ASSESSMENT OF NATURAL GROUND WATER RECHARGE IN UPPER GANGA CANAL COMMAND AREA

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SYNOPSIS

Quantification of the rate of natural ground water recharge is a pre-requisite for efficient ground water resource management. It is particularly important in regions with large demands for ground water supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of ground water resources. Estimation of recharge, by whatever method, is normally subject to large uncertainties and errors. In this paper, an attempt has been made to derive an empirical relationship to determine ground water recharge from rainfall in Upper Ganga Canal command area based upon seasonal ground water balance study carried out for a number of years.

KEY WORDS: Rainfall, Water Balance, Recharge, Ground Water, Monsoon

INTRODUCTION

The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the ground water recharge. Thus, a quantitative evaluation of spatial and temporal distribution of ground water recharge is a pre-requisite for operating ground water resources system in an optimal manner.

Rainfall is the principal source for replenishment of moisture in the soil water system and recharge to ground water. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that will eventually reach the water table is defined as natural ground water recharge. The amount of this recharge depends upon the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type.

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Estimating the rate of aquifer replenishment is probably the most difficult of all measures in the evaluation of ground water resources. Estimates are normally and almost inevitably subject to large errors. No single comprehensive estimation technique can yet be identified from the spectrum of those available, which gives reliable results. Recharge estimation can be based on a wide variety of models which are designed to represent the actual physical processes. The methods, commonly in use for estimation of natural ground water recharge, include ground water balance method, soil water balance method, zero flux plane method, one-dimensional soil water flow model, inverse modelling technique, and isotope and solute profile techniques.

NATURAL GROUND WATER RECHARGE ESTIMATION IN INDIA

Rainfall is the most important source of ground water recharge in the country. The most commonly used methods for estimation of natural ground water recharge in India include empirical methods and ground water level fluctuation method. Based on the studies undertaken by different scientists and organisations regarding correlation of ground water level fluctuation and rainfall, some empirical relationships have been derived for computation of natural recharge to ground water from rainfall. One such relationship pertinent to the study area (Upper Ganga Canal command area) is given below.

Chaturvedi Formula

Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi in 1936, derived an empirical relationship to arrive at the recharge as a function of annual precipitation.

$$R = 2.0\,(P - 15)^{0.4} \qquad \text{... (1)}$$

where,

R = net recharge due to precipitation during the year (inch);
P = annual precipitation (inch).

This formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified form of the formula is

$$R = 1.35\,(P - 14)^{0.5} \qquad \text{... (2)}$$

The Chaturvedi formula has been widely used for preliminary estimations of ground water recharge due to rainfall. It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage of rainfall recharged commences from zero at P = 14 inches, increases upto 18% at P = 28 inches, and again decreases. The lower limit of rainfall in the formula may account for the runoff, soil moisture deficit, interception and evaporation losses. These factors being site specific, one generalized formula may not be applicable to all the alluvial areas. The above relationship, tentatively proposed for specific hydrogeological conditions (Ganga-Yamuna doab), needs to be examined and established or suitably altered.

A Ground Water Estimation Committee was constituted by Government of India in 1982 to recommend methodologies for estimation of the ground water resource potential in India. It was recommended by the committee that the ground water recharge should be estimated based on ground water level fluctuation method. However, in areas, where ground water level monitoring is not being done regularly, or where adequate data about ground water level fluctuation is not available, adhoc norms of rainfall infiltration may be adopted.

With a view to review the Ground Water Resources Estimation Methodology and to look into all the related issues, a Committee on Ground Water Estimation was again constituted in November 1995. The report of the Committee was released in June 1997. This Committee has proposed several improvements in the existing methodology based on ground water level fluctuation approach. The Committee has also revised the norms of recharge assessment based on rainfall infiltration factor.

It has been reported that the ground water resource estimation methodology recommended by Ground Water Resource Estimation Committee is being used by most of the organisations in India.

GROUND WATER BALANCE METHOD

Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and its dynamic behaviour under the influence of man's activities. The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specified period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system.

The basic concept of water balance is:

Input to the system - outflow from the system
= change in storage of the system (over a period of time)

The general methods of computations of water balance include:

(i) identification of significant components,
(ii) evaluating and quantifying individual components, and
(iii) presentation in the form of water balance equation.

