International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Climate Adaptation Technologies for Flood-Prone Cities: Evidence from Kolhapur, Maharashtra, India

Dr. Harshad Kakade[1], Ms. Nisarga Pawar[2]

[1]Sr. Manager - Environment, Choice Consultancy Services Pvt. Ltd., [2]Consultant for Environment Safeguards

Abstract

Kolhapur, on the Panchganga river in the upper Krishna basin, flooded repeatedly in 2005, 2019, 2021 and in later monsoons. The 2019 event set new highest flood levels at several gauging points on the Krishna, Warna and Panchganga [5], and the 2021 flood closed the Mumbai–Bengaluru national highway near the city for about four days [7]. This paper reviews the physical and institutional drivers of flooding in Kolhapur and assesses the adaptation technologies available to the city: real-time forecasting and decision support, satellite and GIS flood mapping, reservoir and inter-state dam coordination, floodplain regulation, river-conveyance improvement, urban stormwater management, nature-based solutions and property-level floodproofing. It then examines the ₹3,200-crore Maharashtra Resilience Development Programme (MRDP), a World Bank-supported flood-management mission for Kolhapur, Sangli and Ichalkaranji [13][14], and proposes an evaluation framework for measuring adaptation outcomes. We argue that technology alone is insufficient: the 2019 losses were strongly linked to development in the floodplain and to weak enforcement of flood-line regulation [1][3], so adaptation depends on pairing technical systems with land-use governance.

Keywords: climate adaptation; urban flooding; Kolhapur; Panchganga; Krishna basin; early warning; flood-line; nature-based solutions; Maharashtra

1. Introduction

Floods are among the most frequent and damaging natural hazards in India, and their impact is rising as cities expand into river floodplains and monsoon rainfall becomes more intense. A World Bank feature story republished by UN OCHA's ReliefWeb reports that floods afflict some 32 million people in India each year and cost the economy between ₹6,000 and ₹12,000 crore annually; the figure dates from 2017 and is used here only as an indicative order of magnitude [20].

Kolhapur, a historic city in south-western Maharashtra, illustrates this challenge. It lies on the Panchganga river in the upper Krishna basin, where rain-fed tributaries from the Western Ghats meet a river system shared with Karnataka. The city and the neighbouring districts of Sangli and Satara flood often, and Maharashtra has asked Karnataka for controlled releases from the Almatti dam because high Krishna levels cause floods in at least three districts every year [17]. The floods of 2005, 2019 and 2021 caused loss of life, damage to crops and livestock, and closure of the Mumbai–Bengaluru national highway near the city [4][7].

Climate adaptation, meaning the adjustment of infrastructure, institutions and practices to reduce harm from present and expected hazards, has become a priority for the state and its development partners. In July 2026 Maharashtra announced a ₹3,200-crore, World Bank-supported flood management mission for Kolhapur, Sangli and Ichalkaranji [13][14]. This paper reviews the flood context of Kolhapur and the adaptation technologies available to a mid-sized Indian river city and outlines a framework for evaluating adaptation outcomes.

The paper is organized as follows. Section 2 describes the study area and data sources; Section 3 presents the flood record and Section 4 the drivers of flood risk. Section 5 reviews adaptation technologies, Section 6 the policy and investment context and Section 7 a proposed evaluation framework. Sections 8 to 10 provide the discussion, limitations and conclusion.

2. Study Area and Data

2.1 Setting

Kolhapur city lies on the Panchganga river, fed by tributaries from the Western Ghats including the Kumbhi, Kasari, Bhogavati and Tulshi. The Panchganga joins the Krishna downstream, so the city is exposed both to local rainfall and to backwater effects when the Krishna is high. Flood status is tracked at the Rajaram weir gauge, where the warning level is 39 ft and the danger level is 43 ft, according to the district disaster management cell and the State Disaster Management Authority [10][11]. Upstream, the Radhanagari dam is operated through automated gates, and its releases affect the Panchganga level [9]. Kolhapur city had about 5.5 lakh residents at the 2011 Census [24].

