Backwater Effect and Flood Dynamics of the Panchaganga River, Kolhapur: A Review

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Abstract

Structures built between the flood lines of the Panchaganga River at Kolhapur, Maharashtra, have raised concern that they worsen floods through the backwater effect, in which an obstruction downstream raises water levels upstream. This review brings together the reported causes of flooding in the basin: intense monsoon rainfall over a large catchment, river dynamics, bridges and flyovers, weirs, unauthorised construction inside flood lines, and the operation of large dams. It then summarises one-dimensional hydraulic modelling, chiefly HEC-RAS, and the role of Manning's roughness coefficient in calibrating such models. Finally, it outlines a methodological framework: field and satellite data collection, validation of official flood boundaries with GIS data, model preparation, comparison of no-structure, existing-structure and remedial-structure scenarios, and design of remedial measures that barely change upstream water levels. The review identifies research gaps, notably the lack of validated, basin-specific Manning's coefficients and of quantitative scenario comparisons for the Panchaganga River.

Keywords: Panchaganga River; Kolhapur; flood; backwater effect; HEC-RAS; Manning's roughness coefficient; GIS

1. Introduction

River flooding is among the most serious natural disasters worldwide. Of India's total geographical area of about 329 million hectares (mha), more than 40 mha is flood prone [7]. Climate change adds to this pressure: in April 2021 the Potsdam Institute for Climate Impact Research reported that it is heavily affecting the Indian monsoon.

The Panchaganga River, a significant watercourse in the Kolhapur region of Maharashtra, has seen human interventions in the form of structures built between its flood lines.
These structures have prompted debate about their effect on flood dynamics, particularly the backwater effect. Understanding that effect is essential for judging how the river behaves hydrologically during floods and what follows for nearby communities and infrastructure.

The aim of this review is to:

- summarise the natural and human-made causes of flooding in Kolhapur;
- describe one-dimensional hydraulic modelling, especially HEC-RAS, as a tool for testing the effect of structures on flood levels;
- set out a methodological framework for comparing flood behaviour with no structures, with existing structures and with remedial structures; and
- identify gaps that future work should address.

2. Study Arca and Flood Contcxt

Kolhapur lies in the upper Krishna basin of Maharashtra, on the Panchaganga River. The Panchaganga is formed by several tributaries, and it joins the Krishna River downstream of the city. Flood-risk mapping of the river by Panhalkar

et al. shows the highest risk concentrated along the lower reach of the river [10].

Recent floods in the area, notably in 2019 and 2021 [8], have focused attention on the structures built between the river's flood lines. Press reports at the time reached three broad views:

- Structures inside the flood lines contribute to the backwater effect and complicate flood management, affecting local communities and infrastructure.
- Areas along the river were redefined as residential zones, according to an activist quoted in a 2019 report on the Kolhapur floods [9].
- The South Asian Network on Dams, Rivers and People (SANDRAP) attributed the 2019 floods in Kolhapur, Sangli and Satara to reservoir mismanagement. It noted that rainfall exceeded the average by 70, 60 and 78 per cent respectively, but was not unprecedented, so the situation could have been managed.

Taken together, these accounts show that flooding in the basin has both natural and human-made drivers, and that a comprehensive assessment of interventions along the river is needed.

3. Causcs ofi Flooding in Kolhapur

The literature and reports point to natural hydrological drivers, human-made obstructions and reservoir operation acting together [4, 6].

3.1 High-intcnsity rainfiall and runofifi in a largc catchmcnt

Intense monsoon rainfall over the Panchaganga catchment sends large volumes of water into the river quickly. Once the flow exceeds channel capacity, banks are breached and water spreads over Kolhapur city and the surrounding floodplain, sometimes as flash floods with little warning. Four catchment features amplify this:

- **Catchment size.** A large basin collects and channels more rainfall into the river system.
- **Soil saturation.** Saturated soil or very intense rain increases runoff, flow and velocity.
- **Tributary confluence.** The Panchaganga is formed from several tributaries; if they peak together, downstream flood risk rises.
- **Terrain and slope.** Steep slopes and areas with little natural percolation speed up conveyance to the river and worsen prolonged rain.

3.2 Structurcs in and across thc rivcr

Human-made structures can restrict flow during floods, especially where they were not designed for high water levels:

- **Bridges and flyovers.** Structures built across the river and its branches obstruct flow and cause localised flooding as water seeks other paths. Bridge piers and abutments are a recognised source of backwater and flood hazard [1, 2], and flood damage to bridges on the Krishna has itself been documented [3].
- **KT weirs.** Weirs used to control flow and for irrigation change flow and water heights, and their operation can raise flood levels at Kolhapur and nearby areas when the river is already full.
- **Unauthorised construction within flood lines.** Encroachment on the floodplain reduces the room for the river and enlarges the area flooded.