Considering the various inflow and outflow components, the ground water balance equation for a time period Δt is given as:

$$R_i + R_c + R_r + R_t + S_i + I_g = E_t + T_p + S_e + O_g + \Delta S \qquad \text{... (3)}$$

where,

R_i = recharge from rainfall;
R_c = recharge from canal seepage;
R_r = recharge from field irrigation;
R_t = recharge from tanks;
S_i = influent seepage from rivers;
I_g = inflow from other basins;
E_t = evapotranspiration;
T_p = draft from ground water;
S_e = effluent seepage to rivers;
O_g = outflow to other basins; and
ΔS = change in ground water storage.

Equation (3) is the general ground water balance equation for an unconfined aquifer. The boundaries of an area usually studied, do not represent stream lines, i.e. they are not perpendicular to the equipotential lines. Hence, the lateral inflow and outflow (I_g and O_g) of ground water crossing the area's boundaries must be accounted in the balance equation. One of the factors influencing the change in water table is the specific yield, S_y, of the zone in which the water table fluctuations occur. It has been recognized that S_y changes as the depth of the water table changes, especially for water tables less than 3 meters deep. Furthermore, it should be noted that if the water table drops, part of the water is retained by the soil particles; if it rises, air can be trapped in the interstices that are filling with water. Hence S_y for rising water is, in general, less than for a falling water table.

All elements of the water balance equation are computed using independent methods wherever possible. Computations of water balance elements always involve errors, due to shortcomings in the techniques used. The water balance equation therefore usually does not balance, even if all its components are computed by independent methods. The discrepancy of water balance is given as a residual term of the water balance equation and includes the errors in the determination of the components and the values of components which are not taken into account. If it is not possible to obtain the value of a balance component by computation, the component may be evaluated as a residual term in the water balance equation.

The water balance may be computed for any time interval. In areas where most of the rainfall occurs in a part of year, it is desirable to conduct water balance study on part year basis, that is, for monsoon period and non-monsoon period. Generally, the periods for study in such situations will be from the time of maximum water table elevation to the time of minimum water table elevation as the non-monsoon period and from the time of minimum water table to the time of maximum water table elevation as monsoon period. For northern India, the water year can be taken as November 1 to October 31 next year. The monsoon and non-monsoon periods can be taken as June to October and November to May next year respectively. It is desirable to use the data of a number of years preferably covering one cycle of a dry and a wet year.

The complexity of the computation of the water balance tends to increase with increase in area. This is due to a related increase in the technical difficulty of accurately computing the numerous important water balance components. To apply equation (3) correctly, it is essential that both the area and the period for which the balance is assessed, be carefully chosen.

A pre-requisite for successful application of this technique is very extensive and accurate hydrological and meteorological data. The water balance approach is valid for the areas where the year can be divided into monsoon and non-monsoon periods with the bulk of rainfall occurring in former. Water balance study for monsoon and non-monsoon periods is carried out separately. The former yields an estimate of recharge coefficient and the later determines the degree of accuracy with which the components of water balance equation have been estimated.

The steps to be followed in a seasonal ground water balance study are:

1. Divide the year into monsoon and non-monsoon periods.

2. Estimate all the components of the water balance equation other than rainfall recharge for monsoon period using the available hydrological and meteorological information and employing the prevalent methods for estimation.

3. Substitute these estimates in the water balance equation and thus calculate the rainfall recharge and hence recharge coefficient (recharge/rainfall ratio). Compare this estimate with those given by various empirical relations valid for the area of study.

4. For non-monsoon season, estimate all the components of water balance equation including the rainfall recharge which is calculated using recharge coefficient value obtained through the water balance of monsoon period. The rainfall recharge will be of very small order in this case. A close balance between the left and right sides of the equation will indicate that the net recharge from all the sources of recharge and discharge has been quantified with a good degree of accuracy.

