Racing the Monsoon: A Bibliometric Review of Operations Research for Flood Preparedness

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Abstract—**Every year the Brihanmumbai Municipal Corporation (BMC) races to remove about 10 lakh tonnes of silt from Mumbai's drains before the monsoon, then hires more than 500 dewatering pumps for chronic waterlogging spots. Deadlines are routinely missed, yet neither task is planned with formal operations research (OR) tools. This study combines a PRISMA-guided bibliometric review with four classical OR models calibrated to public BMC reports. An EBSCOhost search identified 209 records, of which 169 journal articles published between 2010 and 2026 were analysed. Output grew at 13.9% a year, more than half of it appearing from 2021 onwards, and two journals, Annals of Operations Research and Computers & Operations Research, form the Bradford core. Authorship is highly dispersed (Lotka's β = 3.37; 91% of authors wrote one article). The field is dominated by post-disaster response and facility location: 77% of articles address relief, response or evacuation, only 11 mention floods, 3 study India, and none studies Mumbai, drainage maintenance or project scheduling with PERT/CPM. The case study fills part of this gap. A PERT model with Monte Carlo simulation shows that the desilting programme has a 21% chance of meeting its 31 May deadline and a 68% chance of finishing before monsoon onset; a crashing linear programme shows that about INR 2.9 crore, spent mainly on faster tendering, raises the latter to 95%. A transportation model finds that Vogel's approximation matches the optimal silt-disposal plan while the north-west corner rule costs 14.6% more; a pump-allocation integer programme finds that about INR 6 crore protects 95% of 11.5 lakh exposed residents at eight hotspots; and an assignment model cuts the worst storm-day response time from 169 to 92 minutes. Monsoon readiness is decided as much by tender timing as by machinery.**

I. INTRODUCTION

1.1 Mumbai and its residents

Mumbai floods almost every monsoon. Since the deluge of July 2005, the BMC has run an annual pre-monsoon programme with two parts: desilting its major and minor drains (nullahs), the Mithi River and highway drains, and hiring dewatering pumps for low-lying spots where heavy rain coinciding with high tide overwhelms the drains. Both parts have grown: according to BMC figures, the desilting target is about 9.7 to 10.2 lakh metric tonnes a season (Free Press Journal, 2026), the pump fleet has risen to 547 from 481 in 2024, and 386 flooding spots have been identified across the city. When the programme fails, waterlogging at spots such as Hindmata, Sion and Andheri Subway disrupts road and rail travel for lakhs of commuters.

The programme is a race against an uncertain finish line. For 2026 the BMC set 31 May as the deadline for 100% desilting (Swarajya, 2026), but the monsoon does not wait for deadlines. Its normal onset over Mumbai is 11 June, yet in 2025 it arrived on 26 May, the earliest since records began in 1950 (The Week, 2025). Deadlines also slip: Mithi River desilting was extended to 7 June after a contractor scam probe and the blacklisting of another firm (Free Press Journal, 2026).

1.2 Why this is an operations research problem

These are classical OR problems. Will a project with uncertain activity times finish before an uncertain deadline, and what does it cost to make sure? Where should silt go to minimise haulage? How should a limited pump budget be spread across hotspots, and which reserve unit should respond where? PERT/CPM, the transportation problem, integer programming and the assignment problem were designed for exactly these questions. Yet, as Section 4 shows, OR research on floods and disasters concentrates on relief and evacuation after the event, not on preparing a city's drainage before it.

1.3 Motivation, research questions and objectives

This study is motivated by a mismatch: a city that spends crores every year on preparedness, a well-developed OR toolbox, and almost no research connecting the two. We pose three research questions:

1. RQ1: How has OR research on flood preparedness and disaster logistics evolved, which methods and journals dominate, and where are the gaps for Indian cities?
2. RQ2: What is the probability that Mumbai's pre-monsoon desilting finishes before the deadline and before monsoon onset, and what does crashing the schedule to a safe probability cost?
3. RQ3: How should a limited pump budget be allocated across chronic waterlogging hotspots, and how should reserve pump units be dispatched on a storm day?

The research objectives are to (i) map the growth, journals, authors and themes of the field through performance analysis and science mapping; (ii) quantify the schedule risk of Mumbai's desilting programme and the cost of reducing it; (iii) determine cost-effective silt disposal, pump allocation and storm-day dispatch; and (iv) set out a future research agenda from the gaps found.

Section 2 reviews the literature; Section 3 describes the methodology; Section 4 presents the bibliometric analysis; Sections 5 to 7 present the case, models and results; Section 8 discusses implications, limitations and a research agenda; Section 9 concludes.