3.3 Dams and thc backwatcr cfificct on thc Krishna

The Krishna and Panchaganga confluence area is affected by backwater, with the reach from Ajjarki and Bhavanpuri to Desur singled out in the study material. Backwater here means that high water levels downstream hold up the discharge from the Panchaganga and Krishna, so levels rise upstream. The Almatti Dam on the Krishna in Karnataka is the main structure

discussed in this context. It lies downstream of Kolhapur, so its reservoir levels and gate operation can influence water levels in the Kolhapur reach. Its effects arise through:

- **Reservoir operation.** When storage is high during heavy rain, the dam must pass large flows, and the timing of releases matters.
- **Hydrological modification.** Damming alters depth, velocity and carrying capacity of the river, and with them its ability to pass floods.
- **Cumulative effects.** Dam operation combines with local rainfall, backwater and local drainage conditions to raise flood levels.

SANDRAP argues that reservoir mismanagement, rather than rainfall alone, caused the 2019 floods in Kolhapur and Sangli. Reservoirs elsewhere in the basin matter too, and poor dam management can aggravate flooding through:

- badly timed or excessive releases during wet weather or when the reservoir is full;
- failure to anticipate weather events, from inaccurate forecasts of rain and river conditions;
- loss of storage capacity through sedimentation;
- poorly maintained gates, spillways and monitoring systems; and
- weak coordination between dam managers, weather agencies and downstream authorities.

Managing this risk requires cooperation between Karnataka and Maharashtra, covering dam operation, flood forecasting and advisories, and release schedules that limit downstream impact.

4. Hydraulic Modclling Approachcs

One-dimensional hydraulic models are the standard way to test how channel structures change flood levels, and HEC-RAS is the most widely used of them.

4.1 Onc-dimcnsional hydraulic modcls

A one-dimensional model solves the equations of flow in a single direction, along the channel. Examples are HEC-RAS, MIKE 1D (DHI) and SWMM. For open-channel flow the governing equations are the Saint-Venant equations. Given topography, channel cross-sections, flow rates and boundary conditions such as downstream water level, the model predicts water-surface profiles during floods and normal flows. Typical applications include:

- flood inundation mapping, hazard assessment and risk management (levees, zoning, warning systems);
- bridge, culvert and weir analysis, including encroachment studies;
- river engineering, sediment and channel-stability studies; and
- real-time forecasting and hydraulic-model verification.

Costabile et al. compared scenarios with and without bridges in one- and two-dimensional models to analyse backwater effects [1], and Wang et al. examined the effect of bridge piers on flood hazards on the Jialing River [2].

4.2 HEC-™AS

HEC-RAS (River Analysis System) was developed by the Hydrologic Engineering Center of the US Army Corps of Engineers. It analyses steady and unsteady flow, water-surface profiles, flow through bridges and culverts, and sediment transport. Its graphical interface supports data entry, viewing of results and reporting. Outputs include water-surface profiles, floodplain maps and velocity distributions. It is widely used internationally by engineers, consultants and researchers in river and floodplain hydraulics, bridge and levee design, and flood-risk analysis.

4.3 Manning's roughncss cocfifiicicnt

Manning's roughness coefficient (n) measures the average roughness of the wetted perimeter of a channel and lets Manning's formula correct for the way roughness slows the flow:

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V = \frac{1}{n} R^{2/3} S^{1/2}
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Here V is mean velocity, R is hydraulic radius and S is channel slope. Values of n range from about 0.01 for smooth surfaces such as concrete channels to over 0.1 for rough natural channels with vegetation, rocks and debris. Engineers determine n from field measurements, published tables or guidelines for the channel type and condition.
Because n controls flow resistance, it strongly influences simulated water levels and velocities, so it must be calibrated against field data, satellite imagery or local knowledge.

4.4 Validation with GIS data

Official flood-hazard boundaries can be checked by overlaying them on topographic, hydrological, land-use and historical flood data in a GIS. Differences between physical (surveyed) data and GIS-derived flood boundaries and water elevations arise from data resolution, modelling assumptions and the interpretation of terrain. They are narrowed by comparison with ground-truth data, calibration of models and refinement of GIS methods.