THE STUDY AREA

The Upper Ganga Canal (U.G.C.) system is a leading irrigation system in India. It extends over an area of 24,000 sq.km. bounded by natural or man made water courses on all sides, river Ganga on the eastern side, river Hindon and Yamuna on the western side, a portion of U.G.C. and Deoband branch on the northern side and lower Ganga canal on the southern side. The command area of the system is located between 27^o N to 30^o N latitude and 77^o 15' E to 78^o 40' E longitude covering the districts of Bulandshahr and Aligarh and parts of the districts of Saharanpur, Muzaffarnagar, Meerut, Ghaziabad, Mathura, Agra, Etah and Mainpuri (Uttar Pradesh). However, because of the limited availability of data, the study area has been restricted upto Bulandshahr district only, with the study area of around 12,500 sq.km., covering the Bulandshahr district and parts of the districts of Saharanpur, Muzaffarnagar, Meerut and Ghaziabad (figure 1).

Climatically, the area belongs to dry sub-humid to moist-humid category. The normal annual rainfall varies from 1050 mm in the north to 650 mm in the south. Around 90% of annual rainfall occurs in monsoon season (June to October). The annual pan evaporation for the area is around 150 cm. The temperature varies from 3^o C to 4^o C in January to 43^o C to 45^o C in May or June.

The Upper Ganga Canal system is fed through a head work complex with a regulation at Mayapur and a diversion weir at Bhimgoda across the river Ganga. The important branches of the system are Deoband branch (taking off on left bank at 35 km), Anupshahr branch (taking off on left bank at 80 km), Mat branch (taking off on right bank at 177 km), and Hathras branch (taking off from Mat branch on left bank at 80 km). The main canal is 290 km long upto the supply channel. The system is unlined with a network of 115 distributories, out of which 52 distributories come under the present study area. The distributories and minor irrigate nearly 60% of the area. The canal system is connected with natural drains and rivers to discharge surplus water of canal.

The main and branch canals of the system are designed as ridge canals and run mostly in cutting or partial cutting. The aquifers in the region are part of Indogangetic alluvium and very deep. They are tapped mostly by private devices (tubewells, pumpsets, rahats etc.) in shallow depth of around 25 metres to 35 metres and state/public tubewells to a depth of 100 metres to 150 metres. The permeability of the aquifer ranges from 17 metres/day to 33 metres/day in the study area. The ground water elevation in the study area varies from 280 metres above M.S.L. in the north to 180 metres above M.S.L. in the south. The depth to water table in the region varies, the fluctuation being 0.3 metre to 0.8 metre between the pre-monsoon and post-monsoon periods.

DETERMINATION OF NATURAL GROUND WATER RECHARGE

Part of the rain water, that falls on the ground, is infiltrated into the soil. This infiltrated water is utilized partly in filling the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. Recharge due to rainfall depends on various hydrometeorological and topographic factors, soil characteristics and depth to water table.

The ground water balance for the study area of Upper Ganga Canal command was carried out seasonwise for monsoon (June to October) and non-monsoon (November to May) seasons from 1972-73 to 1983-84 (Kumar and Seethapathi, 1988). All components of the ground water balance equation, other than the rainfall recharge, were estimated using the relevant hydrological and meteorological information. The rainfall recharge for monsoon seasons of the study period was calculated by substituting these estimates in the ground water balance equation. Table 1 presents the rainfall recharge in monsoon seasons of the study period and the corresponding recharge coefficients.

Table 1 : Ground Water Recharge from Rainfall

S. No.	Year	Mean Rainfall in Monsoon Season (inch)	Ground Water Recharge from Rainfall in Monsoon Season (inch)	Recharge Coefficient
1	1972-73	26.496	4.004	0.1511
2	1973-74	27.433	4.301	0.1568
3	1974-75	25.760	3.485	0.1353
4	1975-76	52.252	9.625	0.1842
5	1976-77	24.665	3.426	0.1389
6	1977-78	33.512	5.737	0.1712
7	1978-79	44.654	8.319	0.1863
8	1979-80	14.516	0.864	0.0595
9	1980-81	26.382	3.918	0.1485
10	1981-82	19.016	1.816	0.0955
11	1982-83	19.740	1.889	0.0957
12	1983-84	38.256	6.714	0.1755

It was observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. Recharge coefficients (based upon the rainfall in monsoon season) were calculated for the monsoon seasons of the study period and given as recharge/rainfall ratio. The recharge coefficient was found to vary between 0.05 to 0.19 for the study area.