2.2 Data sources and method

The study uses (i) gauge and warning-level data reported by the Kolhapur district disaster cell and SDMA; (ii) satellite flood mapping by the National Remote Sensing Centre (NRSC) for 2021 [8]; (iii) government statements on programme costs; and (iv) peer-reviewed and policy literature. The Appendix lists primary datasets to obtain: CWC daily gauge series, IMD gridded rainfall, WRD reservoir release logs, the KMC Development Plan flood-line maps, and NDRF/SDMA damage assessments.

3. Flood Record

Table 1. Selected flood events affecting Kolhapur

Event	Key reported figures	Source
2005	Previous benchmark flood. Kolhapur recorded about 159–160 mm in a 31-day period (monthly record at that time)	[4]
Aug 2019	Rajaram weir reported at 52 ft on 6 Aug against the 43 ft danger level; about 1.32 lakh people reported as affected (The Quint, 8 Aug) or as evacuated (Pune divisional commissioner, 7 Aug) across Pune division; 22 NDRF teams deployed; Warna and Panchganga crossed highest flood levels at Samdoli and Terwad	[5][6][27][29]
Aug 2019, losses	About 50–60 deaths across the Kolhapur–Sangli region (reports range from about 50 to at least 60); about 96,000 ha of farmland damaged with potential	[3][4][12]

Event	Key reported figures	Source
	agricultural loss of ₹700 crore	
Aug 2020	Panchganga at 41.2 ft against 39 ft alert and 43 ft danger on the day of the alert; reported at 44.6 ft (above danger level) on 8 Aug; about 90 weirs submerged; four NDRF teams deployed	[10][30]
Jul 2021	Rajaram weir at 48.1 ft on 23 Jul and 50.7 ft on 26 Jul; 114 bunds submerged; Mumbai–Bengaluru highway closed about four days with about 2,000 vehicles stranded	[7]
Jul 2022	Panchganga above warning level (about 40.6 ft); Almatti releasing about 85,857 cusecs; 81 bunds submerged	[9]
Aug 2022	40.2 ft at Rajaram weir; university exams suspended	[11]
Jul 2024	Rajaram weir at about 46.4 ft on 27 Jul, above the 43 ft danger level; more than 5,000 people shifted to safety in Kolhapur	[25]

Data caveats: Two sources describe Kolhapur's 2019 rainfall as 180 mm in nine days, while another phrase it as 180 per cent of normal; the IMD station series should be used to settle this. One wire report calls 49 ft the danger mark whereas all other reports use 43 ft; the SDMA figure is used here. A Lok Sabha submission put losses in Kolhapur district at about ₹1,300 crore but the flood year needs confirmation [18].

4. Drivers of Flood Risk

4.1 Extreme rainfall

In 2019 Kolhapur and Sangli received very large rainfall totals in about nine days, exceeding the 2005 monthly record [4]. Whether this trend is attributable to climate change needs regional attribution analysis (see IPCC AR6 on increasing heavy-precipitation events over South Asia [22]). The paper treats rainfall intensification as a planning assumption, not a proven attribution.

4.2 Floodplain encroachment and flood-line errors

The most policy-relevant finding in the literature is that development in the floodplain increased exposure. Documents obtained under the Right to Information Act, as reported by Moneylife, indicate that roughly 1,250 acres along the Panchganga that fall inside the red and blue flood lines, where building is prohibited, have nonetheless been built upon [3]. The flood-line study behind these claims was prepared by the Water Resources Department in 2018 and verified by IIT Bombay [1]. Mongabay India reports that Kolhapur's 2010 Development Plan had marked observed historical flood levels as though they were flood lines; because those levels lie below the computed lines, floodplain land was opened to real-estate development [1]. In a January 2019 communication to the Municipal Corporation, the Water Resources Department stated that the earlier red, blue and green markings were observed flood levels and not formally computed flood lines [1][2]. The National Green Tribunal, in an order of 27 September 2019, directed the irrigation department to complete demarcation of the red and blue lines within one month, and it repeated the direction in 2020 [3][26]. These claims come from activists,

journalists and official documents; the legal position and the current status of the 2024–26 demarcation should be confirmed against the Tribunal's orders.

