

## A meso-scale study of groundwater fluctuations of Delhi in relation to rainfall

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(Received 11 February 1970)

**ABSTRACT.** A study of groundwater level at Delhi in relation to rainfall has been conducted. Groundwater data for the period 1956 to 1966 in respect of 97 bores/holes in Delhi have been processed and synchronised and maps of mean ground-water level for urban Delhi have been prepared at fortnightly intervals for the monsoon period and at monthly intervals for the remaining months of the year. Monthly variations of groundwater levels against distance from river *Yamuna* have been studied and the distribution of the groundwater slope evaluated.

Inter-relationship between the rainfall and the groundwater levels has been studied graphically. A regression equation for the estimation of fortnightly groundwater level fluctuations from rainfall amount, duration of rainfall and the level of water in river *Yamuna* has been formulated and tested for its applicability.

### 1. Introduction

India is mainly an agricultural country depending, primarily, on the monsoon rainfall for crop irrigation. The failure of the monsoon for two consecutive years in 1965 and 1966 and the resulting drought conditions over certain parts of the country during this period caused much anxiety and concern both to the public and the Government. Since the failure of monsoon and the subsequent droughts are a recurring phenomenon for most parts of the country, the modern agriculturist is concerned to have an alternative stand-by source of irrigation, like tapping of groundwater. The groundwater resources are, however, not unlimited and it becomes essential to study the aspect of groundwater losses and recharge before banking upon this source as a permanent solution to the problem of irrigation. The present investigation is mainly devoted to the study of groundwater recharge of the Delhi region during the rainy season.

As an introduction to the approach followed in the present study it may be mentioned that the main sources of groundwater recharge over a particular region are (i) lateral flow of groundwater from the adjoining regions, (ii) percolation process in rivers, lakes, canals, drains and other water courses in the region, and (iii) infiltration of rain water into the ground. The contribution to groundwater from the first two sources is, however, more or less a continuous process in varying magnitudes but slower than the rate of contribution from the third factor, if and when operative, particularly in alluvial regions like the one under study. Thus in rainy season it is more

important to consider the contribution to groundwater from the rainfall whereas the other two factors may be of considerable importance during the dry season. Accordingly, an attempt has been made to correlate groundwater regime changes with particular reference to water table changes over urban Delhi during the monsoon season with the rainfall amount and its duration, taking also into consideration the effect of water level in river *Yamuna*.

### 2. Climatological, physical and geological features of Delhi

Delhi area, climatically, is a semi-arid region with normal annual rainfall of about 66 cm and with annual number of rainy days as 35. Nearly 85 per cent of the annual rainfall over this region occurs during monsoon season (June to September). From geological and morphological setting point of view, the quartzite ridge constitutes a striking feature. At good number of places the flat plains also figure with a general slope from west to east. A large portion of soil consists of fine particles and a small portion of coarse particles. Due to this characteristic of the soil lateral movement of underground water would be restricted. In the alluvial deposits, the permeable strata are present close to the land surface and the water table aquifer is sensitive to rise or fall of regional water levels depending on accretment to or extraction from the groundwater body through natural processes.

### 3. Source and the nature of groundwater data used

The available groundwater data for the period 1956 to 1966 of 97 bores/holes, selected on considerations of their length of record and regularity

