ASSESSMENT OF GROUND WATER POTENTIAL

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ABSTRACT

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. In this paper, an attempt has been made to describe the methodologies to understand and evaluate the various recharge and discharge components of ground water balance equation and to establish the recharge coefficient with a view to work out the ground water potential of an area.

INTRODUCTION

In view of increasing demand of water for various purposes like agricultural, domestic, industrial etc., a greater emphasis is being laid for a planned and optimal utilization of water resources. Due to uneven distribution of rainfall both in time and space, the surface water resources are unevenly distributed. Also, increasing intensities of irrigation from surface water alone may result in alarming rise of water table creating problems of waterlogging and salinization, affecting crop growth adversely and rendering large areas unproductive. This has resulted in increased emphasis on development of ground water resources. The simultaneous development of ground water specially through dug wells and shallow tubewells will lower water table, provide vertical drainage and thus can prevent waterlogging and salinization. Areas which are already waterlogged can also be reclaimed. On the other hand continuous increased withdrawals from a ground water reservoir in excess of replenishable recharge may result in regular lowering of water table. In such a situation, a serious problem is created resulting in drying of shallow wells and increase in pumping head for deeper wells and tubewells. This has led to emphasis on planned and optimal development of water resources.

An appropriate strategy will be to develop water resources with planning based on conjunctive use of surface water and ground water. For this the first task would be to make a realistic assessment of the surface water and ground water resources and then plan their use in such a way that full crop water requirements are met and there is neither waterlogging nor excessive lowering of ground water table. It is necessary to maintain the ground water reservoir in a state of dynamic equilibrium over a period of time and the water level fluctuations have to be kept within a particular range over the monsoon and non-monsoon seasons.

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. 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.

GROUND WATER BALANCE EQUATION

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

$$Ri + Rc + Rr + Rt + Si + Ig = Et + Tp + Se + Og + \Delta S$$

where,

Ri = recharge from rainfall;
Rc = recharge from canal seepage;
Rr = recharge from field irrigation;
Rt = recharge from tanks;
Si = influent seepage from rivers;
Ig = inflow from other basins;
Et = evapotranspiration;
Tp = draft from ground water;
Se = effluent seepage to rivers;
Og = outflow to other basins; and
ΔS = change in ground water storage.

This equation considers only one aquifer system and thus does not account for the interflows between the aquifers in a multi-aquifer system. However, if sufficient data related to water table and piezometric head fluctuations and conductivity of intervening layers are available, the additional terms for these interflows can be included in the governing equation.

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.

The water balance may be computed for any time interval. 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.

STUDY AREA

A basinwise approach yields the best results where the ground water basin can be characterized by prominent drainages. A thorough study of the topography, geology and aquifer conditions should be taken up. The limit of the ground water basin is controlled not only by topography but also by the disposition, structure and permeability of rocks and the configuration of the water table. Generally, in igneous and metamorphic rocks, the surface water basin and ground water basin are coincident for all practical purposes, but marked differences may be encountered in stratified sedimentary formations. Therefore, the study area for ground water balance study is preferably taken as a doab which is bounded on two sides by two streams and on the other two sides by other aquifers or extension of the same aquifer.

STUDY PERIOD

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.

DATA REQUIREMENT

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

Rainfall data : Monthly rainfall data of sufficient number of stations lying within or around the study area should be available. The location of raingauges should be marked on a map.

Land use data and cropping patterns : Land use data are required for estimating the evapotranspiration losses from the water table through forested area. Crop data are necessary for estimating the spatial and temporal distributions of the ground water withdrawals and canal releases, if required. Evapotranspiration data and monthly pan evaporation rates should also be available at few locations for estimation of consumptive use requirements of different crops.

River data : River data are required for estimating the interflows between the aquifer and hydraulically connected rivers. The data required for these computations are the river gauge data, monthly flows and the river cross-sections at a few locations.

Canal data : Monthwise releases into the canal and its distributories along with running days each month will be required. To account for the seepage losses, the seepage loss test data will be required in different canal reaches and distributories.

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

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

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

Draft from wells : A complete inventory of the wells operating in the area, their running hours each month and discharge are required for estimating ground water withdrawals. If draft from wells is not known, this can be obtained by carrying out sample surveys.

ESTIMATION OF GROUND WATER BALANCE COMPONENTS

The estimation of the various inflow and outflow components of the ground water balance equation are discussed below.

1. Recharge from Rainfall (Ri)

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 methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions, ground water estimation committee norms, water balance approach, and soil moisture data based methods.

Empirical Methods

(i) 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.

$$R = 2.0 (P - 15)^{0.4}$$

where,

R = net recharge due to precipitation during the year, in inches;
P = annual precipitation, in inches.

