1. Explain the mechanism of the Indian monsoon system. How do global climatic phenomena such as El Niño and La Niña influence its onset and intensity?

Introduction

The Indian monsoon system is a seasonal reversal of winds accompanied by large-scale rainfall, primarily occurring between June and September. It is critical for agriculture, hydrology, and overall economic stability. This system is influenced by the thermal contrast between land and ocean, upper air circulations, and global climatic factors like El Niño and La Niña.

Mechanism of the Indian Monsoon

1. **Differential Heating and Pressure Gradient**
   - During summer, the Indian landmass heats up more quickly than surrounding oceans, creating a **low-pressure zone over the subcontinent** and a **high-pressure zone over the Indian Ocean**.
   - This pressure gradient drives the **southwest monsoon winds** from the ocean towards the land.
2. **Inter-Tropical Convergence Zone (ITCZ)**
   - The ITCZ, or monsoon trough, shifts northward in summer. This low-pressure belt attracts **moisture-laden winds from the Indian Ocean**, resulting in widespread rainfall across the subcontinent.
3. **Jet Streams**
   - The **subtropical westerly jet** retreats northward in summer, allowing the **tropical easterly jet** to dominate. The arrival of the easterly jet correlates with the **burst of monsoon** over Kerala.
4. **Orographic Features**
   - Mountains like the **Western Ghats** and **Himalayas** enhance rainfall through orographic uplift, especially on the windward side.
5. **Retreating Monsoon (Northeast Monsoon)**
   - In winter, the land cools faster than the ocean, reversing the pressure pattern. Dry **northeast winds** blow from land to sea, though parts of southeast India (e.g., Tamil Nadu) receive rain due to cyclonic activity over the Bay of Bengal.

Global Climatic Influences

1. El Niño

- El Niño refers to abnormal **warming of the central and eastern Pacific Ocean**, disrupting the **Walker circulation**.
- **Impact on Monsoon:**
  - Weaker pressure gradient and suppressed convection over the Indian Ocean.
  - Leads to **weakened monsoon winds**, reduced rainfall, and **droughts** (e.g., 1987, 2002, 2015).
  - In 2023, El Niño was linked to **delayed monsoon onset**, as per IMD reports.

2. La Niña

- La Niña is characterized by **cooling of the Pacific Ocean**, strengthening the Walker circulation.
- **Impact on Monsoon:**
  - Stronger cross-equatorial flow and enhanced rainfall.

- Often leads to **above-normal monsoon** (e.g., 2010–11) but can also cause **flooding** in vulnerable regions.

Conclusion
The Indian monsoon is a product of complex interactions between atmospheric and oceanic systems. Global phenomena like El Niño and La Niña significantly alter the **onset, duration, and intensity** of the monsoon. Accurate forecasting of these interactions is essential for managing India's agrarian economy and disaster resilience.

2. Evaluate the role of non-conventional energy sources in addressing India's energy security. Assess the potential and limitations of solar, wind, and biomass energy.

Introduction
India's growing energy demand, over-dependence on fossil fuel imports (~85% crude oil import), and climate change commitments under the Paris Agreement necessitate a transition to **non-conventional (renewable) energy sources**. These include solar, wind, biomass, small hydro, and others which are **renewable, sustainable**, and **environmentally benign**.

Role in Energy Security
1. **Diversification of Energy Mix:**
   Reduces over-reliance on coal and petroleum-based sources.
2. **Reducing Import Dependency:**
   Renewable energy minimizes exposure to global fuel price shocks.
3. **Decentralized Access:**
   Especially crucial for **rural electrification** and off-grid solutions.
4. **Climate Resilience:**
   Helps meet India's NDC targets—**achieving 500 GW non-fossil capacity by 2030**.
5. **Economic Opportunity:**
   Drives **green jobs** and local manufacturing, such as under **PLI for solar modules**.

Assessment of Major Non-Conventional Sources
1. Solar Energy
- **Potential:**
  - India receives over **5,000 trillion kWh/year** of solar radiation.
  - Estimated potential: **748 GW** (as per NISE).
  - Supported by schemes like **National Solar Mission, PM Surya Ghar Yojana**, and **International Solar Alliance (ISA)**.
- **Limitations:**
  - **Intermittent** – depends on sunlight; affected by clouds and seasons.
  - **Storage Costs** – Battery technology remains expensive.
  - **Land Acquisition** – Large-scale solar farms compete with agriculture.

2. Wind Energy
- **Potential:**
  - Estimated at **302 GW** at 100 m height (NIWE).
  - High potential in states like **Tamil Nadu, Gujarat, Karnataka, and Maharashtra**.
  - Backed by **Green Energy Corridor (GEC)** and **Wind-Solar hybrid policy**.

- **Limitations:**
  - **Intermittency** – wind speeds vary seasonally and diurnally.
  - **Environmental Impact** – affects bird migration and creates noise concerns.
  - **Infrastructure Challenges** – remote terrain hinders logistics and maintenance.

3. Biomass Energy

- **Potential:**
  - Utilizes **agricultural residues, animal dung, and forest waste**.
  - Aims to convert waste to energy, reducing pollution (e.g., crop stubble burning).
- **Limitations:**
  - **Supply Chain Constraints** – collection and storage of feedstock is inefficient.
  - **Low Efficiency** – traditional combustion emits pollutants.
  - **Land Use Concerns** – large-scale production can compete with food crops.

Conclusion

Non-conventional energy sources are **vital for ensuring India's long-term energy security**, reducing carbon footprint, and enabling sustainable development. However, realizing their full potential demands **technological innovation**, **robust policy support**, and **grid modernization**. A balanced and region-specific deployment strategy can help India emerge as a **renewable energy leader** globally.