
April	11	0.0038	5.45	1.4638	3.72	5.52
May	12	0.0833	4.88	1.5471	3.15	4.92

* Estimated water table depths were calculated from the equation:

$$D = R_c(24.0469 - 15.9964t + 5.0102t^2 - 0.7316t^3 + 0.0502t^4 - 0.0013t^5)$$

$$\text{Now, Coefficient of determination}(r^2) = \sqrt{\frac{S_T - S_E}{S_T}}$$

$$S_E = \sum (D_{obs} - D_{est})^2 = 0.0676$$

$$S_T = \sum D_{obs}^2 - \sum (D_{obs})^2 / N = 7.4969$$

$$r^2 = 0.995$$

APPENDIX - II

Prediction of monthly variation in water table depths with reference to time for the year 1978-'79 for PT-3

Month	Value of month t	Observed water table depths D _{obs} (m)	Estimated water table depth, D _{est} (m)
June	1	2.89	2.34
July	2	3.05	3.55
August	3	3.59	4.32
September	4	4.79	4.68
October	5	5.22	4.72
November	6	4.69	4.49
December	7	4.66	4.07
January	8	2.98	3.51
February	9	2.80	2.89
March	10	2.19	2.28
April	11	1.45	1.74
May	12	1.65	1.34

* Estimated water table depths were calculated from the equation :

$$D = 0.58242 + 2.0403t - 0.2981t^2 + 0.0111t^3$$

$$r^2 = \frac{(S_T - S_E)}{S_T}$$

$$S_E = \sum (D_{obs} - D_{est})^2 = 2.2129$$

$$S_T = \sum D_{obs}^2 - \frac{(\sum D_{obs})^2}{N} = 17.7216$$

$$r^2 = 0.935$$

Now, $\frac{d(D)}{d(t)} = 0.58242 + 2.0403t - 0.2981t^2 + 0.0111t^3$ // Requires check-up

$$\frac{d^2D}{dt^2} = 2.0403 - 2 \times 0.2981t + 3 \times 0.0111t^2$$

$$0 = 2.0403 - 0.5962t + 0.0333t^2$$

Therefore, $t_{min} = 13.2$ and $t_{max} = 4.6$

Here, $t_{max} = 4.6$ indicated that the highest depth of water table occurred on 18.9.1978 (from mean sea level) and $t_{min} = 13.3$ meant that the lowest depth of water table occurred

on 6.6.1979. This may be 6.5.1979. For maximum & minimum, first derivative is equated to zero. The negative & positive values of second derivatives signifies a maximum & a minimum.

APPENDIX - III

Prediction of ground water recharge during July-August-September

A model was developed to predict the gain in water table height within a Thiessen polygon area. It is assumed that ground water table within the same Thiessen polygon area was influenced by the rain which falls in that area. It is also assumed that the recharge of ground water takes place mainly in the months of July, August and September, i.e., during the rainy season. During this season, main recharge takes place (it was observed from the data), but the discharge during this season could not be isolated from recharge. Hence, 85 per cent of 1/3rd of the total discharge during October to June is considered as total discharge during July-August-September and added with the rise in height of water table during this period to obtain actual recharge (Δd) value for each year for modelling purposes. (The actual recharge (Δd), here is considered in height unit and is expressed in metre scale.) During the rainy season, consumption of ground water is less than the other seasons, hence 15 per cent were deducted from the 1/3rd of the total discharge during October to June. The rainfall data for the July-August-September of seven years were arranged in an ascending order ignoring its chronology but retaining the corresponding recharge (Δd) values. The recharge here was considered for the area which is influenced by that raingauge station determined through Thiessen polygon method. The cumulative values of rainfall (R_c) and cumulative recharge (Δd_c) values for the seven years show the straight line in logarithmic plot. The model may be expressed in the form :

$$\Delta d_c = a R_c^b \quad \dots\dots (a.1)$$

Where, a and b are empirical constants

Since it is better to use rainfall data for any particular period of observation for prediction of recharge, the

following symbols are used for the purposes mentioned against each of them:

R = rainfall for any particular month averaged over the period of observation, cm.

d = ground water recharge value averaged over number of piezometers and years for particular season, m.

$R_c = 7R$, as there were 7 years' data used for cumulative rainfall.

$\Delta d_c = 7\Delta d$, as there were 7 years' data used for cumulative ground water recharge for a Thiessen polygon area.

Replacing R_c by $7R$ and Δd_c by $7\Delta d$ in Eq(4.7) the equation obtained as:

$$7\Delta d = a 7^b R^b \quad \dots\dots\dots(a.2)$$

$$\text{or, } \Delta d = \frac{a}{7^{1-b}} R^b \quad \dots\dots\dots(a.3)$$

A case study for developing Eq (4.7) :

Part 1					
Year	Rainfall (cm)	Recharge for July-Aug-Sept (m)	Average discharge of Oct-June, (m)	85 % of average discharge, (m)	Actual Recharge in July-Sept, (m)
(1)	(2)	(3)	(4)	(5)	(3-5)
1978	61.55	1.059	0.164	0.139	1.198
1979	113.27	1.887	0.810	0.688	2.578
1980	53.08	0.594	0.486	0.413	1.007
1981	85.60	1.380	0.567	0.482	2.312
1982	50.05	2.448	0.935	0.795	3.243
1983	103.34	1.701	0.973	0.827	2.528
1984	96.80	2.976	0.458	0.389	3.365

Part 2

Rainfall,* R (cm)	Actual recharge, Δd (m)	Cumulative rainfall, R _c (cm)	Cumulative recharge, Δd _c (m)	Estimated** recharge, Δd (m)
50.05	3.243	50.05	3.243	1.540
53.08	1.007	103.13	4.250	1.604
61.55	1.198	164.68	5.448	1.778
85.60	2.312	250.28	7.760	2.238
96.80	3.365	347.08	11.125	2.438
103.34	2.528	540.42	13.653	2.551
113.27	2.575	563.69	16.228	2.720

*Rainfall is arranged in an ascending order ignoring its chronology

** Estimated recharge was calculated from the Eq :

$$\Delta d_c = 0.1823 R^{0.6963}$$

$$\text{As } R_c = 7R \text{ and } \Delta d_c = 7 \Delta d$$

$$\text{Therefore, } 7 \Delta d = 0.1823 (7R)^{0.6963}$$

$$\text{or, } \Delta d = \frac{0.1823}{7^{(1-0.6963)}} R^{0.6963}$$

$$\text{or, } \Delta d = 0.10096 R^{0.6963}$$

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The procedure adopted for developing Eq (4.7) is applied for the remaining five Thiessen polygon areas and the Eqs. (4.8) to Eq (4.12) are obtained.

$$r^2 = \sqrt{(S_T - S_E) / S_T}$$

$$\text{Where, } S_T = \sum \Delta d_{\text{obs}}^2 - \sum (\Delta d_{\text{obs}})^2 / N = 5.0351$$

$$S_E = \sum (d_{\text{obs}} - d_{\text{est}})^2 = 4.4790$$

$$\text{Therefore, } r^2 = 0.332$$