4.3 Reservoir operations and inter-state coordination

Backwater from the Krishna, influenced by Almatti dam releases in Karnataka, has long worsened flooding in Kolhapur and Sangli. Karnataka agreed during the 2019 flood to release large flows from Almatti to lower levels downstream [29], and a joint Maharashtra–Karnataka committee to manage monsoon floods has been proposed [28]. Maharashtra has asked for controlled releases [17].

4.4 Infrastructure bottlenecks

The Mumbai–Bengaluru highway near Shiroli was closed for four days in 2021 because the bridge stretch was inundated, which stranded freight and delayed relief [7]. The then Deputy Chief Minister proposed flyovers on the highway and called for action against encroachments on natural water bodies feeding the Panchganga [7].

5. Adaptation Technologies

5.1 Real-time forecasting and decision support

The Water Resources Department of Maharashtra, with World Bank funding, has sought a real-time decision support and flow forecasting system for reservoir operations and flood management in the Krishna and Bhima basins [16]. Core components for Kolhapur: telemetry rain and river gauges; coupled rainfall–runoff and hydrodynamic models (for example HEC-HMS with HEC-RAS or MIKE); integration of Radhanagari, Dudhganga and Almatti release schedules; and ward-level flood-depth products linked to evacuation plans.

5.2 Satellite and GIS flood mapping

NRSC produced pre-flood and during-flood maps for Kolhapur and Sangli in July 2021 [8]. Sentinel-1 SAR can map inundation under cloud, and LiDAR or drone-derived DEMs can improve floodplain delineation. These layers give the evidence base for statutory flood lines and for insurance and relief targeting.

5.3 Reservoir operation and basin transfers

The Krishna–Bhima Stabilisation Project, as described by the National Water Development Agency, would transfer about 115 TMC (3,256 million m^3) of flood water from rivers including the Kumbhi, Kasari, Warna, Koyna and Panchganga to water-short parts of the Upper Bhima basin [12]. The World Bank approved ₹2,328 crore in January 2024 for infrastructure to divert flood water from western Maharashtra to Marathwada, with a state contribution of ₹998 crore [21]. The effect of such diversions on Kolhapur's peak stages has not been established in the public domain and needs hydraulic modelling.

5.4 River conveyance and stormwater

According to the July 2026 announcement, the MRDP targets three outcomes in Kolhapur, Sangli and Ichalkaranji: more storage for rainwater, a river channel able to carry more flow, and better stormwater drainage [13]. Options include channel and weir modification (the Rajaram weir and similar bunds submerge repeatedly [7][9][10]), removal of encroachments, bypass or relief channels, and sustainable urban drainage (detention basins, permeable surfaces, retrofitted storm drains) integrated with the NDMA urban-flood guidelines [23].

5.5 Nature-based solutions

Floodplain reserve zones, wetland and tank restoration, riparian buffers and catchment afforestation in the Ghats reduce runoff peaks and provide room for the river. Their effect is hard to quantify at city scale and should be tested through scenario modelling against engineering options.

5.6 Property-level and community adaptation

Plinth raising, flood-proofed utilities, community early-warning volunteers, and livestock and crop protection reduce losses where structural protection is not feasible. A veterinary assessment after the 2019 flood by ICAR-CCARI visited several Kolhapur talukas, showing livestock as a major loss category [19]. Residents in Shirol told reporters that levels rose 1.5 to 2 ft in one night, leaving no time to move belongings [5], which makes lead time and local alerts important.

Table 2. Technology options for Kolhapur

Option	Main benefit	Main constraint	Indicator
Forecasting and DSS	Longer lead time; better dam releases	Data sharing with Karnataka	Warning lead time (hours)
SAR/GIS mapping	Evidence for flood lines	Needs legal adoption	Area mapped vs. area regulated
Conveyance works	Lower peak stage	Cost; environmental impact	Stage reduction at Rajaram weir
Stormwater/SuDS	Reduces urban waterlogging	Retrofit in dense wards	Waterlogging hours per event
Nature-based	Co-benefits	Hard to measure	Storage added (m^3)
Property-level	Quick, low-cost	Depends on household resources	Losses avoided per household