II. LITERATURE REVIEW

Reviews of disaster operations. Altay and Green (2006) classify OR work across the four phases of disaster management (mitigation, preparedness, response and recovery) and find that mitigation and preparedness receive the least attention. Caunhye et al. (2012) and Galindo and Batta (2013) confirm the imbalance: pre-disaster work is mostly evacuation planning, facility location and stock pre-positioning, while most models address relief distribution and casualty transport after the event. A recent review of AI-driven decision support (Abdulrashid et al., 2026) finds the same pattern in newer methods.

Evacuation, shelters and relief facilities. The oldest stream locates shelters and routes evacuees (Sherali et al., 1991; Kongsomsaksakul et al., 2005) or relief facilities (Balcik & Beamon, 2008). Later work adds uncertainty: Rawls and Turnquist (2010) pre-position supplies under uncertain disaster location, Hong et al. (2015) design relief networks with probabilistic reliability constraints, and Erbeyoğlu and Bilge (2020) add fairness to robust preparedness models.

Flood-specific models. Flood studies in OR are few and mostly locate relief facilities: Sangsawang and Chanta (2020) design a hub network for flood relief in Thailand, Shu et al. (2021) design a relief supply network for the 2013 floods in Northeast China, and Chakraborty et al. (2018) locate relief facilities on flood-vulnerable roads in Bankura district, India. The closest study to prevention is Austgen et al. (2025), who deploy temporary flood barriers to protect electrical substations before a hurricane.

Scheduling. PERT (Malcolm et al., 1959) and CPM (Kelley & Walker, 1959) estimate completion of projects with uncertain activities; analytic PERT is optimistic when parallel paths merge, which Monte Carlo simulation corrects (Fulkerson, 1962; Van Slyke, 1963). In disaster OR, scheduling appears only for post-disaster repair crews (Shin et al., 2019), not for pre-season maintenance.

Urban flooding in Mumbai. Studies of Mumbai's floods come from hydrology and planning rather than OR. Gupta (2007) traces the 2005 floods to undersized drains, encroachment and siltation, and calls for better preparedness planning.

Table 1 codes the core studies from the screened corpus.

Table 1: Core studies from the screened corpus

Study	Problem	Method	Phase
Caunhye et al. (2012)	Review of emergency logistics models	Content analysis	All
Hong et al. (2015)	Pre-disaster relief network design	Risk-averse stochastic programming	Preparedness
Chakraborty et al. (2018)	Relief facility location on flood-prone roads, India	Multi-objective optimisation	Preparedness
Shin et al. (2019)	Scheduling repair crews and relief vehicles	MILP, ant colony optimisation	Response

Erbeyoğlu and Bilge (2020)	Fair and robust preparedness network	Logic-based Bender's decomposition	Preparedness
Sangsawang and Chanta (2020)	Hub location for flood relief	Capacitated hub location model	Response
Shu et al. (2021)	Relief supply network, 2013 China flood	Expander-graph model, cutting planes	Preparedness
Austgen et al. (2025)	Flood barriers for electrical substations	Two-stage stochastic and robust models	Mitigation
Abdulrashid et al. (2026)	Review of AI decision support in disasters	Systematic review	All

III. RESEARCH METHODOLOGY

3.1 Search strategy

Following the course protocol and the guidelines of Donthu et al. (2021), EBSCOhost was searched on 7 October 2026 with the mandatory terms "operations" AND "research" [confirm database name and date]: "operations" AND "research" AND ("flood*" OR "waterlogging" OR "urban drainage" OR "stormwater" OR "monsoon" OR "disaster" OR "humanitarian logistics") AND ("linear programming" OR "integer programming" OR "transportation problem" OR "assignment" OR "PERT" OR "critical path" OR "project scheduling" OR "facility location")

Results were limited to academic journals in English published from 2010 to 2026 and exported in BibTeX format into Mendeley.

3.2 Screening (PRISMA)

Screening followed the PRISMA guidelines in four phases (Figure 1). The search identified 209 records. Mendeley's duplicate check found no duplicates. Titles and abstracts were then screened against explicit criteria: a record was included if it concerned flood or disaster preparedness, response or logistics and developed, applied or reviewed an OR method. Thirty-eight records were excluded at this stage: 30 were out of scope (disasters mentioned only as one possible application, or unrelated fields such as cloud computing, biofuels or hydropower), 5 used no OR method (empirical, qualitative or Delphi studies) and 3 were editorials, prefaces or non-journal items. At eligibility, 2 non-English articles were excluded, leaving 169 articles. Screening was AI-assisted, with each decision and reason recorded in a screening log for verification by the authors [confirm after checking the log].