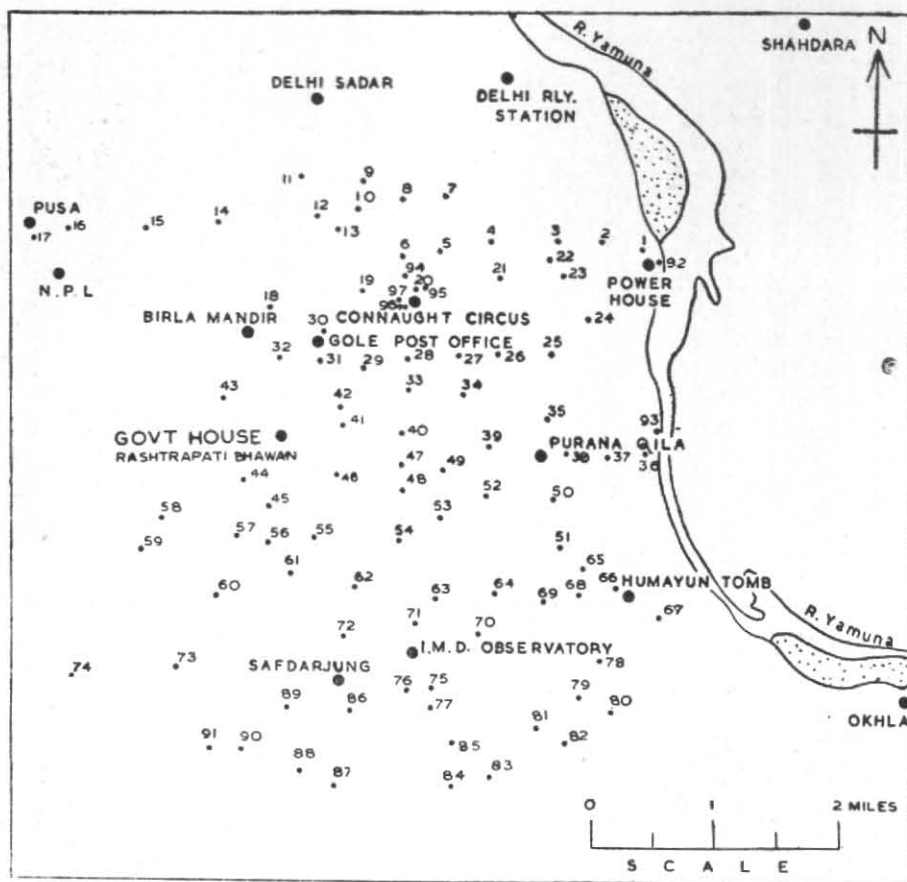


Fig. 1. Delhi and neighbourhood showing the location of bores/holes

of observations and of the adequacy of network of observations for map analysis, were obtained from the Central Public Works Department, New Delhi who are maintaining records of these observations at fortnightly intervals during the monsoon months (June to September) and at monthly intervals for the remaining months for over 400 bores/holes scattered over urban Delhi. Locations of these 97 bores/holes are shown in Fig. 1.

It will not be out of place to mention here that although there exists a good network of bores/holes over urban Delhi, their observations have a limited utility as they are not recorded at a fixed hour of time on the same day, and are instead arranged in such a way that one round of observations for all the bores/holes is completed in a period of 15 days. Nevertheless, an attempt has been made to synchronize the available data in the best possible manner to make them suitable for drawing any valid conclusions.

After proper scrutiny of the data for all the 16 observations in each year the same has been used

for the preparation of maps of mean groundwater levels as explained in Section 4. For the study of groundwater recharge, in relation to rainfall during monsoon season, only the groundwater data in respect of monsoon months, *i.e.*, 8 observations per year, have been made use of in combination with the rainfall totals, for the corresponding periods as discussed in Section 7.

#### 4. Maps of mean groundwater level

Using the scrutinised data of 11-year period from 1956 to 1966 mean groundwater level was calculated corresponding to the 16 observations per year at each of the 97 bores/holes considered for the study. Since, as pointed out earlier, the available groundwater observations do not have a fixed time base, the maps of mean groundwater level prepared from this data cannot also have a fixed time base. However, since observations are so arranged that a particular bore (or group of bores) gets its turn for observational record on one fixed date in each of the non-monsoon months and on two fixed dates in each of

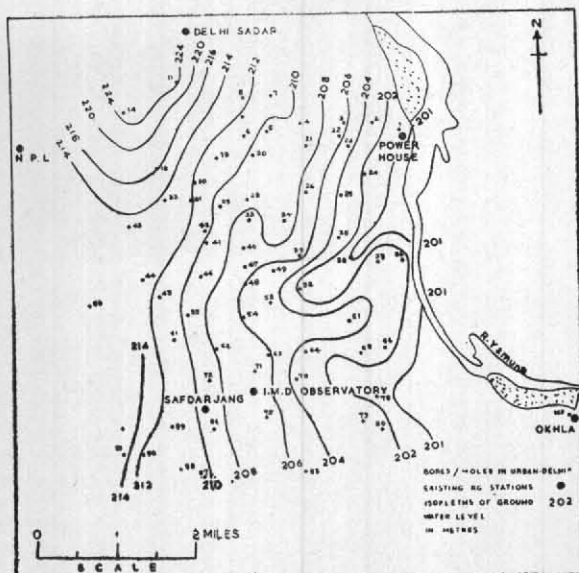


Fig. 2 (i)