6. Policy and Investment Context

In August 2024 the Maharashtra government said the World Bank would provide ₹2,240 crore for flood prevention in the Krishna–Bhima basin under a ₹3,200-crore Maharashtra Resilience Development Programme benefiting Sangli and Kolhapur [14]. Phase 1 administrative approval for works was reported in May 2025 with funding of 70 per cent from the World Bank and 30 per cent from the state [15]; the programme is to be executed in two phases [15]. On 27 July 2026 the Chief Minister announced the ₹3,200-crore flood management mission for Kolhapur, Sangli and Ichalkaranji, stating that the state and the World Bank had finished the preparatory work needed for implementation [13]. The trade press reported a Phase 1 sanction of ₹963 crore [15]; this figure has not yet been checked against the government resolution and should be treated as indicative. Other amounts in the public record should not be confused with the MRDP total: the ₹2,328-crore World Bank approval of January 2024 for the Krishna–Bhima flood-diversion project, with a state share of ₹998 crore [21], and a ₹165-crore World Bank component for post-disaster relief and financing that the state cabinet approved in April 2026 [31].

7. Proposed Evaluation Framework

We propose assessing adaptation along four dimensions, each with measurable indicators:

1. **Hazard reduction:** peak stage at Rajaram weir for a 2019-equivalent event (hydraulic model before and after works).
2. **Exposure reduction:** number of buildings and hectares inside red and blue flood lines; encroachment removed.
3. **Vulnerability and response:** warning lead time; evacuation time; share of households with alerts; highway downtime (days).
4. **Cost-effectiveness:** benefit–cost ratio using avoided losses for 2005-, 2019- and 2021-scale events.

A before–after design should use 2019 and 2021 as baselines because both are well-documented.

8. Discussion

Three findings stand out. First, the flood record shows repeated threshold crossings: the 43 ft danger level at Rajaram weir was exceeded in 2019, 2020, 2021 and 2024, and the 39 ft warning level in 2022, so adaptation must be planned for a recurring hazard rather than a rare event. Second, documented controversy over flood-line demarcation implies that the cheapest adaptation measure, keeping development out of the floodplain, was not fully implemented [1][3]. Third, the Krishna backwater and the Almatti release regime mean that city-level technology cannot succeed without inter-state data sharing [17][28].

9. Limitations

Many figures rely on press reports of official statements, and several are inconsistent across outlets (Section 3). Rainfall attribution to climate change is not tested. No hydraulic modelling is presented in this draft; that is the main addition required to turn the review into a research paper.

10. Conclusion

Kolhapur's flood risk results from intense Western Ghats rainfall, backwater from the Krishna, constrained river conveyance and floodplain development. Forecasting, mapping, conveyance upgrades and nature-based storage can all contribute, but their benefit depends on enforceable flood-line regulation and basin-level coordination. The MRDP provides a funded opportunity to implement these measures and to test them against the indicators proposed here.

References

1. Mongabay India (Oct 2019). Western Maharashtra floods: a man-made disaster. india.mongabay.com/2019/10/western-maharashtra-floods-a-man-made-disaster/
2. The Wire. In western Maharashtra, the possibility of a man-made deluge. thewire.in/environment/in-western-maharashtra-the-possibility-of-a-man-made-deluge
3. Moneylife. Kolhapur defies NGT on Panchganga flood-lines, sets perilous precedent for other cities too. moneylife.in/article/kolhapur-defies-ngt-on-panchganga-floodlines-sets-perilous-precedent-for-other-cities-too/61267.html
4. Mongabay India (Jun 2024). The forgotten victims of Maharashtra's 2019 floods. india.mongabay.com/2024/06/the-forgotten-victims-of-maharashtras-2019-floods
5. Scroll.in (2019). In photos: the long-lasting effects of the great Maharashtrian deluge of 2019. scroll.in/article/943463
6. PTI / The Hitavada (9 Aug 2019). Western Mah flood situation grim. thehitavada.com