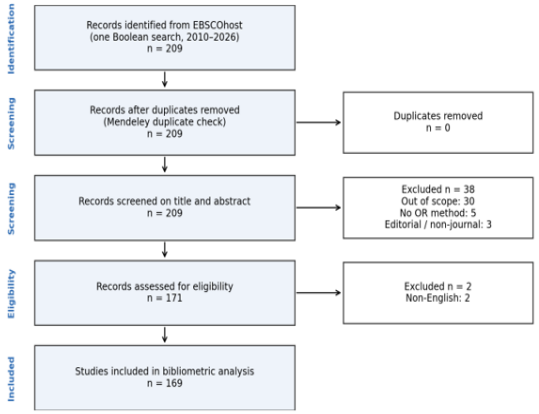

Figure 1: PRISMA flow of record identification and screening.

3.3 Bibliometric analysis

The 169 records were analysed for performance and science mapping following the Bibliometrix approach (Aria & Cuccurullo, 2017): annual production with linear and exponential trends, a logistic life-cycle model, Bradford's law of journal scattering, a three-field plot of authors, journals and themes, cumulative term frequency over time, and Lotka's law of author productivity. Keywords are EBSCO subject terms; industry classification codes that EBSCO attaches as keywords were removed. Theme counts use terms in titles, abstracts and keywords. The EBSCO export does not include citation counts, so citation analysis is not reported.

3.4 Modelling framework

The case study links four OR models across two phases. Before the monsoon, a PERT/CPM model (M1) estimates when the desilting programme will finish relative to the deadline and an uncertain onset, and a crashing linear programme prices faster completion; a transportation model (M2) routes silt to disposal sites. During the monsoon, an integer programme (M3) allocates a pump budget across

hotspots, and an assignment model (M4) dispatches reserve pump units on a storm day. All models are implemented in Python using SciPy's interface to the HiGHS solver; code and data are in the project repository [GitHub link].

Use of AI tools. An AI assistant (Claude) was used to help locate public data, screen records, run the bibliometric analysis, write and test model code, and draft text. All sources, results and text were checked by the authors [confirm].

IV. BIBLIOMETRIC ANALYSIS

4.1 Annual scientific production

The corpus contains 169 articles by 521 authors in 40 journals. Output rose from 3 articles in 2010 to 21 in 2025, a compound annual growth rate of 13.9% (Figure 2), and 54% of all articles appeared from 2021 onwards. The partial year 2026 already holds 22 articles, the highest annual count. Growth has been uneven, with dips in 2020 and 2023. A linear trend fits the 2010–2025 counts slightly better than an exponential one (R^2 = 0.57 against 0.53), so, unlike fast-growing fields such as financial risk analytics, growth here is steady rather than compounding.

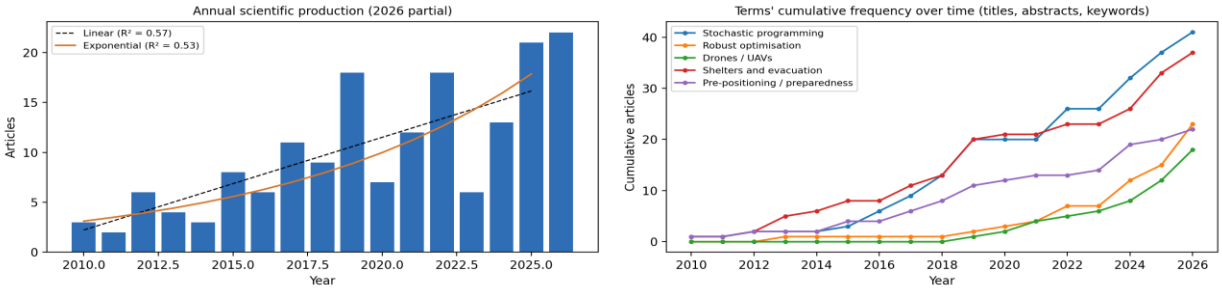

Figure 2: Annual scientific production with linear and exponential trends (left; 2026 is a partial year) and cumulative frequency of key terms (right).

4.2 Life-cycle model

A logistic life-cycle model fitted to cumulative output for 2010–2025 (R^2 = 0.995) places the peak of annual production in 2021 and saturation at about 185 articles (Figure 3). Taken literally, the field would be over 90% mature. However, the two most productive years on record are 2025 and 2026, which contradicts a decline after 2021. The plateau is better read as an artefact of a single, narrowly defined search: the field captured by this query is still growing, and a wider search would be needed to estimate its life cycle reliably.

