

Causes and Characteristics of Tropical Cyclones, Storm Surges and Flooding

Introduction

Tropical cyclones are intense circular storms formed over warm ocean waters near the equator. They have strong winds, heavy rain, and move toward land, bringing destruction to coastal areas. When cyclones reach the shore, they push seawater inward, creating **storm surges**. These surges cause **coastal flooding**, destroying homes, farms, and infrastructure near the sea. Flooding also occurs inland when rivers overflow after heavy rainfall or glacier melting. In Pakistan, Sindh and Balochistan's coasts often face tropical cyclones from the Arabian Sea. Cyclones usually occur between May and November when sea temperatures are highest. They can last several days and travel hundreds of kilometres across land and sea. Flooding may continue even after the cyclone passes due to persistent rainwater accumulation. Both events are examples of **hydro-meteorological hazards**, influenced by climate and geography. Their intensity depends on temperature, air pressure, and wind circulation patterns over oceans. Pakistan's flat coastal plains and poor drainage make it highly vulnerable to such disasters. Understanding these natural processes is key for disaster risk reduction and public safety.

Causes of Tropical Cyclones

Cyclones form when the ocean surface becomes very warm, above **26°C**, providing energy. Warm air rises quickly, cools, and condenses to form tall thunderclouds with heavy rain. This process releases **latent heat**, further strengthening the storm and lowering air pressure. As pressure drops, air from surrounding areas rushes in, spinning because of **Coriolis effect**. The spinning creates a circular system with an eye in the center and strong outer winds. Moisture from the sea fuels the cyclone, making it larger and more powerful continuously. Calm upper-level winds allow it to develop without being torn apart by crosswinds. Most cyclones form between **5° and 20° latitude**, where rotation is strong enough to spin storms. They do not form directly on the equator due to zero Coriolis force there. Once formed, cyclones move toward coastal areas driven by global wind patterns. As they reach land, they bring heavy rains, thunder, and extremely strong gusts of wind. When cut off from ocean moisture, they weaken and slowly disappear within a few days. Thus, warm oceans, moist air, and earth's rotation are the main causes of cyclones.

Characteristics of Tropical Cyclones

A tropical cyclone has a clear, circular structure with different layers and zones. At the center lies the **eye**, a calm area with low pressure and clear skies. Surrounding the eye is the **eyewall**, where winds and rain are most intense. This wall contains tall clouds reaching up to 15 kilometers into the atmosphere. Winds around the eyewall can exceed **200 km/h**, damaging trees, buildings, and power lines.

The outer part of the cyclone has spiral rainbands that bring continuous rainfall. Cyclones are massive — sometimes over 500 kilometers wide — covering large ocean areas. Their speed and direction change depending on sea temperature and regional wind flow. Meteorologists categorize them into levels like tropical storms, severe cyclones, and super cyclones. They move slowly, often lasting several days before weakening or merging with other systems. When a cyclone hits land, it causes flash floods, landslides, and power breakdowns. In Pakistan, recent cyclones like **Cyclone Phet and Biparjoy** caused major coastal damage. Their strength and duration depend heavily on sea heat, humidity, and wind stability.

Storm Surges: Causes and Impacts

A **storm surge** is a sudden rise in sea level during a cyclone or storm. Strong winds push seawater toward the shore, causing it to rise above normal tides. At the same time, low air pressure over the sea allows water to expand upward. When combined, these effects flood coastal areas rapidly, even before rainwater arrives. The shape of the coastline and sea depth affect how high the surge becomes. Shallow coasts, like Sindh's delta region, experience higher surges and greater flooding. Storm surges destroy homes, roads, and farms, forcing thousands of people to evacuate. Saltwater entering farmland damages soil and reduces productivity for several years afterward. Drinking water also gets polluted, leading to diseases and shortages in affected areas. Mangrove forests and sand dunes act as natural shields, reducing the surge's strength. However, deforestation and coastal development have made many areas more exposed to surges. Pakistan's Indus Delta and Makran Coast are highly vulnerable to these sea-level rises. Thus, storm surges remain one of the most dangerous effects of tropical cyclones.

River and Coastal Flooding

Flooding occurs when water overflows onto normally dry land due to rain or sea forces. **River flooding** happens after prolonged rainfall or glacier melting fills rivers beyond capacity. The Indus and its tributaries often overflow during summer monsoon seasons in Pakistan. **Coastal flooding** happens during cyclones or high tides, especially along Sindh and Balochistan. Heavy rains can also cause **urban flooding** when drainage systems fail in major cities. Floods damage houses, crops, livestock, bridges, and roads, affecting millions every year. The 2010 and 2022 floods in Pakistan displaced millions and caused huge economic loss. Floodwaters spread diseases, contaminate drinking water, and harm infrastructure for months. Deforestation, population growth, and poor land planning worsen the intensity of floods. In mountainous areas, flash floods are caused by glacier melt or sudden rainstorms. Rising sea levels are now increasing coastal flooding frequency due to climate change. Government measures include dams, embankments, canals, and early warning technology. Therefore, managing floods requires both engineering solutions and community preparedness efforts.

Management and Mitigation of Cyclones and Floods

To reduce cyclone and flood damage, strong disaster management and early warnings are essential.

Weather satellites and radar systems monitor storm paths and alert vulnerable coastal populations.

Governments build **cyclone shelters**, elevated homes, and sea walls to protect communities.

Tree planting along coasts reduces wind force and prevents soil erosion effectively.

River control through dams and canals helps manage overflow during heavy rains safely.

Public awareness campaigns teach evacuation routes and emergency actions before disasters strike.

Disaster response agencies coordinate rescue, medical care, and food supply after the event.

Improving drainage systems prevents waterlogging and protects cities from urban floods.

Climate adaptation plans help communities prepare for future changes in rainfall and sea levels.

Reforestation in upper catchment areas reduces flash flood and landslide risks downstream.

International cooperation helps Pakistan receive aid and training for better disaster preparedness.

Long-term success depends on linking environmental conservation with development and safety measures.

Thus, effective management combines technology, education, and sustainable environmental planning for resilience.