



**COMPILATION ON RVA
LEADING TO
RESILIENCE OF BRIDGES**

Researched by

UBMS RESEARCH GROUP



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Tundalwar and Sreenath Menon**

COMPILATION ON RVA LEADING TO RESILIENCE OF BRIDGES

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ARTICLE 1:


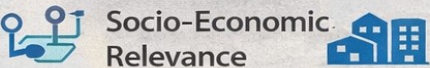
**PILOT PROJECT TO EVALUATE RISK AND
VULNERABILITY OF BRIDGES IN KOLHAPUR
DISTRICT**





**PILOT PROJECT TO EVALUATE RISK AND
VULNERABILITY OF BRIDGES IN KOLHAPUR DISTRICT**




PILOT PROJECT TO EVALUATE RISK AND VULNERABILITY OF BRIDGES IN KOLHAPUR DISTRICT

 **HAZARD**
Dynamic Frequency & Severity


 **EXPOSURE**
Functional & Socio-Economic Relevance


 **VULNERABILITY**
Structural Condition, Funds, Resilience & Policies


RISK INDEX
 Sustainable Development Goals & Regional Growth


 Sustainable Development Goals & Regional Growth
 Loss of Lives, Economic Loss & Collapse


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PROJECT TO EVALUATE RISK AND VULNERABILITY OF BRIDGES IN KOLHAPUR DISTRICT

Purpose:

Risk-based evaluation of bridge infrastructure within multiple river basins in Kolhapur district to support resilience planning, prioritization of interventions, and informed decision-making.

1. Introduction:

1.1 Background

UBMS Research Group [URG] approached the Kolhapur district disaster management authorities to conduct a Technology demonstration project whereby Risk and Vulnerability Analysis [RVA] for Bridges would be conducted. URG received a good ahead to this demonstration from Kolhapur Collector. Subsequently in an on-line meeting organized, the respected Collector directed URG and DDMA to work together. PWD was directed to assign 15 bridges for RVA. Accordingly the bridges were assigned as per Annex 2 to this report. Sreenath Menon from URG visited Kolhapur from 4th January 2026 to collect bridge data essential for RVA. The focus was on hazard [flooding, landslides, cyclone, earthquake] related distress and resulting deterioration in the bridges.

Bridges are vital components of transportation infrastructure, ensuring connectivity across rivers, floodplains, and key corridors. Their reliable performance is essential for economic activity, public safety, and emergency response. Historically disruption of bridge services resulted in significant mobility constraints, economic losses, and reduced disaster response efficiency.

Kolhapur District, located at the eastern foothills of the Western Ghats within multiple river basins, is exposed to multiple natural hazards due to its tropical monsoon climate, intense seasonal rainfall, and complex geo-morphology. High-intensity monsoon precipitation often causes rapid rises in river levels, subjecting bridges to severe hydraulic forces, prolonged submergence, debris impact, and foundation scour. These conditions accelerate structural deterioration and reduce serviceability.

The district is also indirectly affected by cyclonic systems from the Arabian Sea and Bay of Bengal, which intensify rainfall and trigger flooding and landslides, particularly in the western hilly talukas. Additionally, Kolhapur lies in Seismic Zone III, indicating moderate earthquake risk, with many older bridges designed without modern seismic provisions. Historical flood events, notably in 1975, 1978,

1993, 2005, 2019, and 2021, highlight the vulnerability of bridge infrastructure and underscore the need for proactive, risk-based, and resilience-oriented bridge management.

1.2 Purpose and Scope

The purpose of this study is to assess the risk and vulnerability of bridges assigned by PWD in Kolhapur District under multiple natural hazards. The scope includes road bridges of varying age, design, material, and functional importance across state highways, and major district roads. The assessment integrates historical hazard data (1975–2025), bridge inspection records, and risk-based analytical methods, considering flooding, indirect cyclone impacts, landslides, and earthquakes. A semi-quantitative approach is adopted to support prioritization of interventions and enhance the resilience of bridge infrastructure.

1.3 Objectives

The primary objectives of the present study are outlined as follows:

- I. To identify and characterize the major natural hazards affecting bridge infrastructure in Kolhapur District, with emphasis on historical occurrence, spatial distribution, and triggering mechanisms.
- II. To assess the structural vulnerability of bridges based on inspection data, condition ratings [Structural, Functional and Socio-Economic], material deterioration, design characteristics, and maintenance history. This assessment was implemented using the Global Analytics for Bridge Management [GABM] system.
- III. To evaluate the risk associated with each bridge by systematically combining hazard likelihood, vulnerability with respect to the three parameters [Structural, Functional and Socio-Economic], and potential consequences of failure or functional disruption.
- IV. To prioritize bridges for mitigation, retrofitting, monitoring, and resilience enhancement measures using a risk-based Multi-Criteria Decision Making [MCDM] framework. RVA and application of MCDM was conducted using Global Analytics for Risk and Resilience Management [GARM] system.
- V. To provide technical inputs that can support policy decisions, bridge management systems, and the development of early-warning and disaster preparedness strategies.