5. Mcthodological Framcwork

The studies reviewed support a six-step framework for assessing how structures affect flooding on the Panchaganga.

1. **Survey flood data and riverbank infrastructure.** Field inspection of flood-prone areas and of the structural condition of bridges, dams and levees identifies vulnerabilities and likely flood impacts.

2. **Collect satellite data.** Remote sensing records precipitation patterns, water levels and flood extents over large areas. Processed with algorithms, it shows flood onset and progression and supports early warning and emergency response.

3. **Identify data gaps and unauthorised structures.** Gaps come from incomplete surveys, outdated information or limited coverage, and are closed by field surveys, remote sensing and integration of multiple sources. Unauthorised structures on the riverbank obstruct flow, alter drainage and raise inundation risk. They are identified through aerial surveys and ground inspection, followed by regulatory enforcement.

4. **Determine Manning's n and prepare the HEC-RAS model.** Collect topography, cross-sections and boundary conditions. Assign Manning's n to the river bed, floodplain, vegetation and structures. Build the model with cross-sections along the reach, inflow and outflow conditions and hydraulic structures such as bridges, culverts and levees. Run simulations for different return periods or rainfall intensities. Calibrate and validate against observed data or historical floods, and test sensitivity to n and other parameters.

5. **Design a remedial structure.** For an existing structure that raises upstream levels, one option is a spillway or flood bypass channel beside it, sized to match anticipated flood flow without causing backwater upstream. Adjustable gates or weirs in the spillway allow discharge to be controlled in different floods. Sediment transport, aquatic habitat and regulatory requirements should be assessed, with hydraulic engineers, environmental specialists and stakeholders working together.

6. **Compare scenarios.** Run the model for three cases: no structures (the natural baseline), existing structures, and remedial structures. Compare inundation extents, water depths and velocities between them.

6. Discussion and ™cmcdial Mcasurcs

Flooding at Kolhapur cannot be pinned on one cause. Heavy monsoon rainfall over a large catchment is the primary driver, while bridges, flyovers, weirs, encroachment and reservoir operation change how much of that water the river can pass and how high it rises. The debate over backwater is therefore a question of degree, and it can only be settled by quantitative comparison of scenarios.

6.1 Intcrprcting comparativc simulation rcsults

Results from a model such as HEC-RAS should be read against baseline conditions or historical floods. Rougher surfaces (higher Manning's n) slow the flow and typically raise water levels, so the choice of n directly affects the predicted benefit or harm of a structure. Sensitivity analysis shows which parameters, such as n or channel slope, matter most and where to focus further study. Overlaying simulated flood extents on land use,infrastructure and population data in GIS identifies vulnerable areas and helps prioritise floodplain zoning or structural changes. Interpretation must also allow for uncertainty in the data and for the assumptions built into the model.

6.2 ™cmcdial mcasurcs

Two groups of measures appear in the material:

- **Structural measures with negligible upstream effect.** Floodplain storage areas or retention basins hold excess water during peak events and reduce downstream flood risk without significantly raising upstream levels. A spillway or bypass channel beside an existing structure, with adjustable gates, is another option (Section 5).
- **Management measures.** Stronger infrastructure, better early-warning systems, sustainable water management, watershed management, improved flood forecasting, regular dam inspection and monitoring, and closer coordination between dam managers, weather agencies and downstream communities.

6.3 ™cscarch gaps

- Basin-specific Manning's coefficients for the inundated Panchaganga flood basin have not been validated against survey and GIS data.
- The disparity between surveyed flood levels and GIS-derived flood boundaries has not been quantified for the basin.
- The effect of individual structures, and of remedial designs, on upstream water levels has not been compared quantitatively with a no-structure baseline.
- The relative contributions of local structures and of downstream dam operation to backwater near the Krishna confluence remain to be separated.

7. Conclusions

Floods on the Panchaganga at Kolhapur result from intense monsoon rainfall on a large catchment, made worse by obstructions in the channel and floodplain and by the operation of reservoirs on the Krishna system. One-dimensional modelling with HEC-RAS, calibrated with Manning's coefficients and validated against survey and GIS data, offers a practical way to measure how much each structure raises upstream water levels.

Comparing no-structure, existing-structure and remedial-structure scenarios would show which interventions matter and which remedies, such as retention basins or bypass spillways, reduce flood risk without adding to upstream levels. Combined with better dam coordination, forecasting and enforcement against unauthorised construction, this evidence can support flood management that protects communities and infrastructure in the basin.

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