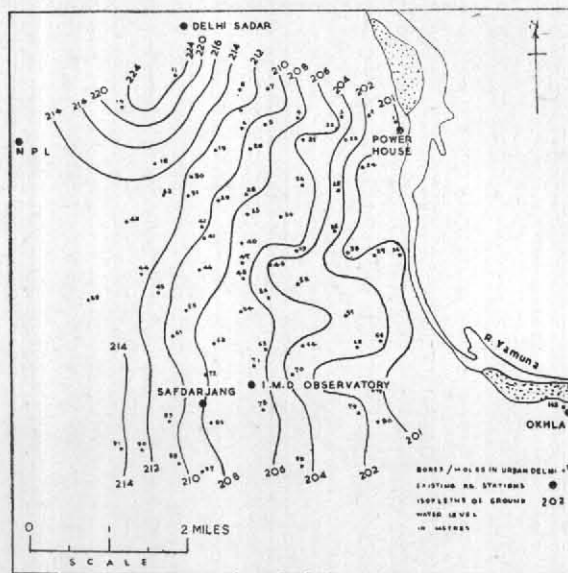


Fig. 2 (ii)

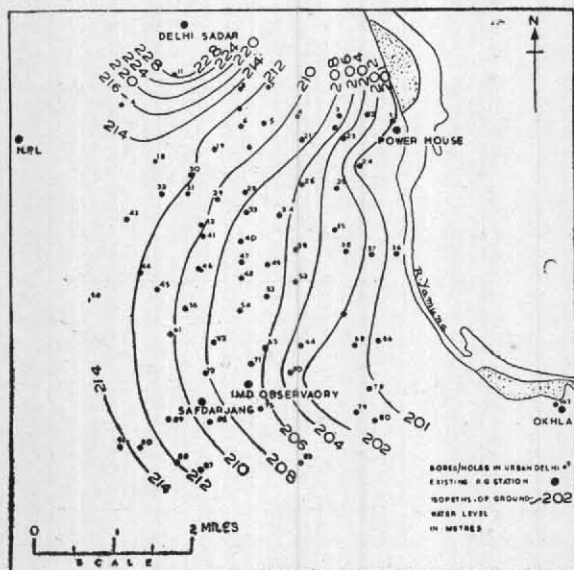


Fig. 2 (iii)

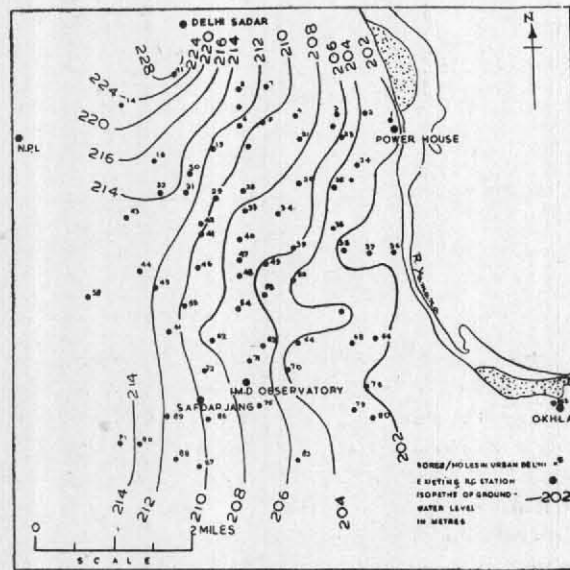


Fig. 2 (iv)

Figs. 2 (i)–(v). Maps of mean groundwater level (a.m.s.l) centred on (i) 8 January, (ii) 8 May, (iii) 1 June, (iv) 1 September and (v) 8 October

the monsoon months, it is possible to prepare maps of mean groundwater level centred on the 8th of each of the non-monsoon months and on 1st and 16th of each of the monsoon months, by considering data of bores/holes which observe groundwater levels within 7 days on either side of these dates. Thus, for example, map of mean groundwater level centred on 1 July can be prepared from the data of bores/holes which take observations between 25 June to 7 July. In this manner, by proper synchronisation of the mean groundwater level of different bores/holes, the maps of

mean groundwater level centred on 8th of each non-monsoon months and on 1st and 16th of each of the monsoon months have been prepared and a few representative maps are presented in Figs. 2 (i) to 2(v).

