Chapter 22: Potential Evapotranspiration over India

Introduction

Evapotranspiration is a critical component of the hydrologic cycle that accounts for the combined loss of water from a land surface through the processes of evaporation and transpiration. In a country like India, where agriculture heavily depends on irrigation and climate variability, understanding **Potential Evapotranspiration (PET)** is essential for efficient water resource management, irrigation planning, and drought assessment. PET is the amount of evaporation that would occur if a sufficient water source were available. It provides a standard reference against which actual evapotranspiration can be compared.

India's vast geographical diversity, encompassing arid deserts, coastal belts, mountainous regions, and tropical forests, leads to substantial spatial and temporal variation in PET. Accurate estimation of PET over India helps water resource engineers and planners make informed decisions regarding crop water requirements, water budgeting, and sustainable development.

22.1 Concept of Evapotranspiration

Evapotranspiration (ET) includes:

- **Evaporation**: The physical process of liquid water converting to vapor from water bodies, soil surfaces, and vegetation.
- **Transpiration**: The physiological process where water is absorbed by plant roots and lost as vapor through leaves.

The **Potential Evapotranspiration (PET)** is defined as the evapotranspiration from a hypothetical, well-watered vegetated surface under given climatic conditions.

22.2 Importance of PET in Water Resources Engineering

- **Irrigation Planning**: Helps in estimating crop water requirements.

- **Drought Monitoring**: Used as a key input in drought indices like Standardized Precipitation Evapotranspiration Index (SPEI).
- **Water Budgeting**: Crucial for estimating water balance components in hydrological models.
- **Reservoir Management**: Estimating losses due to evaporation.

22.3 Factors Affecting PET

Several climatic and geographic factors influence PET:

1. **Solar Radiation (Rs)** – Primary driver of evapotranspiration.
2. **Temperature (T)** – Influences the vapor pressure deficit.
3. **Relative Humidity (RH)** – Affects vapor pressure gradient.
4. **Wind Speed (u)** – Enhances transport of water vapor.
5. **Vegetation Characteristics** – Leaf area index, type of crop.
6. **Altitude and Topography** – Influence climatic variables.

22.4 Methods of Estimating PET

22.4.1 Empirical Methods

These are derived from observed data and statistical relationships.

- **Thornthwaite Method** Based on mean monthly temperature and day length. Suitable for temperate regions but often inaccurate in tropical climates like India.

$$PET = 16\left(\frac{L}{12}\right)\left(\frac{N}{30}\right)\left(\frac{10T}{I}\right)^{a}$$

  Where:

  - L = Average day length
  - T = Mean monthly temperature (°C)
  - I = Annual heat index
  - a = Empirical coefficient
- **Blaney–Criddle Method** Incorporates temperature and daylight hours.

$$PET = p(0.46T + 8)$$

Where:

- p = Mean daily percentage of annual daylight hours
- T = Mean daily temperature

22.4.2 Physically Based Methods

- **Penman Method** Combines energy balance and aerodynamic terms. Requires temperature, humidity, radiation, and wind data.

$$PET = \frac{\Delta R_n + \gamma f(u)(e_s - e_a)}{\Delta + \gamma}$$

Where:

- R_n = Net radiation
- Δ = Slope of vapor pressure curve
- γ = Psychrometric constant
- $f(u)$ = Wind function
- $(e_s - e_a)$ = Vapor pressure deficit

- **Penman–Monteith Method** Recommended by FAO (Food and Agriculture Organization) for global applications. Considered the most accurate.

$$PET = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)}$$

- G = Soil heat flux density
- u_2 = Wind speed at 2m
- Requires comprehensive weather data.

22.4.3 Satellite-Based and Remote Sensing Approaches

- MODIS and Landsat data are used to estimate PET over large areas.
- Remote sensing allows spatial mapping of PET for inaccessible or vast regions like deserts or forests.

22.5 Spatial Variation of PET over India

India exhibits high spatial variability in PET due to its diverse topography and climatic conditions.

- **Western Rajasthan**: Very high PET due to arid climate, high solar radiation, and wind speed.
- **Himalayan Region**: Low PET due to cooler temperatures and snow cover.
- **Coastal Areas**: Moderate PET due to high humidity but warm temperatures.
- **Central India**: Seasonal PET variation influenced by monsoon rainfall and temperature.

22.6 Seasonal and Monthly PET Distribution

- **Summer (March–June)**: Peak PET values due to high temperature and solar radiation.
- **Monsoon (June–September)**: Reduced PET because of cloud cover and higher humidity.
- **Post-monsoon and Winter (October–February)**: Lower PET due to reduced radiation and temperature.

Monthly PET values are critical for irrigation scheduling and estimating soil moisture deficits.

22.7 PET Mapping and Zoning in India

- Various research institutions (e.g., IMD, IITs, ICAR) and government bodies generate PET maps for different seasons.
- **GIS-based PET zoning** supports agro-climatic regional planning.
- **Agro-climatic zones** are classified based on PET and rainfall patterns.

22.8 Applications of PET Estimation

- **Agricultural Water Management**: Determines irrigation water needs of crops (ET_o).
- **Climate Change Studies**: PET trends are used to assess changes in water demand and drought risk.
- **River Basin Modeling**: Accurate PET is essential for hydrological simulations.
- **Groundwater Recharge Estimation**: Helps estimate the unsaturated zone loss.

22.9 Challenges in PET Estimation in India

- **Data Scarcity**: High-quality, continuous weather data is limited, especially in rural regions.
- **Model Uncertainty**: Empirical models may not capture the heterogeneity of India's climate.
- **Climate Variability**: Monsoon fluctuations lead to unpredictable PET behavior.
- **Scaling Issues**: Translating point-based PET values to regional scales can be complex.

22.10 Future Directions and Recommendations

- Expansion of **automated weather stations (AWS)** across India.
- Adoption of **satellite-based PET monitoring** at the district and state levels.
- Integration of **PET models with crop growth and soil moisture models** for real-time water requirement forecasting.
- Encouragement of **open-source hydrological data platforms** for researchers and planners.
