Chapter 33: Occurrence, Movement, and Distribution of Groundwater

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Introduction

Groundwater forms a significant component of the hydrological cycle and serves as a crucial resource for domestic, agricultural, and industrial use. Unlike surface water, groundwater is stored in underground formations called aquifers. Understanding the occurrence, movement, and distribution of groundwater is vital for the effective planning, development, and sustainable management of water resources. This chapter deals with the geological formations that support groundwater storage, mechanisms of its movement, types of aquifers, and distribution patterns in various hydrogeological settings.

33.1 Occurrence of Groundwater

33.1.1 Hydrological Cycle and Groundwater

Groundwater originates from precipitation. A portion of rainfall infiltrates into the soil and percolates down through pores and fractures in rocks, accumulating in underground formations. The infiltration and recharge depend on:

- Soil texture and structure
- Vegetation cover
- Slope gradient
- Land use pattern
- Rainfall intensity and duration

33.1.2 Zones of Subsurface Water

Subsurface water is divided into two main zones:

1. **Zone of Aeration (Vadose Zone):**
    - Lies between the land surface and the water table.
    - Contains soil water, intermediate zone water, and capillary water.
    - Water in this zone is not saturated and is held by molecular forces.
2. **Zone of Saturation (Phreatic Zone):**
    - All pores and voids are filled with water.
    - The top of this zone is known as the **water table**.
    - Water here is called **groundwater**.

33.1.3 Rock Properties Affecting Groundwater Storage

The following properties of rocks and soil affect the occurrence and movement of groundwater:

- **Porosity**: Ratio of void volume to total volume of rock.
- **Permeability**: Ability of the medium to transmit water.
- **Specific Yield**: Volume of water that drains under gravity.
- **Specific Retention**: Water retained by capillary action.

33.2 Types of Aquifers

An **aquifer** is a geological formation that stores and transmits water in usable quantities.

33.2.1 Unconfined Aquifer

- Also known as a water table aquifer.
- Upper surface is the water table.
- Recharge occurs directly from infiltration of precipitation.
- Fluctuates seasonally.

33.2.2 Confined Aquifer

- Sandwiched between two impermeable layers (aquitards).
- Water is under pressure (artesian conditions).
- When tapped, water may rise above the top of the aquifer.

33.2.3 Semi-confined (Leaky) Aquifer

- Partially confined by aquitards of low permeability.
- Water moves slowly across confining layers.

33.2.4 Perched Aquifer

- Occurs above the main water table due to a local impermeable layer.
- Temporary and localized.

33.3 Aquitards and Aquicludes

- **Aquitard**: A layer with low permeability that transmits water at a slow rate.
- **Aquiclude**: Impermeable layer that does not transmit water (e.g., clay).
- **Aquifuge**: Solid, impermeable rock that neither stores nor transmits water.

33.4 Groundwater Movement

33.4.1 Darcy's Law

The fundamental law governing groundwater flow:

$$Q = -KA\frac{dh}{dl}$$

Where:

- Q: Discharge (m^3/s)
- K: Hydraulic conductivity (m/s)
- A: Cross-sectional area (m^2)
- dh/dl: Hydraulic gradient

33.4.2 Hydraulic Head

Total potential energy of groundwater, composed of:

- Elevation head
- Pressure head
- Velocity head (usually negligible)

33.4.3 Factors Affecting Groundwater Movement

- Hydraulic conductivity of aquifer
- Gradient of water table or potentiometric surface
- Type and arrangement of geological formations

33.5 Groundwater Flow Systems

33.5.1 Local Flow System

- Shallow flow paths
- Short residence time
- More affected by seasonal variations

33.5.2 Intermediate Flow System

- Connects local flow with deeper regional systems
- Moderate flow length and depth

33.5.3 Regional Flow System

- Deep flow paths
- Long residence times
- Less impacted by local surface conditions

33.6 Methods of Groundwater Exploration

- **Remote Sensing and GIS**
- **Geophysical Methods**:
  - Electrical resistivity
  - Seismic refraction
  - Gravity and magnetic methods
- **Test Drilling and Borehole Logging**
- **Pumping Tests**: To determine aquifer properties (transmissivity, storativity)

33.7 Groundwater Recharge and Discharge

33.7.1 Natural Recharge

- Infiltration from precipitation
- Streambed percolation
- Lateral flow from adjacent formations

33.7.2 Artificial Recharge

- Recharge pits, trenches, wells
- Check dams and percolation tanks
- Spreading basins

33.7.3 Groundwater Discharge

- Springs and seeps
- Baseflow into streams and rivers
- Pumping through wells

33.8 Distribution of Groundwater

33.8.1 Regional Distribution in India

- **Alluvial Plains (e.g., Indo-Gangetic)**: High yield, unconfined aquifers.

- **Peninsular India**: Hard rock terrain, mostly weathered-fractured aquifers.
- **Coastal Regions**: Risk of saltwater intrusion.

33.8.2 Factors Influencing Distribution

- Geology and structure
- Rainfall and climate
- Topography
- Land use and vegetation
- Human intervention (e.g., pumping, land development)

33.9 Saltwater Intrusion in Coastal Aquifers

When excessive pumping reduces freshwater pressure, seawater enters the aquifer.

Prevention Techniques:

- Maintaining optimal pumping rates
- Artificial recharge
- Use of barriers or injection wells

33.10 Groundwater Management Considerations

- **Monitoring water table fluctuations**
- **Assessing safe yield**
- **Controlling over-extraction**
- **Preventing pollution and contamination**
- **Integrated watershed and aquifer management**