2. RISK AND VULNERABILITY ANALYSIS FRAMEWORK

Risk and Vulnerability Analysis (RVA) provides a structured approach for evaluating the performance and safety of bridge infrastructure under natural hazard conditions. Four natural hazards namely Floods, Cyclones, Landslides, and Earthquakes were focused upon in GABM and GARM.

Bridges are critical nodes in transportation networks, and their failure or loss of serviceability can result in significant social, economic, and emergency response consequences. Evaluation of resultant loss includes direct loss to transportation network and indirect loss arising from the Socio-Economic considerations of the bridge to the region.

The RVA framework adopted in this study integrates hazard characteristics, structural vulnerability, and consequence assessment to support informed decision-making and prioritization of mitigation measures.

2.1 Concept of Risk

Risk is defined as the combined effect of the likelihood of occurrence of a hazardous event and the severity of its consequences. In the context of bridge infrastructure, risk is not determined solely by the presence of hazards but by the interaction between hazard exposure, structural vulnerability, and functional importance.

Hazard exposure refers to the frequency and intensity of natural events such as floods, earthquakes, landslides, and cyclone-induced extreme weather. Vulnerability represents the susceptibility of a bridge to damage under these hazards and depends on factors including structural condition, age, design standards, material properties, foundation type, and maintenance history. Consequence reflects the impacts of bridge damage or failure in terms of public safety, economic losses, traffic disruption, emergency accessibility, and network connectivity.

A bridge with high exposure but good structural condition may pose lower risk than a structurally deficient bridge carrying critical traffic under moderate hazard conditions. Ageing bridge is a bridge that has been in use for more than 50 percent of Designed Service Life [DSL]. Typically all bridges constructed before 1990 can be assumed to have a 50 years DSL. All bridges under study have been in use for more than 30 years and so considered as ageing. It is an accepted knowledge that ageing bridges deteriorate. Such deteriorated bridges have higher vulnerability to natural hazards.

Therefore, an integrated risk perspective is essential for realistic assessment and effective prioritization. In this study, risk is conceptualized as a function of hazard likelihood, bridge vulnerability, and consequences of failure or service disruption.

2.2 Methodology

This study adopts a structured Risk and Vulnerability Analysis framework designed to ensure technical consistency while remaining practical for district-level application. The methodology comprises four key stages: hazard identification, vulnerability assessment, risk analysis, and prioritization.

The flow of data within the Risk and Vulnerability Analysis (RVA) framework follows a structured and sequential process that integrates bridge-level information with hazard data and decision-support analytics. The framework begins with the collection of essential input data related to individual bridges and their operating environment.

The primary inputs include basic bridge geometry such as span length, number of spans, deck width, pier and abutment configuration, foundation type, and construction material. In addition, geospatial data—such as bridge location, river basin, elevation, proximity to floodplains, landslide-prone slopes, and seismic zoning—is incorporated to capture the spatial exposure of each bridge to natural hazards. Alongside physical data, qualitative and semi-quantitative rankings are assigned for structural condition, functional adequacy, and socio-economic importance based on inspection reports, traffic significance, connectivity role, and accessibility during emergencies. Historical hazard data, including records of floods, cyclones (indirect impacts), landslides, and earthquakes affecting the region, form a critical input for understanding hazard frequency and severity.

Hazard identification is carried out using historical records for past 50 years, hazard zoning maps, and regional studies to define the natural hazard environment affecting bridges in Kolhapur District. Vulnerability assessment evaluates the susceptibility of individual bridges based on inspection reports, condition ratings, observed distress, design characteristics, and maintenance history, considering all three parameters namely structural, functional and socio-economic aspects.

This integrated dataset is first analysed within the Global Analytics for Bridge Management (GABM) system. GABM processes bridge-specific information to evaluate current structural condition, deterioration trends, functional performance, and baseline

vulnerability. The outputs generated at this stage include condition indices, vulnerability indicators, and preliminary risk-related parameters for each bridge. These outputs serve as structured and standardized inputs for the next stage of analysis.