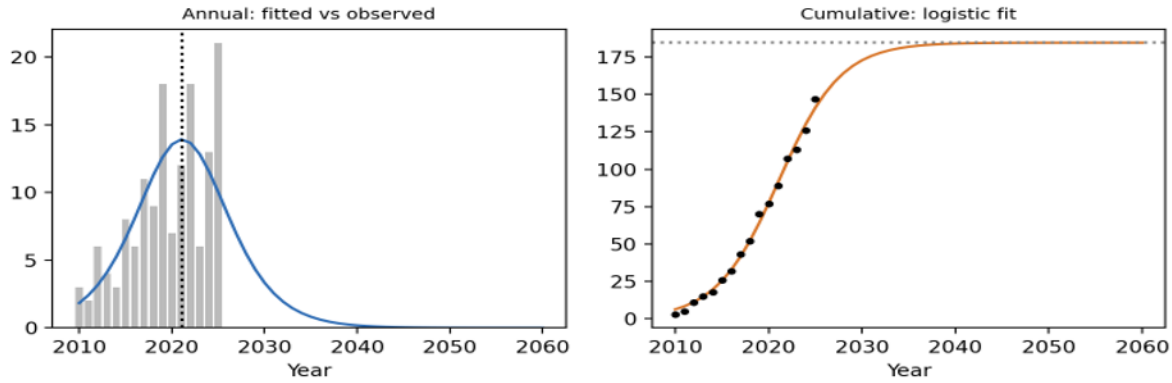

Figure 3: Life-cycle model: fitted annual output (left) and logistic fit to cumulative output (right).

4.3 Bradford's law

Bradford's law divides journals into three zones, each publishing a third of the articles (Figure 4, left). The core is very narrow: two journals, Annals of Operations Research (31 articles) and Computers & Operations Research (26), publish 57 articles. Zone 2 contains 7 journals with 60 articles, led by the European Journal of Operational Research (16) and Transportation Research Part E (15), and Zone 3 contains 31 journals with 52 articles. Research on the topic is therefore concentrated in mainstream OR journals rather than in disaster-management or hydrology outlets, which tells future searches where to start.

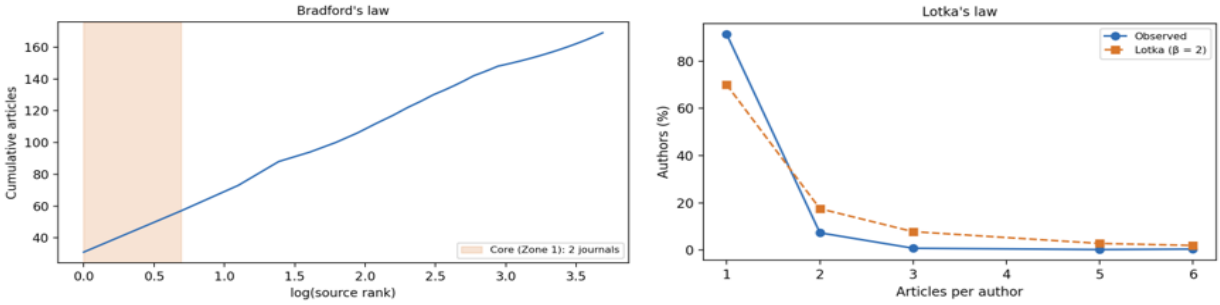

Figure 4: Bradford's law of journal scattering (left) and Lotka's law of author productivity (right).

4.4 Three-field plot

The three-field plot (Figure 5) links the ten most productive authors, the six leading journals and seven themes. Author links are thin and spread across journals: no author dominates any outlet, consistent with the dispersed authorship in Section 4.6. On the right, every leading journal channels most of its articles into facility location (101 articles in total) and stochastic or robust optimisation (59), followed by vehicle routing and shelters and evacuation (37 each). Pre-positioning (22), network restoration (21) and drones (18) are smaller themes.

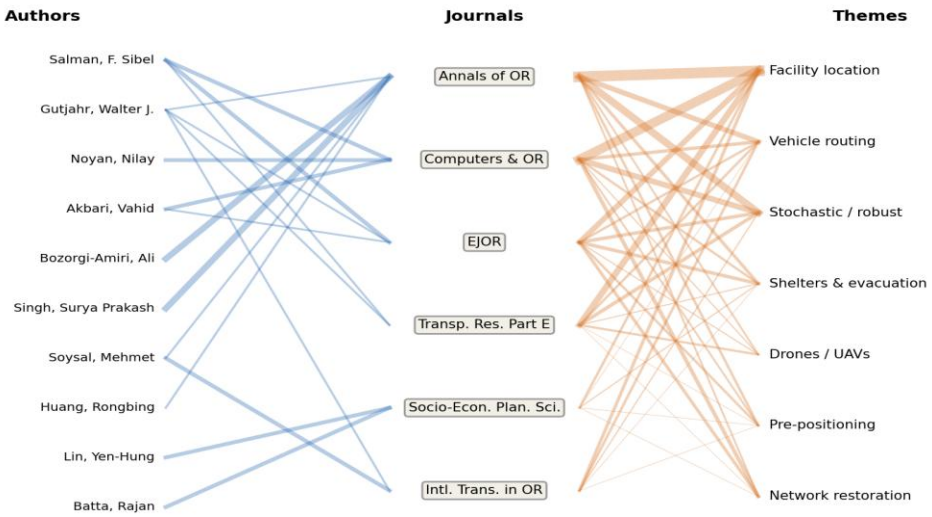

Figure 5: Three-field plot of authors, journals and themes.