7. PTI / Udayavani and Deccan Herald (23–27 Jul 2021). Reports on Kolhapur flood levels and Mumbai–Bengaluru highway closure.
8. National Remote Sensing Centre, ISRO. Maharashtra floods, Map ID 2021/06, Disaster Event 08-FL-2021-MH. nrsc.gov.in
9. Deccan Herald (2022). Panchganga river crosses warning mark after heavy rains in Kolhapur.
10. Deccan Herald (2020). Kolhapur district put on flood alert as Panchganga river overflows.
11. PTI / Careers360 (10 Aug 2022). Heavy rains in western Maharashtra; Kolhapur University suspends exams.
12. National Water Development Agency. Upper Krishna–Bhima (Krishna–Bhima Stabilisation) intra-state link project summary. nwda.gov.in/upload/uploadfiles/files/Summary37.pdf
13. Free Press Journal (27 Jul 2026). Maharashtra rolls out ₹3,200-crore flood management mission for Kolhapur, Sangli.
14. Prasar Bharati News on Air (12 Aug 2024). Maharashtra CM launches Institutional Capacity Building Project. newsonair.gov.in
15. Indian Infrastructure (29 May 2025). Maharashtra government gives administrative approval for works under Phase 1 of the Maharashtra Resilience Development Program.
16. Renewable Energy World. India state seeks flow forecasting for Krishna, Bhima rivers.
17. Hindustan Times (5 Nov 2022). Report on Maharashtra's request for controlled Almatti releases.
18. Lok Sabha Secretariat (eParlib). Need to appoint an expert committee to find permanent solution to recurrence of severe floods in Kolhapur district. eparlib.nic.in/bitstream/123456789/725889/1/3925.pdf
19. ICAR–Central Coastal Agricultural Research Institute. Team visited flood-affected villages of Kolhapur district. ccari.icar.gov.in/Kolhapurfloods0819.html
20. ReliefWeb / UN OCHA (World Bank feature story, 22 Mar 2017). Taking a holistic approach to water management. reliefweb.int/report/india/taking-holistic-approach-water-management
21. PTI / The Week (8 Jan 2024). World Bank to give ₹2,328 cr for project to divert flood water to Marathwada.
22. IPCC (2021). Climate Change 2021: The Physical Science Basis. Working Group I contribution to the Sixth Assessment Report, Chapter 11 (Seneviratne et al.) and Chapter 12 (Ranasinghe et al.). Cambridge University Press.
23. NDMA (2010). National Disaster Management Guidelines: Management of Urban Flooding. National Disaster Management Authority, Government of India, New Delhi.
24. Registrar General and Census Commissioner of India (2011). Census of India 2011: population totals, Kolhapur city.
25. PTI / The Week (27 Jul 2024). Rains: more than 5k persons shifted to safety in Kolhapur; river levels rise in Sangli. theweek.in/wire-updates/national/2024/07/27/bom46-mh-rains-kolhapur-sangli.html
26. National Green Tribunal. Order in OA No. 988 of 2018, Dr. Balkrishna A. Shelar v. State of Maharashtra (order of 27 Sep 2019 and later compliance reports). greentribunal.gov.in
27. The Federal (7 Aug 2019). Flood-hit Kolhapur, Sangli critical; Narmada crosses danger mark. thefederal.com/news/2019/08/07/floods-ravage-kolhapur-sangli-1-32-lakh-evacuated-in-western-maharashtra
28. The News Minute. Karnataka, Maharashtra to set up panel to manage floods during monsoon.

29. The Quint / PTI (8 Aug 2019). 16 dead, 1.32 lakh affected in Maharashtra floods; CM takes stock. thequint.com
30. Deccan Herald / PTI (8 Aug 2020). Panchganga river continues to flow above danger mark in Maharashtra. deccanherald.com
31. Free Press Journal (7 Apr 2026). Maharashtra Cabinet approves World Bank-backed MRDP with ₹165 crore for disaster relief, concessional loans, and MSME support. freepressjournal.in

Appendix A. Data checklist

- CWC/WRD hourly gauge data, Rajaram weir and Samdoli, Terwad, Kurundwad, 2005–2025
- IMD gridded rainfall (0.25°) and station data, Kolhapur and Western Ghats catchment
- Radhanagari, Dudhganga, Koyna and Almatti release logs, July–August 2019 and 2021
- NRSC and Sentinel-1 inundation extents, 2019 and 2021
- KMC ward-wise building footprint, population and Development Plan flood lines
- Damage and relief figures from the divisional commissioner, Pune