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

$$R = 1.35 (P - 14)^{0.5}$$

The Chaturvedi formula has been widely used for preliminary estimations of ground water recharge due to rainfall.

(ii) Amritsar formula : Using regression analysis for certain doabs in Punjab, Sehgal developed a formula in 1973 for Irrigation and Power Research Institute, Punjab.

$$R = 2.5 (P - 16)^{0.5}$$

where, R and P both are measured in inches.

(iii) Krishna Rao : Krishna Rao gave the following empirical relationship in 1970 to determine the ground water recharge in limited climatological homogeneous areas :

$$R = K (P - X)$$

The following relation is stated to hold good for different parts of Karnataka :

$R = 0.20 (P - 400)$ for areas with annual normal rainfall (P) between 400 and 600 mm

$R = 0.25 (P - 400)$ for areas with P between 600 and 1000 mm

$R = 0.35 (P - 600)$ for areas with P above 2000 mm

where, R and P are expressed in millimeters.

The relationships indicated above, which were tentatively proposed for specific hydrogeological conditions, have to be examined and established or suitably altered for application to other areas.

Ground Water Estimation Committee Norms

A committee 'Ground Water Estimation Committee' was constituted in 1982 to improve the existing methodologies for estimation of the ground water resource potential. It was recommended 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. As a guideline, following norms for recharge from rainfall may be adopted :

(i) Alluvial areas

In sandy areas	- 20 to 25 percent of rainfall
In areas with higher clay content	- 10 to 20 percent of rainfall

(ii) Semi-consolidated sandstones

Friable and highly porous	- 10 to 15 percent of rainfall

(iii) Hard rock areas

Granitic terrain :	
Weathered and fractured	- 10 to 15 percent of rainfall
Unweathered	- 5 to 10 percent of rainfall
Basaltic terrain :	
Vesicular and jointed basalt	- 10 to 15 percent of rainfall
Weathered basalt	- 4 to 10 percent of rainfall
Phyllites, limestones, sandstones, quartzites, shales etc.	- 3 to 10 percent of rainfall.

The figures indicated above are given as a guideline and it does not automatically imply that upper limit can invariably be applied. Based upon the status of knowledge available, a value in between can be chosen.

Water Balance Approach

In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevant hydrological and meteorological information. The rainfall recharge is calculated by substituting these estimates in the water balance equation. 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 seasons 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.

Soil Moisture Data Based Methods

Soil moisture data based methods are the lumped and distributed model and the nuclear methods. In the lumped model, the variation of soil moisture content in the vertical direction is ignored and any effective input into the soil is assumed to increase the soil moisture content uniformly. Recharge is calculated as the remainder when losses, identified in the form of runoff and evapotranspiration, have been deducted from the precipitation with proper accounting of soil moisture deficit. In the latter model, the variation of soil moisture content in the vertical direction is accounted for and the method involves the numerical solution of partial differential equation (Richards equation) governing one-dimensional flow through unsaturated medium, with appropriate initial and boundary conditions.

Nuclear techniques have been extensively used for the determination of recharge by measuring the travel of moisture through the soil column. The technique is based upon the existence of a linear relation between neutron count rate and moisture content (% by volume) for the range of moisture contents generally occurring in the unsaturated soil zone. The mixture of Beryllium (Be) and Radium (Ra) provide a convenient source of neutrons. Another method is the gamma ray transmission method based upon the attenuation of gamma rays in a medium through which it passes. The extent of attenuation or absorption is closely linked with moisture content of the soil medium. The method can be used without causing health hazards.

2. Recharge from Canal Seepage (Rc)

Seepage refers to the process of water movement from a canal into and through the bed and wall material. Seepage losses from canals often constitute a significant part of the total recharge to ground water system. Hence it is important to properly estimate these losses for recharge assessment to ground water system. A number of investigations have been carried out to study the seepage losses from canals. The following formulae/ values are in vogue for the estimation of seepage losses :

(a) In Uttar Pradesh, the losses per million square meter of wetted area in unlined channels are usually taken as 2.5 cumecs for ordinary clay loam to about 5 cumecs for sandy loam with an average of 3 cumecs. Empirically the seepage losses can be computed using the following formula :

$$\text{Losses in cumecs/km} = \frac{C}{200} (B + D)^{2/3}$$

where, B and D are the bed width and depth of the channel in meters. C is a constant, being 1.0 for intermittent running channels and 0.75 for constant running channels.

(b) The following formula is very much in vogue in Punjab for estimation of seepage losses from lined channels :

$$S = 1.25\ Q^{0.56}$$

where, S is the seepage loss in cusecs per million square foot of wetted perimeter and Q being the discharge carried by the channel. In unlined channels, the loss rate on an average is four times of this value.