It is interesting to note from Figs. 2(i) to 2(v) that except for a general fall or rise in the groundwater level with the advent of time the pattern of mean groundwater level is almost identical in all the 5 maps and that the groundwater level attains its minimum during the month of May

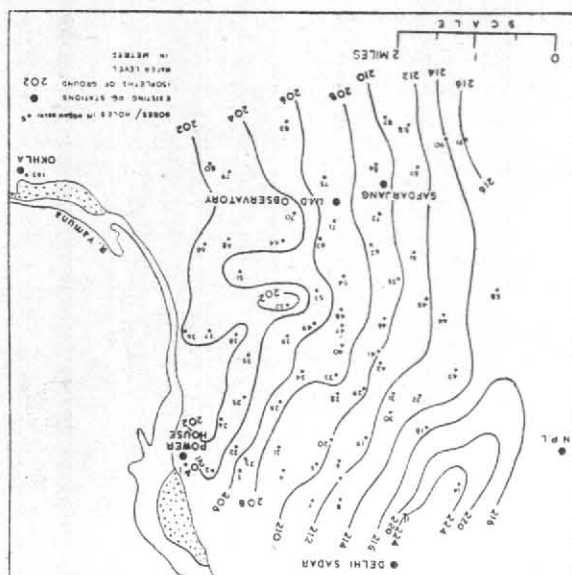


Fig. 2 (v)

TABLE 1

Estimated mean monthly groundwater levels (in metres) at the intersection of western bank of river Yamuna and vertical cross-section through bores 1, 23, 21, 20, 19, 18

Month	Mean level (m)	Month	Mean level (m)
January	201.4	July	200.9
February	201.6	August	201.7
March	201.2	September	202.0
April	201.0	October	202.0
May	200.9	November	201.8
June	200.9	December	201.5

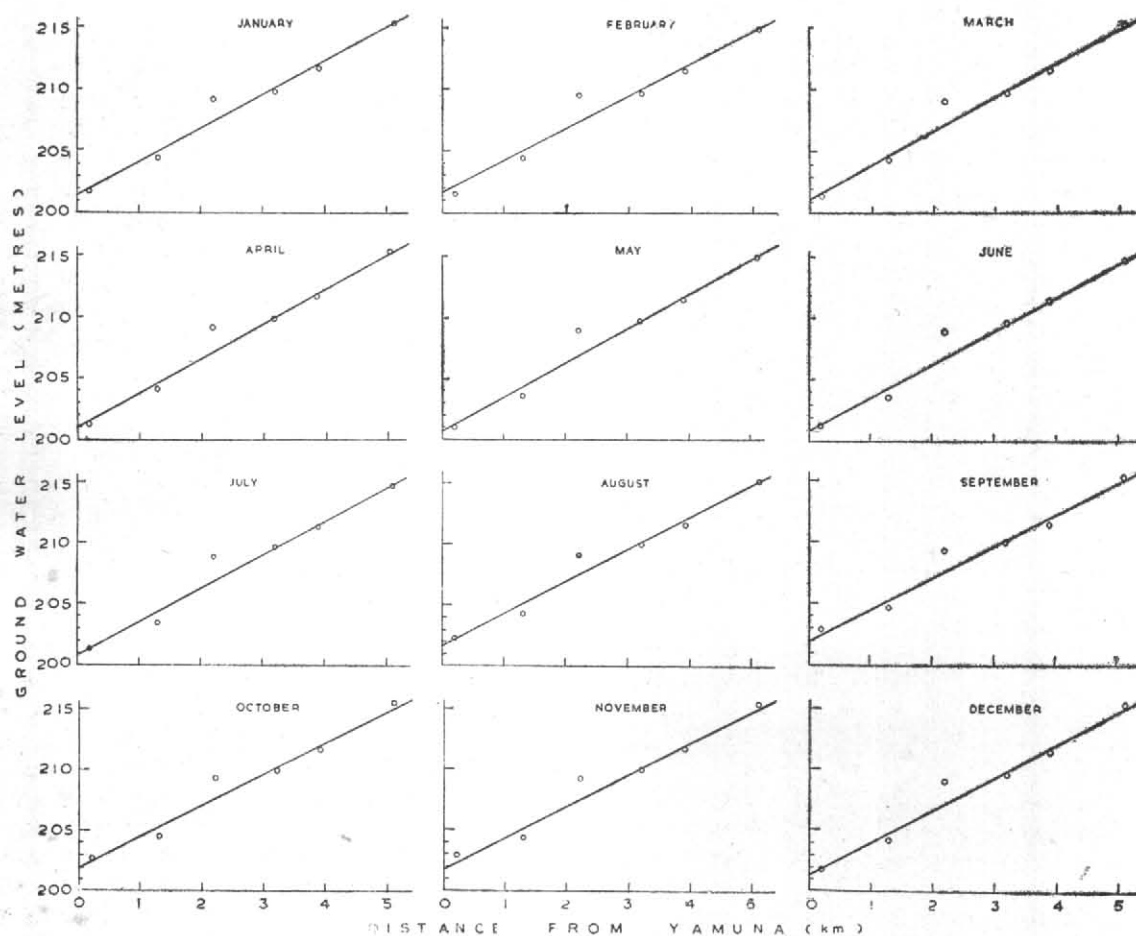


Fig. 3. Monthly variation of groundwater level with distance from river Yamuna (Jan--Dec)