4.5 Term frequency over time

Figure 2 (right) tracks the cumulative frequency of key terms. Stochastic programming and shelters and evacuation are long-established, each with about 20 articles by 2020. Robust optimisation (from 3 articles by 2020 to 23 by 2026) and drones or UAVs (from 2 to 18) grew fastest after 2020, reflecting the field's turn to uncertainty-proof models and new delivery technology. Among EBSCO subject keywords, the most frequent methodological terms are mixed-integer

linear programming (28 articles), integer programming (27), linear programming (21), stochastic programming (20) and robust optimisation (19).

4.6 Lotka's law

Lotka's law predicts that the number of authors publishing n articles fall as $1/n^{\beta}$ with β = 2. In this corpus, 476 of 521 authors (91.4%) wrote a single article and only three wrote five or more: Salman and Gutjahr (6 each) and Noyan (5). The fitted exponent is β = 3.37 (R^2 = 0.94), well above 2, and a Kolmogorov-Smirnov comparison with the classical law gives D = 0.21, above the 5% critical value of 0.06 (Figure 4, right). Output drops off faster than Lotka predicts: the field grows through a constant flow of new entrants rather than a core of repeat authors.

4.7 Research gaps

Counting terms across the 169 articles shows where the gaps lie (Table 2).

Table 2: Coverage of selected topics in the corpus (n = 169)

Topic	Articles	Share
Relief, response or evacuation	130	77%
Facility location	101	60%
Preparedness, mitigation or pre-positioning	28	17%
Floods	11	7%
India	3	2%
Drainage, pumps or desilting	0	0%
PERT, critical path or project scheduling	0	0%
Mumbai or monsoon	0	0%

Three gaps follow. First, the field acts after the disaster: response models outnumber preparedness models more than four to one, and the preparedness work that exists is mostly about pre-positioning relief stocks, not maintaining the infrastructure that prevents flooding. Second, floods and Indian cities are nearly absent; the three Indian studies cover relief facility location in Bankura (Chakraborty et al., 2018), temporary blood banks (Sharma et al., 2019) and aid delivery decisions (Jana et al., 2019), and none studies a monsoon city. Third, no article applies PERT/CPM or project scheduling to disaster preparedness, or treats the onset of a hazard as an uncertain deadline. Our case study addresses all three.

V. CASE AND DATA

The study area is the BMC's jurisdiction of 24 administrative wards across the island city and the eastern and western suburbs. Table 3 lists the inputs; values from public reports are cited, and assumed values are labelled and tested in Section 7.6.

Table 3: Data sources and parameters

Input	Value	Source or basis
Silt targets (MT)	City 30,940; Eastern Suburbs 1,23,553; Western Suburbs 2,35,021; Mithi River 2,16,174; minor drains 3,63,533; highway drains 52,560	BMC figures (Free Press Journal, 2026)
Desilting deadline	31 May	Swarajya (2026)
Monsoon onset	Normal 11 June; SD 6.9 days	IMD (The Week, 2025); long-run onset records
Disposal sites	Deonar (132 ha), Kanjurmarg (141 ha), out-of-city sites	Group research; out-of-city site assumed
Disposal capacity (MT/season)	Deonar 4 lakh; Kanjurmarg 5 lakh; out-of-city 10 lakh	Assumed; Deonar is under phased closure
Pump capacity (m^3/h)	Standard 400 (range 250–500); large 1,500 (range 1,000–3,000)	BMC tenders and press reports
Pump hire (INR crore/season)	Standard 0.18; large 0.45	About INR 54 crore for 298 pumps (press, 2018); large assumed
Hotspots	8 chronic spots, Hindmata to Dahisar	Group research; catchment and exposure assumed
Pumping stations	Haji Ali, Love Grove, Cleveland Bunder, Britannia, Irla, Gazdarbandh	Group research

Other	Road detour factor 1.4; haulage INR 12 per tonne-km; storm-day speed 15 km/h; design storm 75 mm/h against drain capacity 50 mm/h	Assumed

Required pumping at each hotspot equals its catchment area times rainfall above the drains' design capacity, times a runoff coefficient of 0.9, giving 1,350 to 3,375 m³/h per hotspot under a 75 mm/h storm. The eight hotspots expose an assumed 11.5 lakh residents and commuters.

