Groundwater assessment methodology

Fish Spring National Wildlife Refuge, Utah, a key recharge area for the Basin and Range Carbonate aquifer

Groundwater assessment methodology is vital for understanding the relationship of aquifer dynamics to precipitation and to the characteristics of the land surface of the Earth. Rapid industrial development, urbanization and increase in agricultural production have led to freshwater shortages in many parts of the world. In view of increasing demand of water for various purposes such as agriculture, domestic uses and industry, a greater emphasis is being made for a planned and optimal utilization of water resources. The water resources available in the basins remain almost constant, while the demand for water continues to increase, due to the human population explosion.

Background

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 the water table creating problems of water-logging and salinization, affecting crop growth adversely and rendering large areas unproductive. In extreme cases hypersaline lakes are formed, or deterioration of water quality and lake volume may lead to severe adverse consequences such as has occurred in Lake Urmia in Iran. This syndrome has generally resulted in increased emphasis on development of groundwaterresources. The simultaneous development of groundwater, specially through dug wells and shallow tubewells, will lower the water table, provide vertical drainage and thus can prevent water-logging and salinization. Areas, which are already waterlogged, can also be reclaimed.

On the other hand, continuous increased withdrawals from a groundwater reservoir in excess of replenishable recharge may result in regular lowering of the 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 would be to develop water resources with planning based on conjunctive use of surface water and groundwater.

For a sustainable development of water resources, it is imperative to make a quantitative estimation of the available water resources. For this, the first task would be to make a realistic assessment of the surface water and groundwater resources and then plan their use in such a way that full crop water requirements are met and there is neither water-logging nor excessive lowering of groundwater table. It is necessary to maintain the groundwater 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.

Groundwater is a dynamic system. A complexity of factors – hydrogeological, hydrological and climatological – control groundwater occurrence and movement. The precise assessment of recharge and discharge is rather difficult, as no techniques are currently available for their direct measurements. Hence, the methods employed for groundwater resource estimation are all indirect. Groundwater, being a dynamic and replenishable resource, is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable groundwater structures.

For quantification of groundwater resources, proper understanding of the behavior and characteristics of the water-bearing rock formation known as aquifer is essential. An aquifer has two main functions: (i) to transit water (conduit function), and (ii) to store it (storage function). The groundwater resources in unconfined aquifers can be classified as static and dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage, influent seepage, etc.

The methodologies adopted for computing groundwater resources, are generally based on the hydrologic budget techniques. The hydrologic equation for groundwater regime is a specialized form of a water balance equation that requires quantification of the components of groundwater inflow and groundwater outflow, as well as changes in storage therein. Some of these are directly measurable, few may be determined by differences between measured volumes or rates of flow of surface water, and some require indirect methods of estimation.

Water balance techniques have been extensively used to make quantitative estimates of water resourcesand the impact of humans' activities on the hydrological cycle. The study of water balance requires the systematic presentation of data on the water supply and its use within a given study area for a specific period. The water balance of an area is defined by the hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrological cycle. With the water balance approach, it is possible to evaluate quantitatively the individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in the water regime due to changes in components of the system.
A basin-wise approach yields the best results where the groundwater 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 groundwater 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 and groundwater basins are coincident for all practical purposes, but marked differences may be encountered in stratified sedimentary formations. Therefore, the study area for groundwater 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. Once the study area is identified, comprehensive studies can be undertaken to estimate for selected a period of time, the input and output of water, and change in storage to draw up water balance of the basin.
The estimation of groundwater balance of a region requires quantification of all individual groundwater inflows or outflows involving a groundwater system and change in groundwater storage over a given time period. 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 methodology of computing groundwater balance consists of the following:

- Identification of significant components,
- Evaluating and quantifying individual components, and
- Presentation in the form of water balance equation.

The groundwater balance study of an area may serve the following purposes:

- As a check on whether all flow components involved in the system have been quantitatively accounted for, and what components have the greatest bearing on the problem under study.
- To calculate one unknown component of the groundwater balance equation, provided all other components are quantitatively known with sufficient accuracy.
- As a model of the hydrological processes under study, which can be used to predict the effect that changes imposed on certain components will have on the other components of groundwater system.

Groundwater Balance Equation

Considering the various inflow and outflow components in a given study area, the groundwater balance equation can be written as:

$$R_r + R_c + R_i + R_t + S_i + I_g = E_t + T_p + S_e + O_g + \Delta S$$

where,

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

Preferably, all elements of the groundwater balance equation should be computed using independent methods. However, it is not always possible to compute all individual components of the groundwater balance equation separately. Sometimes, depending on the problem, some components can be lumped, and account only for their net value in the equation.

Computations of various components usually involve errors, due to shortcomings in the estimation techniques. The groundwater balance equation therefore generally does not balance, even if all its components are computed by independent methods. The resultant discrepancy in groundwater balance is defined as a residual term in the balance equation, which includes errors in the quantitative determination of various components as well as values of the components which have not been accounted in the equation.

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.

Data Requirements for a Groundwater Balance Study

For carrying out a groundwater balance study, the following data may be required over a given time period:

Rainfall data: Monthly rainfall data of sufficient number of rain-gauge stations lying within or around the study area, along with their locations, should be available.

Land-use data and cropping patterns: Land-use data are required for estimating theevapotranspiration losses from the water table through forested area. Cropping pattern data are necessary for estimating the spatial and temporal distributions of groundwater withdrawals, if required. Monthly panevaporation rates should also be available at few locations for estimation of consumptive use requirements of different crops.

River data: Monthly river stage and discharge data along with river cross?sections are required at few locations for estimating the river-aquifer interflows.

Canal data: Month-wise water releases into the canal and its distributories along with running days during each month are required. To account for the seepage losses through the canal system, the seepage loss test data are required in different canal reaches and distributories.

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

Water table data: Monthly water table data (or at least pre?monsoon and post?monsoon data) from sufficient number of well-distributed observation wells along with their locations are required. The available data should comprise reduced level (R.L.) of water table and depth to water table.

Groundwater draft: For estimating groundwater withdrawals, the number of each type of wells operating in the area, their corresponding running hours each month and discharge are required. If a complete inventory of wells is not available, then this can be obtained by carrying out sample surveys.

Aquifer parameters: Data regarding the storage coefficient and transmissivity are required at sufficient number of locations in the study area.

Establishment of a Recharge Coefficient

A groundwater 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 groundwater losses and recharge from other sources. The steps to be followed are:

1. Divide the year into monsoon and non?monsoon periods (where the year can be distinctly divided into these two seasons).
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 (R_r) 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.

By quantifying all the inflow/outflow components of a groundwater system, one can determine which particular component has the most significant effect on the groundwater flow regime. Alternatively, a groundwater balance study may be used to compute one unknown component (e.g. the rainfall recharge) of the groundwater balance equation, when all other components are known. The balance study may also serve as a model of the area under study, whereby the effect of change in one component can be used to predict the effect of changes in other components of the groundwater system. In this manner, the study of groundwater balance has a significant role in planning a rational groundwater development of a region.

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