or June and maximum towards the close of September. It is also noticed that the groundwater level has a general tendency to rise between June to September, and to fall from October till May or June of next year. Further, isopleths of groundwater level (above mean sea level) run almost in the direction of the flow of river *Yamuna* and acquire increasing values with increasing distance from the river. This shows that the slope of the groundwater is towards river *Yamuna* permitting recharge of the river by the under ground flow. The highest elevation of groundwater table of 228 metres is in Delhi Sadar area and lowest of 201 metres near Indraprastha Estate.

#### 5. Profile study of groundwater level

A profile study of the groundwater slope from the western bank of the river *Yamuna* to about 6 km west of it along a section through bores 1, 23, 21, 20, 19, 18 in order, which roughly coincides with the direction of movement of groundwater has been conducted. Graphs of mean groundwater level against distance from *Yamuna* were plotted for each month of the year, using the data of these 6 bores. All these graphs showed a linear slope. Accordingly, a straight line equation of the form  $Y = a + bX$  was fitted in each case by the method of least squares, where  $Y$  represents the groundwater level (metres),  $X$  the horizontal distance (km) from the western bank of the river *Yamuna* along cross-section through the aforesaid 6 bores,  $b$  the slope of the groundwater level along the chosen section and  $a$  the intercept (metres) above mean sea level along a vertical ordinate in the plane through its intersection with the western bank of the river *Yamuna*. The graphs with fitted linear slope of groundwater are shown in Fig. 3. The physical meaning of the constant  $a$  appearing in the equation  $Y = a + bX$  is that it represents estimated mean groundwater level at the intersection of western bank of the river *Yamuna* and the vertical cross-section through bores 1, 23, 21, 20, 19, 18. For the purpose of their interpretation the values of estimated mean monthly groundwater levels as represented by  $a$  are presented in Table 1.

It may be seen from Table 1 that the estimated groundwater level is minimum in the month of May/June and maximum in the month of September/October. During the period July to September there is a general rise in the groundwater level due to monsoon rainfall while during the period October to May/June (next year), there is a continuous depletion of groundwater. This is in agreement with the observations made from the maps of mean groundwater levels in Figs. 2(i) to 2(v).

#### Distribution of groundwater slope

Using the notation and technique explained in Section 5, the straight line equation  $Y = a + bX$  was fitted to the data of each individual month during the 11-year period from 1956 to 1966 from the data of bores along the cross-section already mentioned. Thus 132 equations were obtained and an equal number of values for the slope  $b$  were obtained. Treating the slope as a variable, a frequency curve was drawn. The shape of the frequency curve so obtained was found to resemble the normal frequency curve. The mean and standard deviation of  $b$  were calculated to be 2.72 and 0.15 respectively.

Normality of the data was tested by the conventional statistical method (Halen *et al.* 1953). On the assumption of the normality of the data the observed frequencies in each of the ten per cent equiprobability class intervals were computed and compared with the theoretical frequency which, for each class interval, is just one tenth of the total frequency, by  $\chi^2$ -test of goodness of fit. The  $\chi^2$ -test does not provide any objection against the assumption of normality of the slope values,  $b$ .

The slope of groundwater along the cross-section under study may, therefore, be assumed to follow a normal distribution with mean 2.72 and standard deviation 0.15. For a 68 per cent confidence the slope, therefore, lies in the interval  $2.72 \pm 0.15$ , *i.e.*, between 2.87 and 2.57 and for a 95 per cent confidence in the interval  $2.72 \pm 1.96 \times (0.15)$ , *i.e.*, between 3.01 and 2.43. Substituting the actual groundwater level near the western bank of the river *Yamuna* for  $a$  in the equation  $Y = a + bX$  the confidence interval for the groundwater level at a known distance,  $X$ , from *Yamuna* along the cross-section under reference can be constructed by using the corresponding confidence interval for  $b$ . Thus when the groundwater level near the western bank of the river *Yamuna* is 200 metres above mean sea level the groundwater level at a distance of 2 km across from the western bank lies with 68 per cent confidence, in the range  $200 + (2.87) \times 2$  to  $200 + (2.57) \times 2$ , *i.e.*, between 205.14 and 205.74 metres.

