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DAILY CURRENT AFFAIRS DATED 03.03.2026

GS Paper III: Disaster Management

1. Urban Flooding and the “Memory” of Landscapes: Understanding Hydrological Hysteresis

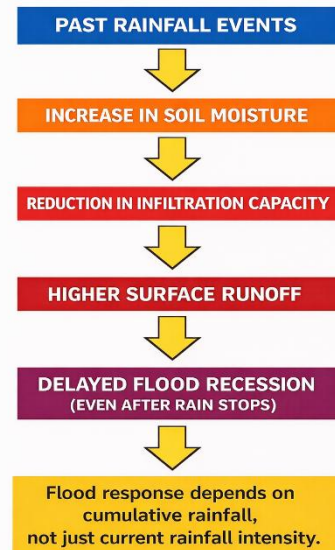
a. Introduction

Urban flooding has increasingly become a recurring problem in many Indian metropolitan regions, including Mumbai, Bengaluru, Chennai, and Hyderabad. After intense rainfall events, roads often remain submerged for extended periods, severely disrupting transportation networks, damaging infrastructure, and affecting everyday economic activity.

Urban floods are commonly attributed to heavy rainfall, inadequate drainage systems, or poor urban planning. While these factors are undoubtedly significant, hydrological science demonstrates that flooding is also strongly influenced by the way landscapes absorb, store, and release water over time. Land surfaces do not react instantaneously to rainfall; instead, they retain a form of hydrological “memory” created by earlier rainfall events.

This phenomenon, known as hydrological hysteresis, helps explain why flooding can persist even after rainfall intensity decreases or stops entirely.

Hydrological Hysteresis: Landscapes Remember Past Rainfall



b. The Concept of Hydrological Hysteresis

Hydrological hysteresis refers to the condition in which the response of a landscape to rainfall depends not only on present rainfall but also on the hydrological conditions created by earlier rainfall events. In other words, the behaviour of water within a landscape reflects the cumulative influence of past moisture conditions.

Illustrative analogy

- Consider the behaviour of a sponge when water is poured onto it.
- When the sponge is dry, it absorbs water easily because its internal pores have sufficient capacity to store moisture.
- However, once the sponge becomes saturated, its ability to absorb additional water declines sharply, and excess water begins to flow outward.

Application to natural landscapes

- A similar process occurs in soils and natural landscapes.
- When soils are relatively dry, rainwater infiltrates into the ground and is stored within soil pores.
- When soils are already saturated due to previous rainfall, the capacity for further infiltration becomes limited.
- Under such conditions, even moderate rainfall can quickly produce surface runoff that accumulates in drainage channels and low-lying areas.

This delayed and history-dependent response of landscapes constitutes the essence of hydrological hysteresis.

c. Natural Mechanisms of Water Storage in Landscapes

Rainwater rarely flows away immediately after precipitation. Instead, natural landscapes temporarily store water in several interconnected components that regulate the speed at which water moves through the hydrological system.

Landscape Component Function in Water Storage

Soils	Absorb and retain rainwater through infiltration
Wetlands	Act as natural sponges that temporarily store excess water
Floodplains	Provide space for rivers to spread during periods of high discharge
Aquifers	Store groundwater beneath the surface
Lakes and ponds	Regulate runoff by delaying the movement of water

Regulation of runoff

- Water retained in these systems is released gradually over time.
- This slow release creates a time lag between rainfall events and the eventual decline of floodwaters.

Hydrological buffering

- Natural storage systems reduce peak discharge during heavy rainfall.
- They also stabilise river flows and maintain groundwater recharge.

The presence of these delayed responses in the hydrological system is a key manifestation of hydrological hysteresis.

d. Evolution of Flood Conditions During the Monsoon

The hydrological behaviour of landscapes evolves progressively during the monsoon as soils and water bodies accumulate moisture.

Early Phase of Rainfall

- During the initial stages of the monsoon, soils are relatively dry and possess high infiltration capacity.
- A large proportion of rainfall infiltrates into the ground.
- Rivers usually remain within their natural channels, and the probability of flooding remains relatively low.

Progressive Soil Saturation

- Continuous rainfall over successive days increases soil moisture levels.
- As soils approach saturation, their capacity to absorb additional rainfall declines.
- Surface runoff therefore increases, and rivers begin to carry larger volumes of water.