(c) U. S. B. R. has recommended the channel losses (in cumecs per million square meter of wetted area) based on the channel bed material as given below :

Clay and clay loam	:	1.5
Sandy loam	:	2.4
Sandy and gravely soil	:	8.03
Concrete lining	:	1.2

(d) Ground Water Over Exploitation Committee has recommended the following norms :

(i) For unlined canals in normal type of soil with some clay content along with sand - 1.8 to 2.5 cumec per million square meter of wetted area.

(ii) For unlined canals in sandy soils - 3 to 3.5 cumec per million square meter of wetted area.

(iii) For lined canals, the seepage losses may be taken as 20 percent of the above values.

However, the various guidelines for estimating losses in the canal system, as given above, are at best approximate. Thus the seepage losses may best be estimated by conducting actual tests in the field. The methods most commonly adopted are:

Inflow - outflow method : The inflow-outflow method consists in measuring the water that flows into and out of the section of canal being studied. The difference between the quantities of water flowing into and out of the canal reach is attributed to seepage. This method is advantageous when seepage losses are to be measured in long canal reaches with few diversions.

Ponding method : The ponding method consists in measuring the rate of drop in a pool formed in the canal reach being tested. Alternatively, water may be added to the pond to maintain a constant water surface elevation. The accurately measured volume of added water is considered equal to the total losses and the elapsed time establishes the rate of loss. The ponding method provides an accurate means of measuring seepage losses and is especially suitable when they are small (e.g. in lined canals).

Seepage meter method : The seepage meter is a modified version of permeameter developed for use under water. Various types of seepage meters have been developed. The two most important are seepage meter with submerged flexible water bag and falling head seepage meter. Seepage meters are suitable for measuring local seepage rates in canals or ponds and used only in unlined or earth-lined canals. They are quickly and easily installed and give reasonably satisfactory results for the conditions at the test site but it is difficult to obtain accurate results when seepage losses are low.

Other methods : These include the use of tracers, electrical logging or resistivity measurement, piezometric surveys and remote sensing. These methods refer to tracing and detecting seepage and its distribution along a canal, with the aim of locating sections with excess seepage.

The total losses from the canal system generally consist of the evaporation losses (Ec) and the seepage losses (Rc). The evaporation losses are generally 10 to 15 percent of the total losses. Thus the Rc value is 85 to 90 percent of the losses from the canal system.

3. Recharge from Field Irrigation (Rr)

Water requirements of crops is met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated fields for growing crops is lost in consumptive use and the balance infiltrates to recharge the ground water. The process of re-entry of a part of the water used for irrigation is called return seepage. Percolation from applied irrigation water, derived both from surface water and ground water sources, constitutes one of the major components of ground water recharge. For a correct assessment of the quantum of recharge by applied irrigation, studies are required to be carried out on experimental plots under different crops in different seasonal conditions. The method of estimation comprise application of the water balance equation involving input and output of water in experimental fields. Ground Water Estimation Committee has recommended the following norms for return seepage from irrigation fields :

(a) Irrigation by surface water sources

(i) 35 percent of water delivered at the outlet for application in the field.

(ii) 40 percent of water delivered at outlets for paddy irrigation only.

(b) Irrigation by ground water sources

30 percent of the water delivered at outlet. For paddy irrigation 35 percent as return seepage of the water delivered may be taken.

In all the above cases, return seepage figures include losses in field channels and these should not be accounted for separately.

4. Recharge from Tanks (Rt)

Studies have indicated that seepage from tanks varies from 9 to 20 percent of their live storage capacity. However, as data on live storage capacity of large number of tanks may not be available, the seepage from the tanks may be taken as 44 to 60 cm. per year over the total water spread, taking into account the agro-climatic conditions in the area. The seepage from percolation tanks is higher and may be taken as 50 percent of its gross storage. In case of seepage from ponds and lakes, the norms as applied to tanks may be taken.

5. Influent and Effluent Seepage (Si & Se)

The aquifer and stream interaction depends on the transmissivity of the aquifer system and the gradient of the water table in respect to the river stage. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent). The effluent or influent character of the river varies from season to season and from reach to reach. It can be determined by dividing the river reach into small sub-reaches and observing the discharges at the two ends of the sub-reach and the discharges of its tributaries and diversions, if any. This could be represented in equation form as :

$$Qd.\ \Delta t = Qu.\ \Delta t + Qg.\ \Delta t + Qt.\ \Delta t - Qo.\ \Delta t - E.\ \Delta t + Srb$$

where,

Qd = discharge at the downstream section;
Qu = discharge at the upstream section;
Qg = ground water contribution (to be evaluated);
Qt = discharge of tributaries;
Qo = discharge diverted from the river;
E = rate of evaporation from river water surface and flood plain; and
Srb = change in bank storage (+ for decrease and - for increase).