VI. MODEL FORMULATION

6.1 M1: Desilting schedule (PERT/CPM with crashing)

The programme is modelled as nine activities starting on 1 March (day 0), so the 31 May deadline is day 91 and the normal onset of 11 June is day 102 (Table 4). Tendering and mobilisation precede six parallel desilting packages, all of which precede final clearance and inspection. Three-point times and crash costs are assumed, informed by reported tender and Mithi River delays.

Table 4: Activities, three-point times (days) and crash costs

ID	Activity	Pred.	a	m	b	t_e	Crash cost (INR cr/day)	Max crash (days)
A	Tendering and work orders	–	10	18	35	19.5	0.20	8
B	Contractor mobilisation	A	5	7	12	7.5	0.30	3
C	City major nullahs	B	35	45	60	45.8	0.40	10
D	Western Suburbs nullahs	B	40	50	70	51.7	0.50	12
E	Eastern Suburbs nullahs	B	40	52	70	53.0	0.50	12
F	Mithi River	B	45	60	85	61.7	1.00	15
G	Minor drains	B	40	55	75	55.8	0.40	12
H	Highway drains	B	30	40	55	40.8	0.30	8
I	Final clearance and inspection	C–H	4	6	10	6.3	0.20	2

For activity k, PERT gives the expected time and variance (Malcolm et al., 1959), and the probabilities of finishing by deadline D and before an onset date $O \sim N(\mu_O, \sigma_O^2)$ along the critical path CP are:

$$t_k = \frac{a_k + 4m_k + b_k}{6}, \qquad \sigma_k^2 = \left(\frac{b_k - a_k}{6}\right)^2$$

$$P(T \le D) = \Phi\left(\frac{D - \sum_{k\in CP} t_k}{\sqrt{\sum_{k\in CP} \sigma_k^2}}\right), \qquad P(T \le O) = \Phi\left(\frac{\mu_O - \sum_{k\in CP} t_k}{\sqrt{\sum_{k\in CP} \sigma_k^2 + \sigma_O^2}}\right)$$

Because analytic PERT understates completion when parallel paths merge (Fulkerson, 1962), we also simulate 100,000 programmes with beta-PERT activity times (Van Slyke, 1963). The crashing model chooses start times S_k and reductions y_k at cost c_k per day to meet a target duration D^*:

$$\min \sum_k c_k\, y_k \quad \text{s.t.} \quad S_l \ge S_k + t_k - y_k \quad \forall (k,l) \in \text{precedence}, \quad S_I + t_I - y_I \le D^*, \quad 0 \le y_k \le u_k$$

6.2 M2: Silt transport (transportation problem)

Zones i supply s_i tonnes; disposal sites j accept up to b_j tonnes; c_{ij} is haulage cost per tonne. A dummy source absorbs spare capacity at zero cost (Hitchcock, 1941):

$$\min \sum_i \sum_j c_{ij}\, x_{ij} \quad \text{s.t.} \quad \sum_j x_{ij} = s_i \;\; \forall i, \quad \sum_i x_{ij} = b_j \;\; \forall j, \quad x_{ij} \ge 0$$

The optimum is compared with the north-west corner rule and Vogel's approximation (Reinfeld & Vogel, 1958).

6.3 M3: Pump allocation (integer programming)

Hotspot h has n_h people exposed and requires q_h m³/h of pumping. The model chooses integer numbers of standard pumps p_h (capacity k_S, cost f_S) and large pumps l_h (k_L, f_L), and a protected share y_h, within budget B:

$$\max \sum_h n_h y_h \quad \text{s.t.} \quad q_h y_h \leq k_S p_h + k_L l_h \quad \forall h, \quad \sum_h (f_S p_h + f_L l_h) \leq B, \quad 0 \leq y_h \leq 1, \quad p_h, l_h \in \mathbb{Z}_{\geq 0}$$

Sweeping B gives a protection curve, a variant of maximal covering (Church & ReVelle, 1974).

6.4 M4: Storm-day dispatch (assignment problem)

Eight reserve pump units are staged at the six pumping stations (two each at Irla and Gazdarbandh). With travel time τ_{uh} from unit u to hotspot h:

$$\min \sum_u \sum_h \tau_{uh} x_{uh} \quad \text{s.t.} \quad \sum_h x_{uh} = 1 \ \forall u, \quad \sum_u x_{uh} = 1 \ \forall h, \quad x_{uh} \in \{0,1\}$$

It is solved by the Hungarian method (Kuhn, 1955) and compared with greedy dispatch, in which the most-exposed hotspot claims the nearest free unit first.

VII. RESULTS

7.1 Schedule risk (M1)

The desilting programme is more likely to miss its deadline than meet it (Table 5). The critical path runs through tendering, mobilisation and the Mithi River, with an expected duration of 95 days (about 4 June).