Onset of Flooding

- Flooding occurs when the storage capacity of soils, wetlands, and river channels is exceeded.
- Rivers may overflow their banks and spread into floodplains and low-lying areas.
- In urban environments, constrained drainage pathways intensify this flooding process.

Delayed Drainage and Persistent Flooding

- Even after rainfall ceases, water stored in soils, wetlands, and floodplains drains gradually.
- Because this stored water moves slowly through the landscape, floodwaters may remain for several days.

- This delayed recession of flood levels represents a clear manifestation of hydrological hysteresis.

e. Influence of Urbanisation on Hydrological Processes

Urbanisation dramatically alters the natural hydrological behaviour of landscapes by replacing permeable surfaces with impermeable built structures.

Urban Transformation	Hydrological Consequence
Construction of concrete roads and buildings	Reduction in infiltration of rainwater into soil
Loss of wetlands and lakes	Elimination of natural water storage systems
Encroachment upon floodplains	Obstruction of natural floodwater pathways
Channelisation of rivers and drains	Acceleration of water flow
Obstruction of stormwater drains	Slower removal of accumulated water

Reduction in natural infiltration

- Impermeable surfaces prevent rainwater from entering the soil.
- As a result, a larger proportion of rainfall becomes surface runoff.

Loss of hydrological buffers

- Urban expansion often destroys wetlands, lakes, and floodplains.
- The removal of these natural storage systems intensifies flood risks.

These transformations significantly reduce the capacity of urban landscapes to absorb and regulate rainfall, thereby increasing both the frequency and persistence of flooding.

f. Ecological Role of Lakes, Wetlands, and Floodplains

Natural water bodies act as ecological buffers that regulate hydrological processes within river basins and urban environments.

Flood mitigation

- Wetlands and lakes temporarily store excess rainfall during intense precipitation events.
- This reduces peak flood levels and delays runoff.

Groundwater recharge

- Water stored in wetlands gradually infiltrates into aquifers.
- This process helps maintain groundwater reserves.

Stabilisation of river flows

- Floodplains allow rivers to spread during periods of high discharge.
- Stored water is released slowly, stabilising river flows over time.

When these natural systems are degraded, filled, or disconnected from river networks, landscapes lose their inherent capacity to buffer floods. Consequently, flood events become more frequent and more persistent.

g. Importance of Basin-Scale Planning

Urban flood management cannot rely solely on engineering interventions such as stormwater drains, pumping stations, or embankments. Effective flood management must consider the broader hydrological functioning of entire watersheds and river basins.

Integrated urban planning

- Urban wetlands and lakes should be protected and restored.
- Natural drainage channels must be preserved.

Floodplain protection

- Construction within floodplains should be strictly regulated.
- Floodplains must remain available for temporary water storage.

Blue-green infrastructure

- Urban planning should integrate green spaces, permeable surfaces, and water bodies.
- Such infrastructure enhances infiltration and regulates runoff.

These approaches recognise that natural landscapes themselves function as vital components of flood management infrastructure.

h. Climate Change and Increasing Flood Risk

Climate change is expected to increase the frequency and intensity of extreme rainfall events across many regions of India.

Interaction with hydrological memory

- Intense rainfall occurring over landscapes already saturated from earlier precipitation significantly increases flood risk.
- The hydrological memory of landscapes therefore becomes a critical factor in determining flood severity.

Implications for disaster management

- Understanding cumulative rainfall patterns is essential for improving flood forecasting systems.
- Disaster preparedness strategies must account for the delayed responses inherent in hydrological systems.

Conclusion

Urban flooding in India cannot be explained solely by heavy rainfall or inadequate drainage infrastructure. The behaviour of water in landscapes reflects a complex interaction between rainfall patterns, natural storage systems, and the cumulative influence of earlier hydrological conditions.

The concept of hydrological hysteresis demonstrates how landscapes retain a form of hydrological memory that shapes flood dynamics. Rapid urbanisation has weakened many of the natural systems that historically regulated water flows, including wetlands, lakes, and floodplains.

Building flood-resilient cities therefore requires integrating natural hydrological processes with urban infrastructure. Protecting ecological water systems, adopting basin-scale planning, and incorporating blue-green infrastructure into urban design will be essential for managing flood risks in an era of accelerating climate change.

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While every effort has been made to balance depth with brevity, please keep the following in mind:

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However, the PrepAlpine team is simultaneously developing a dedicated Prelims-focused Current Affairs Series, designed for:

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- data recall
- Prelims-style MCQs
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