The change in bank storage can be determined by observing the water table along the cross-section normal to the river. Thus from the above equation, ground water contribution to river (effluent seepage) over a certain interval of time Δt can be found out. Negative value of Qg will indicate the influent seepage. However, this would be the contribution from aquifers on both sides of the stream. The contribution from each side can be separated by the following method :

$$\text{Contribution from left} = \frac{I_l T_l}{I_l T_l + I_r T_r} \cdot Q_g$$

$$\text{Contribution from right} = \frac{I_r T_r}{I_l T_l + I_r T_r} \cdot Q_g$$

where, Il and Tl are gradient and transmissivity respectively on the left side and Ir and Tr are those on the right.

6. Inflow from and Outflow to Other Basins (Ig & Og)

For the estimation of sub-surface inflow/outflow of ground water, contour maps of the phreatic surface have to be prepared based on the phreatic level data of wells located both within and outside the section delimiting the basin outlet. The flow into the region or out of the region will be governed mainly by the hydraulic gradient and the transmissivity of the aquifer. The gradient can be determined by taking the slope of the water table normal to water table contour and the transmissivities of different aquifers have to be determined separately. The length of the section, across which ground water inflow/outflow occurs, is determined from contour maps, the length being measured parallel to the contour. Then the inflow or outflow can be determined by the following relationship :

$$Q = \sum^{L} T \, I \, \Delta L$$

where, T is the transmissivity, I is the hydraulic gradient averaged over a length ΔL, and L is the total length of the contour line.

7. Evapotranspiration from Ground Water Reservoir (Et)

Evapotranspiration is the amount of water loss by evaporation and that transpired through plants for a certain area. When this evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from the plants will be at the maximum possible rate i.e. at potential rate. This potential evapotranspiration will take place in a waterlogged tract due to the rise in the water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. The evapotranspiration from such areas can be worked out by usual methods of computing potential evapotranspiration using the known data. Depth to water table maps may be prepared based on well inventory data to bring into focus the extensiveness of shallow water table areas. During well inventory, investigation should be specifically oriented towards accurately delineating water table depth for depths less than 2 meter.

8. Draft from Ground Water (Tp)

Draft is the amount of water lifted from the aquifer by means of various lifting devices. The withdrawal can be made by means of state tubewells, private tubewells and open wells. An inventory of wells and a sample survey of ground water draft from various types of wells are pre-requisites for computation of ground water use.

For the case of state tubewells, information about their number, running hours per day, discharge and number of days of operation in a season is generally available in the concerned departments, to calculate the volume pumped in each season. In order to determine the draft from private tubewells, pumping sets and rahats etc., sample surveys have to be conducted regarding their number (of each type), discharge and withdrawals over the season.

Where wells are energized, power consumption data give adequate information to compute the draft from the wells. By conducting tests on wells, the average draft per unit of electricity consumed can be determined for different ranges in depth to water levels. By noting the depth to water level at each distribution point and multiplying the average draft value with the number of units of electricity consumed, the draft at each point can be computed for every month.

9. Change in Ground Water Storage (ΔS)

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

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

$$\text{Change in storage, } \Delta S = \sum h\ A\ Sy$$

where,

h = change in water level;
A = area influenced by the well; and
Sy = specific yield.

The specific yield may be computed from pumping tests. As a guide, the following specific yield values for different types of geological formations in the zone of water level fluctuation may be adopted :

(i)	Sandy alluvial area	:	12 to 18 percent
(ii)	Valley fills	:	10 to 14 percent
(iii)	Silty/Clayey alluvial area	:	5 to 12 percent
(iv)	Granites	:	2 to 4 percent
(v)	Basalts	:	1 to 3 percent
(vi)	Laterite	:	2 to 4 percent
(vii)	Weathered phyllites, shales, schist and associated rocks	:	1 to 3 percent
(viii)	Sandstone	:	1 to 8 percent
(ix)	Limestone	:	3 percent
(x)	Highly karstified limestone	:	7 percent

ESTABLISHMENT OF RECHARGE COEFFICIENT

Ground water balance study is a convenient way of establishing the rainfall recharge coefficient, as well as to cross check the accuracy of the various prevalent methods for the estimation of ground water losses and recharge from other sources. The steps to be followed 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 (Ri) 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.

CONCLUSION

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. For proper assessment of potential, present use and additional exploitability of water resources at optimal level, a water balance study is necessary.

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