Hydrogeology Lab 4

Estimation of aquifer recharge using chloride mass balance (CMB) technique

Groundwater recharge can be defined simply as the downward flow of water reaching the groundwater reservoir via the soil and unsaturated zone. The amount of precipitation that reaches the groundwater reservoir depends upon several factors. Among these are the character and thickness of the soil and other deposits above and below the water table, the topography, vegetal cover, land use, soil moisture content, the depth to the water table, intensity and distribution of the rainfall, the occurrence of precipitation as rain or snow, and the air temperature and other meteorological factors (humidity, wind, …etc). The major sources of recharge to aquifers are direct precipitation on intake areas and /or downward percolation of stream runoff. The quantity of vertical leakage varies from place to place and is controlled by the permeability and thickness of the deposits through which leakage occurs, the head differential between sources of water and the aquifer and the area through which leakage takes place.

Various techniques are available to quantity recharge; however, choosing appropriate techniques is often difficult. Generally, there are two main methods for estimating recharge rate: direct and indirect. In direct method a suitable instrument such as lysimeter is used for direct recharge measurements. Generally, in the semiarid and arid regions installation and maintenance of lysimeter are expensive and difficult and is not suitable because of low average rainfall. The indirect methods are not accurate than direct methods but they are preferable in practical applications due to their simplicity, economy, and quick finding-results. Among such techniques are various balance approaches such as surface water balance and groundwater budget analysis, water table fluctuation method, numerical groundwater flow model, measurements of environmental isotopes, and use of chemical mass balance method such as with chloride.

Because of the variability of rainfall in many semiarid and arid regions physical methods which rely on direct measurements of hydrological parameters are problematic, because the recharge rates are low and changes in these parameters will be small and difficult to detect. Thus for estimating recharge rate, chemical and isotopic methods show more promise than physical methods. The **Chloride Mass Balance (CMB)** method can yield regional rate of recharge under certain conditions and assumptions. Various applications of the CMB method have been presented for different parts of the world. The application of the CMB method is simple with no independence on sophisticated instruments.

The CMB method for estimating groundwater recharge is economic and effective, provided that the hydrological conditions for its applications are met and the modeling parameters are known. In the CMB, measurements of chloride concentration (Cl^-) in pore water and precipitation are used to estimate the recharge rate. The Cl^- is used in groundwater recharge studies because of its conservative nature and its relative abundance in precipitation. The ion neither leaches from nor is absorbed by the sediment particles. Also, it does not participate in any chemical reaction. The assumptions in the CMB approach for estimating recharge are that (Şen, 2008):

1. There is no Cl^- source in groundwater storage prior to the rainfall.
2. There are no additional sources or sinks for Cl^- concentration in the area of the application.
3. The rainfall either evaporates or infiltrates in the region without any runoff.
4. Long – term rainfall and its Cl^- concentration amounts have a balanced situation, i.e they are in a steady – steady condition.

Chloride concentration in single and consecutive rain events may differ significantly due to: (Seiler and Gat, 2007)

1. The origin and the trajectory of air masses.
2. The storage of chloride in the atmosphere.
3. The distance from the coast.
4. The regional condensation altitude, above which interception deposition is favored.
5. The velocity of rain-out.

Therefore, most precipitation starts with high and continuous with low chloride concentration. Thus, to avoid the variation of chloride concentration, the rainfall depth-weighted average of chloride Cl_{wav} is used. It is calculated based on the following equation: (Dassi, 2010)

$$Cl_{wav} = \frac{\sum Cl_i h_i}{h_i} \quad \textbf{(3-15)}$$

where Cl_{wav} : rainfall depth-weighted average of Cl^- concentration (mg/l)

Cl_i: chloride concentration in a considered rainfall event (mg/l)

h: depth of a considered rainfall event (mm)

On the basis of these assumption, the conservative of mass leads to the following relation between rainfall and recharge (Wood and Sanford, 1995; Ting el al. 1998; Wood, 1999):

$$R = \frac{P \times Cl_{wav}}{Cl_{gw}} \quad \textbf{(3-16)}$$

where P : mean annual precipitation in the study area (mm)

Cl_{wav} : rainfall depth-weighted mean of chloride concentration (mg/l)

Cl_{gw} : average chloride concentration of the groundwater (mg/l)

R : annual recharge amount (mm)

Exercise:

For the following data, estimate groundwater recharge, knowing that the mean annual rainfall is 120mm.

Month	Mean monthly rainfall(mm)	Cl- concentration in rainfall(mg/l)	Cl- concentration in groundwater (mg/l)
November	138	4.5	18.2
December	144	6.1	14.1
January	38	9.1	14.1
February	22.5	6.2	16.4
March	110	4.2	18.1
April	116	2.2	16.1