#### 6. Groundwater recharge through rainfall

The monthly groundwater fluctuations in respect of bore No. 71 nearest to Central Hydromet Observatory have been studied in relation to monthly rainfall (Jatinder Singh *et al.* 1966). A graph showing simultaneous variations of monthly rainfall at Central Hydromet. Observatory and fluctuations of groundwater level at bore No. 71 is given in Fig. 4. An important observation that can be made from this graph is that as against

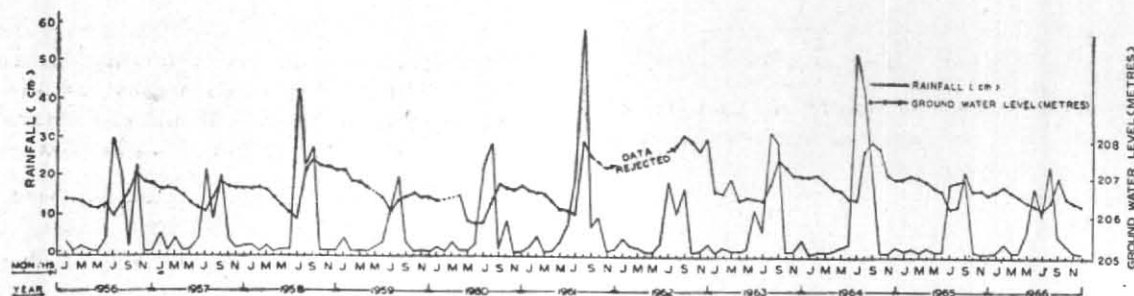


Fig. 4. Graph showing monthly variations of groundwater level (in metres) for bore No. 71 and monthly rainfall (in cm) for Central Hydromet. Observatory for the period 1956-1966

significant rainfall being recorded in the month of June, a significant rise in the groundwater table takes place from the month of July. This, apparently reveals a time lag of nearly one month between the rainfall and its effect on the groundwater table.

#### 7. Formulation of regression equation for the estimation of groundwater level

##### 7.1. Approach

Groundwater level at time  $t$  can be considered as the sum of groundwater level at unit time earlier and the change in groundwater level in the last unit time-interval. Mathematically, if  $Y_t$  be the groundwater level at time  $t$  and  $F_t$  the change in groundwater level during the unit interval preceding  $t$ , we can write —

$$Y_t = Y_{t-1} + F_t$$

Clearly, if groundwater level at a time  $t-1$ , is known and if the change  $F_t$  can be estimated by a suitable statistical method, the groundwater level at time  $t$ , can be obtained as their sum.

For the estimation of  $F_t$ , it may be recalled that although there are a number of factors which account for the total groundwater recharge, rainfall is the main source as far as the rainy season is concerned especially in water table aquifers. However, the same rainfall amount is apt to contribute differently to the groundwater recharge depending upon its intensity and duration. Consequently in the estimation of groundwater recharge the rainfall amount has been considered in conjunction with the duration of rainfall. Also as there is apparently a time lag of about one month between the commencement of rainfall and the corresponding significant rise in the groundwater level, the rainfall amounts and rainfall durations during the preceding one month should be considered for estimating the changes in groundwater.

Since, during the monsoon season the observations of groundwater level and, therefore, the change in groundwater levels, are available at a fortnightly intervals, it is possible to formulate a regression formula for the estimation of fortnightly groundwater changes only. Obviously, the unit of time as used in the estimation of groundwater changes has necessarily to be a fortnightly period. It is thus clear that in the estimation of groundwater change during the unit interval of time (fortnight) just preceding a given time  $t$ , the rainfall totals and the duration of rainfall during the two unit time intervals, viz., from  $t-1$  to  $t$  and from  $t-2$  to  $t-1$ , should be used.

It has also been considered relevant to include the possible influence of Yamuna level on the groundwater recharge. In order to ensure that the effect of river level is not under-estimated, the highest level reached by the river during the unit period just preceding the time at which the groundwater level is being estimated, has been taken as the appropriate parameter. Based on the above guidelines it is proposed to adopt the following regression model for the estimation of fortnightly groundwater changes.