The results from GABM are then transferred to the Global Analytics for Risk and Resilience Management (GARM) system, where advanced risk and vulnerability assessments are performed. Within GARM, hazard likelihood is combined with bridge vulnerability and consequence parameters to estimate overall risk levels. This stage also enables identification of dominant risk drivers and potential failure mechanisms under different hazard scenarios.

Risk analysis integrates hazard likelihood with vulnerability and consequence indicators to determine overall risk levels. Due to limitations in detailed probabilistic data, a semi-quantitative scoring and ranking approach is adopted to ensure consistency and comparability across the bridge inventory.

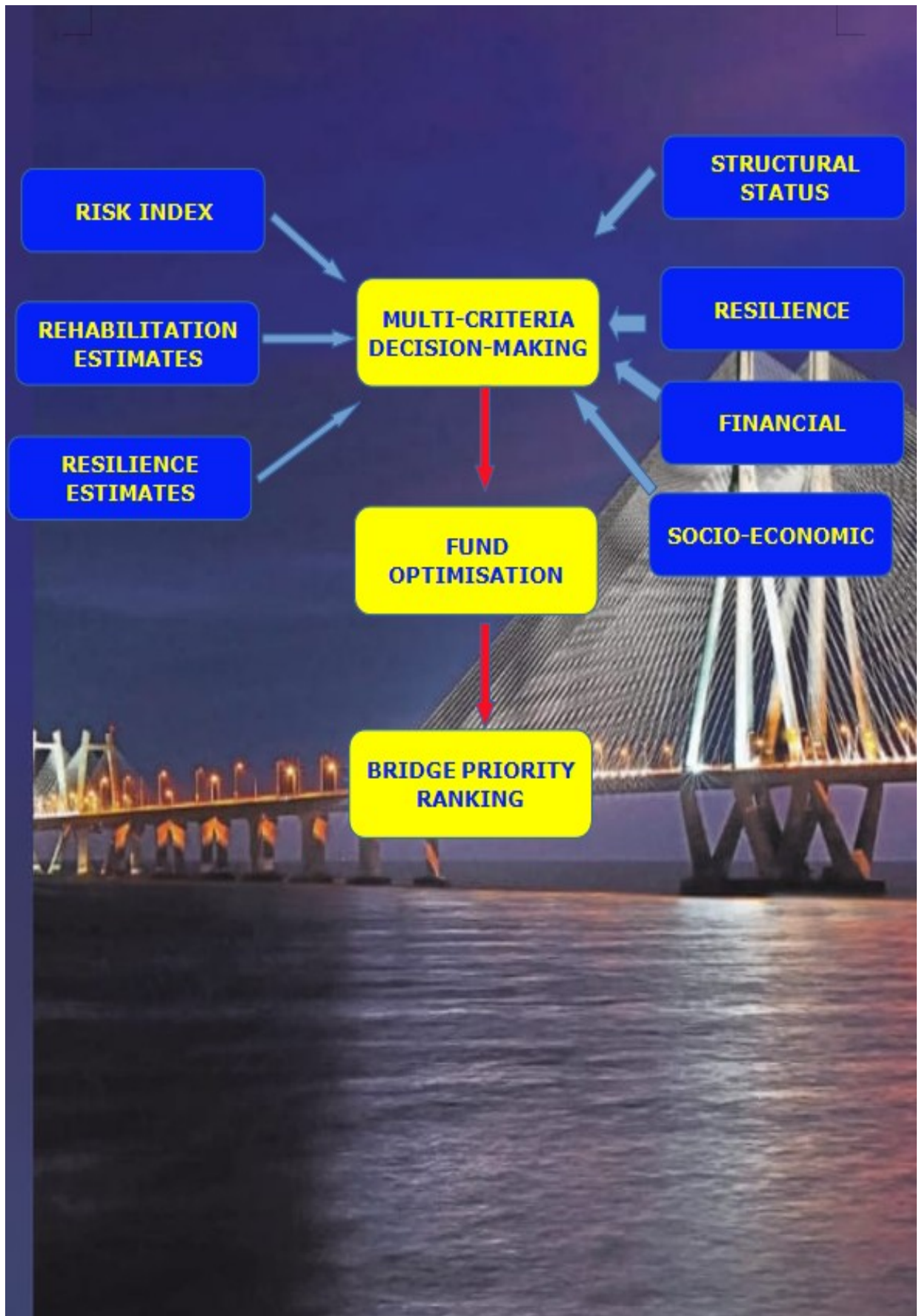
Based on the risk assessment outcomes, GARM supports the definition of appropriate remedial and mitigation measures. These may include structural rehabilitation actions such as strengthening, scour protection, or bearing replacement, as well as resilience enhancement measures such as improved drainage, slope stabilization, monitoring systems, and operational preparedness strategies. Cost estimates for both rehabilitation and resilience measures are generated to support economic evaluation.