Table 5: Completion probabilities

Measure	Analytic PERT	Monte Carlo (100,000 runs)
Expected completion (days after 1 March)	95.0	97.4
P (finish by 31 May)	0.31	0.21
P (finish before monsoon onset)	0.75	0.68

Analytic PERT overstates the chance of meeting the deadline by about 10 percentage points because six parallel packages can each become critical. If work orders are issued 15 days late, the probability of finishing before onset falls from 68% to 16%; in an early-onset year like 2025, only 6% of simulated programmes finish in time (Figure 6, left).

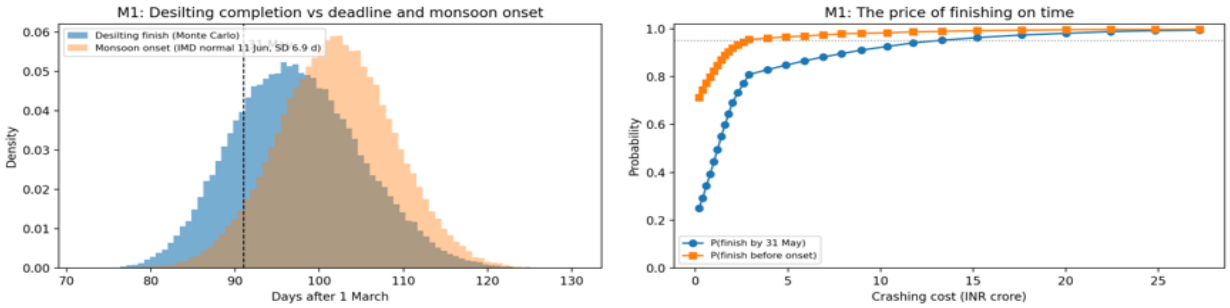

Figure 6: Simulated completion against the deadline and onset distribution (left) and crashing cost against on-time probability (right).

7.2 The price of finishing on time (M1 crashing)

The cheapest way to finish earlier is administrative. The crashing programme shortens tendering first, then inspection and mobilisation, and turns to the costly Mithi River package only after those are exhausted (Table 6, Figure 6, right). About INR 2.9 crore raises the probability of finishing before onset to 95%; meeting 31 May with the same confidence costs about INR 13.3 crore, 4.6 times as much.

Table 6: Crashing cost and on-time probability

Target (days)	Cost (INR crore)	P(by 31 May)	P(before onset)	Activities crashed (days)
95 (none)	0.00	0.21	0.68	–
91	0.80	0.39	0.80	A 2, I 2
85	2.00	0.69	0.92	A 8, I 2
82	2.90	0.81	0.96	A 8, B 3, I 2
76	8.97	0.91	0.98	A 8, B 3, F 6, G 0.2, I 2

73	13.33	0.95	0.99	A 8, B 3, E 0.3, F 9, G 3.2, I 2

7.3 Silt transport (M2)

Moving 10.2 lakh tonnes of silt costs INR 15.56 crore at the optimum. Vogel's approximation finds the optimum exactly, while the north-west corner rule costs INR 17.83 crore, 14.6% more, because it ignores distance. Both city landfills fill to their assumed capacity, so about 1.2 lakh tonnes, from the Eastern Suburbs, must leave the city; with Deonar under closure, disposal capacity rather than distance becomes the binding constraint.

7.4 Pump allocation (M3)

Protection rises steeply with the first few crores and then flattens (Figure 7). About INR 6 crore a season protects 95% of exposed residents at the eight hotspots under a 75 mm/h storm, and INR 7 crore protects all of them. Large pumps cost less per unit of capacity (INR 30 lakh against 45 lakh per 1,000 m³/h), so the model favours them, hiring 12 large and 3 standard pumps at INR 6 crore. The hotspots left partly unprotected, Chembur (74%) and Dahisar (83%), have the fewest people exposed.

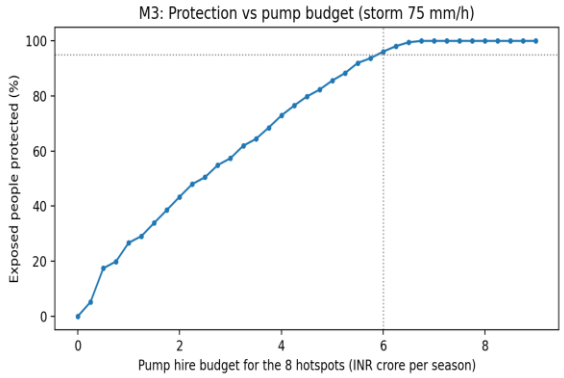

Figure 7: Share of exposed people protected against pump hire budget.