#### Regression Model —

$$F_t = \alpha_1 R_t + \alpha_2 D_t + \alpha_3 R_{t-1} + \alpha_4 D_{t-1} + \alpha_5 L_t - \beta$$

In this regression model,  $\alpha_1$ ,  $\alpha_2$ ,  $\alpha_3$ ,  $\alpha_4$  and  $\alpha_5$  are regression constants and  $\beta$  is an absolute constant. The meaning of the other symbols used in the regression model is as under —

$F_t$  = Groundwater change in cm in the unit interval of time ending at time  $t$

$R_t$  = Total rainfall in mm during the unit interval of time ending at time  $t$

$D_t$  = Duration of rainfall in quarters of an hour during unit interval of time ending at time  $t$

$R_{t-1}$  = Total rainfall in mm during unit interval of time ending at time  $t-1$

$D_{t-1}$  = Duration of rainfall in quarters of an hour ending during unit interval of time ending at time  $t-1$

$L_t$  = Maximum level of *Yamuna* river in cm at Delhi Railway Bridge above a datum of 200 metres above mean sea level reached during the unit interval of time ending at time  $t$ .

### 7.2. Data requirements of the regression model

For mathematical evaluation of the above regression model it is essential to choose the proper data. Whereas there is no difficulty in the choice of proper data for elements appearing on the right hand side of the regression model it is a tricky problem to extract the appropriate data for the element on the left of the regression model, namely, the groundwater fluctuations. Strictly speaking it will be incorrect to use the mean groundwater level of a group of bores unless the groundwater observations on all these bores are taken simultaneously. Since there are no two bores, of which the data is maintained by Central Public Works Department, New Delhi, which are under simultaneous observation this would mean restricting the study of the proposed regression model as applied to a single bore. On the other hand, if we see from the point of observational error, the single bore observations and the fluctuation computed from them are likely to be more erroneous than the mean groundwater level of the number of bores and the fluctuations calculated from them. As a compromise, therefore, it is considered to be most appropriate to work out and test the above regression model for the groundwater fluctuations computed from the mean data of a few bores which are close to each other and have small observational time difference. Adopting this approach, bores 70, 71 and 72 on which groundwater observations during the rainy season are taken on 2nd or 3rd and 17th or 18th of each of the monsoon months and are close to the Central Hydromet. Observatory have been selected for this study. The fortnightly fluctuations of groundwater level have been worked from the average groundwater level in the three bores.

The correct meteorological data required for the proposed regression model, *viz.*, the total amount of rainfall and the duration of rainfall are easy to extract. They have been read for each fortnight in the monsoon season from the autographic records of rainfall for Central Hydromet. Observatory at Lodi Road, New Delhi.

Maximum fortnightly levels of river *Yamuna* were obtained from the daily stage records at Delhi Railway Bridge maintained by the Delhi Administration, Central Water and Power Commission and the Railway Authorities.

The proposed regression model has been evaluated from the data of five-year period for 1956 to 1960 and tested for its applicability to the remaining data up to 1966.

### 7.3. Evaluation of the regression constants

The regression constants have been evaluated by the least square method and regression equation so obtained is —

$$F_t = 0.215R_t + 0.025 D_t - 0.074 R_{t-1} - 0.106D_{t-1} + 0.057 L_t - 15.2$$

In the regression model the coefficient of  $R_{t-1}$  and  $D_{t-1}$  may be seen to be negative. This in plain language means that the rainfall and its duration in the period of 15 days to one month prior have a slight depleting effect on the groundwater level. One possible explanation for this could be that whenever there is a tendency of groundwater level to rise in association with excessive rainfall in a particular interval of time, the Central Public Works Department authorities pump out substantial amount of groundwater causing thereby an artificial depletion of groundwater level.