Finally, the results of the Risk and Vulnerability Analysis, along with associated cost estimates, are processed within the Multi-Criteria Decision-Making (MCDM) module of GARM. This module evaluates multiple competing factors—including risk reduction potential, cost, structural condition, functional importance, and socio-economic impact—to prioritize interventions. The outcome is an optimized solution that supports efficient fund allocation, maximizes risk reduction benefits, and ensures transparent and justifiable decision-making for bridge management and resilience planning. The bridges are prioritized into high, medium, and low risk categories to support decision-making related to inspection, retrofitting, monitoring, and disaster preparedness planning.

FLOW OF DATA IN RVA



FLOW OF DATA BEYOND RVA



RISK INDEX

REHABILITATION ESTIMATES

RESILIENCE ESTIMATES

STRUCTURAL STATUS

RESILIENCE

FINANCIAL

SOCIO-ECONOMIC

MULTI-CRITERIA DECISION-MAKING

FUND OPTIMISATION

BRIDGE PRIORITY RANKING

2.3 Hazard Identification and Likelihood

Based on regional characteristics, four major natural hazards are considered: flooding, cyclones (indirect impacts), landslides, and earthquakes. Flooding is identified as the dominant hazard due to intense monsoon rainfall and the topography of Panchaganga river system. Cyclones influence the district indirectly by intensifying rainfall and wind conditions. Landslides primarily affect bridges in western talukas within the Western Ghats region. Earthquake hazard is assessed based on regional seismic zoning, with Kolhapur classified under Seismic Zone III, indicating moderate seismic risk.

Hazard likelihood is estimated using historical records spanning approximately 50 years (1975–2025), regional hazard classifications, and recurrence of extreme events. This forms the basis for subsequent vulnerability and risk evaluation.

3. HISTORICAL NARRATIVE OF KOLHAPUR DISTRICT

3.1 Geographic and Climatic Setting

Kolhapur District is located in southern Maharashtra along the eastern margin of the Western Ghats. The district exhibits varied topography, with hilly terrain in the western talukas and relatively flat plains toward the east. This physio-graphic setting significantly influences local climate and hydrology.

The district experiences a tropical monsoon climate, with the southwest monsoon contributing the majority of annual rainfall between June and September. Orographic effects of the Western Ghats result in high-intensity rainfall over short duration, particularly in western regions. The Panchaganga River and its tributaries form the principal drainage system of the district, making riverine flooding a recurrent hazard. Bridges across these rivers are frequently exposed to high flow velocities, debris impact, and scour.

3.2 Flood History

Flooding is the most significant and recurring natural hazard affecting Kolhapur District. Major flood events recorded in 1975, 1978, 1993, 2005, 2019, and 2021 caused widespread inundation of riverbanks and low-lying areas. Bridges were subjected to prolonged submergence, foundation scour, and approach road damage.

In many cases, bridge superstructures remained intact, but loss of serviceability occurred due to submerged or damaged approaches. The 2019 flood event was particularly severe, leading to large-scale disruption of transportation networks. These events highlight the need for flood-focused risk assessment and implementation of mitigation measures for bridge infrastructure.

3.3 Cyclone Influence

Kolhapur does not experience direct cyclone landfalls; however, cyclonic systems originating in the Arabian Sea and Bay of Bengal have indirect impacts on the district. Cyclones such as Nisarga (2020) and Tauktae (2021) resulted in extreme rainfall and strong winds across western Maharashtra.

These systems intensified monsoon conditions, increasing flood severity and triggering landslides in susceptible areas. Wind effects also posed risks to non-structural bridge components. Although indirect, cyclone influences significantly contribute to multi-hazard exposure in the district.

3.4 Landslide Occurrence

Landslides are common in the western talukas of Kolhapur District, including Gaganbawda and Radhanagari, due to steep slopes, weathered rock formations, and intense monsoon rainfall. Landslides primarily affect bridge approaches, embankments, and retaining structures rather than the main bridge superstructure.

Damage to approach roads often leads to functional failure of bridges despite structural integrity. This underscores the importance of incorporating geotechnical stability and slope protection measures in bridge vulnerability assessments.

3.5 Earthquake History

Kolhapur District lies within Seismic Zone III, indicating moderate seismic risk. Although no major earthquakes have originated within the district, regional events such as the 1992 Latur and 2001 Bhuj earthquakes were felt across the region.