7.5 Storm-day dispatch (M4)

Optimal assignment cuts total response time from 366 to 330 minutes (10%) and the worst single response from 169 to 92 minutes (45%) compared with greedy dispatch. Greedy dispatch serves the busiest hotspots fastest but leaves Dahisar to a unit from Haji Ali at the far end of the city. Even optimally, Dahisar and Malad wait more than 50 minutes because none of the modelled pumping stations lies in the northern suburbs.

7.6 Sensitivity analysis

The pump budget needed for 95% protection depends mainly on storm intensity and barely on pump size: about INR 4 crore at 65 mm/h, 6 crores at 75 mm/h and 9 to 9.5 crore at 90 mm/h, whether a standard pump moves 250, 400 or 500 m³/h. For M1, tendering is crashed first in every scenario, and the deadline is at risk whenever work orders slip.

VIII. DISCUSSION AND FUTURE RESEARCH AGENDA

8.1 Implications for the BMC

Readiness is decided in the tender office. Finalising work orders a week earlier cost far less than rushing the Mithi River in May, and protects against the most damaging scenario, late work orders. Issuing desilting work orders by mid-February would let tender delays eat into slack rather than into the monsoon.

Plan to the onset, not only to the deadline. Reporting progress as a probability of finishing before onset, updated weekly, would give a more honest picture than a single date that is routinely extended. Monte Carlo simulation, rather than single-path PERT, corrects a systematic 10-point optimism.

Secure disposal capacity and size pumps to the outlook. Out-of-city disposal sites should be secured in the tender rather than left to contractors. Pump budgets should go first to the densest hotspots, favour large pumps, and rise with the season's rainfall outlook; mobile reserve units should be staged in the northern suburbs.

8.2 Limitations

Several model inputs are assumed and should be replaced with BMC records: activity durations and crash costs, hotspot catchments and exposure, disposal capacities and pump costs. Distances use a detour factor rather than road routing, the pump model ignores tides and breakdowns, and PERT assumes independent activities. On the bibliometric side, the corpus comes from a single database and one search string, screening was AI-assisted and title-and-abstract based, the EBSCO export lacks citation counts, and EBSCO subject keywords differ from author

keywords. The small corpus also makes the life-cycle estimate unreliable.

8.3 Future research agenda

From response to preparedness. With response models outnumbering preparedness models four to one, future work should model the recurring maintenance that prevents floods, such as desilting, culvert cleaning and pump servicing, as decisions in their own right (Altay & Green, 2006; Galindo & Batta, 2013).

Scheduling against natural deadlines. No article in the corpus applies project scheduling to preparedness. Stochastic and robust scheduling models could update completion probabilities with weekly progress data and hedge against correlated delays, building on the robust optimization that the corpus shows is now growing fastest.

Integrating maintenance and response. An unfinished drain raises the pumping needed at its hotspots. Joint models of maintenance and pump allocation, extending pre-positioning models (Rawls & Turnquist, 2010; Hong et al., 2015), would show where the two budgets substitute for each other.

Indian cities and open data. With only 3 Indian studies and none on a monsoon city, validation against ward-level desilting progress, pump logs and flooding records, obtainable under the Right to Information Act, and extension to Chennai and Kolkata are priorities.

Climate and equity. Models should use forecasts of onset and rainfall intensity rather than historical averages, given 2025's record-early onset, and add equity weights so that less dense areas such as Dahisar are not systematically left behind, extending the fairness work of Erbeyoğlu and Bilge (2020).

IX. CONCLUSION

RQ1. OR research on flood preparedness and disaster logistics grew at 13.9% a year from 2010 to 2025, steadily rather than exponentially, and is concentrated in two core journals, Annals of Operations Research and Computers & Operations Research. It is dominated by facility location and stochastic programming, with robust optimisation and drones growing fastest, and authorship is highly dispersed ($\beta = 3.37$). The field acts after disasters: 77% of articles address response, only 7% floods and 2% India, and none studies drainage maintenance, PERT/CPM scheduling or Mumbai.

RQ2. Mumbai's desilting programme has about a 21% chance of meeting its 31 May deadline and 68% of finishing before monsoon onset. About INR 2.9 crore of crashing, mostly through faster tendering, raises the latter to 95%.

RQ3. About INR 6 crore a season of pump hire, favouring large pumps at the densest hotspots, protects 95% of exposed residents at eight chronic hotspots, and optimal storm-day dispatch cuts the worst response time by 45%.

Implications. Academically, the study links disaster OR, which concentrates on response, with urban flood studies of Mumbai. Managerially and socially, the cheapest readiness gains for the BMC and Mumbai's commuters come from earlier tendering, probability-based progress reporting, secured disposal capacity and outlook-based pump budgets (Section 8.1). For policy, publishing ward-level desilting, pump and flooding data would allow these models to be validated with real records. Monsoon readiness in Mumbai is decided as much in the tender office as on the nullah bank.

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