For non-monsoon seasons, unaccounted water was computed as (inflow - outflow - change in ground water storage), the discrepancy being less than 150 Million Cubic Metres in all cases. Keeping in view the large study area (12,508.938 sq.km.) and the total quantity of water involved, this amount of unaccounted water seems to be quite reasonable and within limits. Therefore, overall water balance can be considered in order although individual components may have some errors.

The following empirical relationship (similar to Chaturvedi formula) was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$$R = 0.63 (P - 15.28)^{0.76} \quad \text{... (4)}$$

where,

R = Ground water recharge from rainfall in monsoon season (inch);
P = Mean rainfall in monsoon season (inch).

Table 2 : Relative Errors with Proposed Relationship

S. No.	Year	Mean Monsoon Rainfall, P (inch)	Rainfall Recharge during the Monsoon Season, R (inch)		Relative Error (%)
			Ground Water Balance Study	Proposed Relationship $R=0.63(P-15.28)^{0.76}$	
1	1972-73	26.496	4.004	3.956	1.20
2	1973-74	27.433	4.301	4.204	2.26
3	1974-75	25.760	3.485	3.757	7.80
4	1975-76	52.252	9.625	9.793	1.74
5	1976-77	24.665	3.426	3.454	0.82
6	1977-78	33.512	5.737	5.722	0.26
7	1978-79	44.654	8.319	8.222	1.17
8	1979-80	14.516	0.864	-	-
9	1980-81	26.382	3.918	3.925	0.18
10	1981-82	19.016	1.816	1.715	5.56
11	1982-83	19.740	1.889	1.963	3.92
12	1983-84	38.256	6.714	6.822	1.61

Table 3 : Relative Errors with Chaturvedi Formula

S. No.	Year	Mean Monsoon Rainfall, P (inch)	Rainfall Recharge from Ground Water Balance Study (inch)	Chaturvedi Formula $R=2.0(P-15)^{0.4}$		Modified Chaturvedi Formula $R=1.35(P-14)^{0.5}$	
				Rainfall Recharge (inch)	Relative Error (%)	Rainfall Recharge (inch)	Relative Error (%)
1	1972-73	26.496	4.004	5.312	32.67	4.772	19.18
2	1973-74	27.433	4.301	5.481	27.44	4.948	15.04
3	1974-75	25.760	3.485	5.173	48.44	4.630	32.86
4	1975-76	52.252	9.625	8.501	11.68	8.350	13.25
5	1976-77	24.665	3.426	4.956	44.66	4.409	28.69
6	1977-78	33.512	5.737	6.427	12.03	5.963	3.94
7	1978-79	44.654	8.319	7.760	6.72	7.474	10.16
8	1979-80	14.516	0.864	-	-	0.970	12.27
9	1980-81	26.382	3.918	5.291	35.04	4.750	21.24
10	1981-82	19.016	1.816	3.488	92.07	3.024	66.52
11	1982-83	19.740	1.889	3.727	97.30	3.234	71.20
12	1983-84	38.256	6.714	7.041	4.87	6.649	0.97

The "proportion of variance explained" was found to be 98.86% for the above proposed relationship. Equation (4) indicates that recharge to ground water commences at P = 15.28 inch. Therefore, it gives no recharge for the year 1979-80 with P = 14.516 inch. Table 2 presents the relative errors (%) in the estimation of rainfall recharge from the proposed empirical relationship as compared to ground water balance study. In almost all the years, the relative error was found to be less than 8%. On the other hand, relative errors (%) computed from Chaturvedi formula (equations 1 and 2) were found to be quite high, as indicated in Table 3. Therefore equation (4) can conveniently be used for better and quick assessment of natural ground water recharge in Upper Ganga Canal command area.

CONCLUSION

The choice of method for estimating natural ground water recharge should be guided by the objectives of the study, available data and possibilities to get supplementary data. Water balance approach, essentially a lumped model study, is a viable method of establishing the rainfall recharge coefficient and for evaluating the methods adopted for the quantification of discharge and recharge from other sources.

Based upon the seasonal ground water balance study for Upper Ganga Canal command area, an empirical relationship has been suggested for estimation of the ground water recharge from rainfall with reasonable accuracy.

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