### 7.4. Applicability of the regression model

Before accepting the proposed regression model as a suitable tool for estimating groundwater fluctuations, it is desirable to put it to test. As a preliminary step it will be worthwhile to examine the closeness between the estimate provided by the regression model and the observed data of groundwater fluctuations utilised in its derivation. This can be seen from the graphs of observed and estimated fluctuations super-imposed over each other for monsoon months during the period 1956 to 1960. The agreement between the observed and estimated values in these graphs is exceedingly good except for the values for August and September 1956 (Fig. 5), when the trend shown by the two sets of values have gone out of phase. Thus, the regression equation is considered to fit well with the data utilised for its evaluation. As a next step it is necessary to test the applicability of the regression equation to the data of subsequent years. For this purpose similar graphs have been prepared for the period 1961 to 1966 and also for the year 1967 the data for which was received at the time of finalisation of the paper. A few more graphs are shown in Fig. 5. Here also the fortnightly values of computed and actual groundwater fluctuation

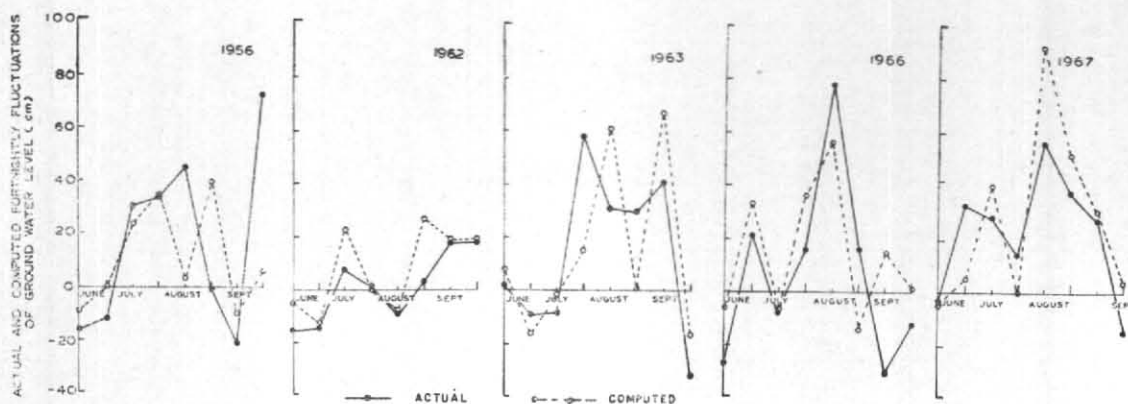


Fig. 5. Actual and computed fortnightly fluctuations of ground water level (cm) for June to September  
(i) 1956 (ii) 1962, (iii) 1963, (iv) 1966 and (v) 1967

are in good agreement in most of the cases during the entire period under study except for a few major departures particularly during mid-July to mid-August 1961 ; August 1963 ; September 1964 ; and mid-August to mid-September 1965.

The closeness of the fit between the actual and computed values of groundwater fluctuation establishes the usefulness of the proposed regression model. In fact the regression model can be used to project groundwater fluctuation  $F_t$ , a fortnight in advance by substituting the expected values of  $R_t$ ,  $D_t$  and  $L_t$  in place of their actual values in the regression model. The sum of  $Y_{t-1}$  and the projected value  $F_t$  then gives the projected value  $Y_t$  of groundwater level.

#### 8. Conclusions

- (i) The water table in urban Delhi rises or falls as a whole so that the configuration of groundwater level does not very much alter with the advent of time.
- (ii) The groundwater level rises during the monsoon season from June to October and recedes thereafter till May/June next year when this cycle starts once again.

(iii) The isopleths of mean groundwater level run almost in the direction of the flow of the river *Yamuna* and acquire increasing values with increasing distance to the west of the river. This implies that the groundwater level slopes down to the *Yamuna* river, thus permitting recharge of the river by underground flow.

(iv) The effect of rainfall on the recharge of groundwater is reflected after a lapse of 15 to 30 days.

(v) The proposed regression model estimates the fluctuations of groundwater level reasonably accurately and can also be used for projecting groundwater level a fortnight in advance.

*A acknowledgement*—The authors are grateful to Dr. P. Koteswaram, Director General of Observatories for his keen interest in hydrometeorological studies and to Delhi Administration Authorities (Central Public Works Department), for providing the necessary groundwater data. The authors are thankful to S/Shri T. C. Jasra, H. D. Bahl, P. K. Datta Roy, O. P. Arora and S. D. Gaur for their assistance in the preparation of this manuscript.

#### REFERENCES

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|--|------|--|
| Rao, Raghava and Raju, T. S.                     | 1962 | <i>Proc. natn. Inst. Sci., India</i> , 28A, 4. |
| Singh, Jatinder, Sehgal, S. R. and Singh, Rattan | 1966 | <i>A. Bull. int. Commn. Irrig. Drain.</i>      |
| Walker, Helen M. and Joseph, Lev.                | 1953 | <i>Statistical Inference</i> , pp. 119-121.    |