Several bridges were constructed prior to the adoption of modern seismic design standards, potentially increasing vulnerability. Ageing infrastructure and increased traffic demands further necessitate consideration of seismic effects in risk and vulnerability analysis.

ANNEXURE 1 provides the historical narrative of floods, cyclone, landslide and earthquake in Kolhapur district over the last 50 years.

4. BRIDGE INSPECTION REPORTS

4.1 Bridge Inventory and Description

A comprehensive bridge inventory was prepared to establish baseline information for the assessment. The inventory includes details such as bridge location, structural configuration, construction material, year of construction, span arrangement, and functional importance within the road network. The assessed bridges range from older reinforced cement concrete (RCC) slab and T-beam bridges to newer girder-type bridges constructed to modern standards. These structures serve varying functions, including national highways, state highways, major district roads, and urban connectivity routes. The diversity in bridge type and age provides a representative understanding of infrastructure performance across the district.

4.2 Structural Health Assessment

Structural health assessment was carried out using available inspection reports and visual condition surveys. The assessment covers key bridge components, including decks, superstructures, substructures, bearings, expansion joints, and foundations. Observed distress conditions include surface and structural cracking, corrosion of reinforcement, bearing wear or malfunction, joint deterioration, and evidence of scour around piers and abutments. The severity and extent of these defects vary across bridges and are influenced by factors such as age, exposure to flooding, traffic loading, and maintenance practices. These observations form the basis for evaluating structural condition and vulnerability. All the data was input in Global Bridge Management System [GABM] and the analysis to evaluate the structural health was conducted. It is observed that most of bridges are more than 50 years old. [Barring Ibrahimpur Bridge, Majgaon Bridge, and Gothe Bridge] The oldest bridge being Kur and Balinge Bridge both of which are nearly 90 years old. Since the bridges are old, Fatigue and Overload would be the main cause of deterioration. This is corroborated by the observation and results of GABM. Mechanical and Chemical are the principal causes for propagating deterioration. Since the bridges are typically above 50 years, Balance Service life [BSL] and Absolute Service life [ABSL] evaluated are assuming 100 years of service life. Typically bridges have about 5 years of BSL and 1 year of ABSL. Barring four bridges all other bridges show Severe level of distress. All the bridges show probability of collapse under three possible failure modes for Flooding. Few bridges also show similar probability for earthquake failure. Bridges are low-lying, and have been reported to have undergone over topping many times in the past. Such over topping could erode foundation and result is early scour.

Typical narration of all 15 bridges is enumerated herein under in Table 1.

TABLE 1

BRIDGE ID	BRIDGE NAME	STATUS / CAUSE	BSL	ABSL
MHSH0189B002	KUR BRIDGE	Severe / Mechanical	5.31	1.06
MHSH0189B003	TARMAPARNI BRIDGE	Severe / Mechanical & Chemical	5.36	1.29
MHSH0130B004	PATNE BRIDGE	Severe / Mechanical & Chemical	5.36	1.29
MHSH0201B005	IBRAHIMPUR BRIDGE	Severe / Mechanical & Chemical	6.31	2.59
MHSH0397B006	SARUD BRIDGE	Safe / Mechanical & Chemical	6.41	1.86
MHSH0150B007	KADAVI BRIDGE	Safe / Mechanical & Chemical	5.36	1.39
MHSH0192B008	KODOLI BRIDGE	Severe / Mechanical & Chemical	6.32	1.83
MHDR0018B009	MAJGAON BRIDGE	Severe / Mechanical & Chemical	6.31	2.9
MHDR0039B010	GOTHE BRIDGE	Safe / Mechanical & Chemical	8	4.4
MHSH0192B011	VATHAR BRIDGE	Safe / Mechanical & Chemical	8	2.88
MHSH0192B012	ICHALKARANJI OLD BRIDGE	Severe / Mechanical & Chemical	5.36	1.23
MHSH0195B013	SIDHNERLI BRIDGE	Safe / Mechanical & Chemical	5.36	1.34
MHDR0053B014	KAPSHI BRIDGE	Severe / Mechanical & Chemical	5.36	1.34
MHDR0037B015	HALADI BRIDGE	Safe / Mechanical & Chemical	6.31	1.77
MHSH0166B016	BALINGE BRIDGE	Safe / Mechanical & Chemical	6.31	1.51

Typical bridge report is included herewith in for guidance purpose only. Similar reports can be generated for all bridges from GABM. The report is combination of three results sheets namely HISTORY, OUTPUT, and DECISION MAKING.

**TYPICAL BRIDGE REPORT
CREATED FROM GABM**



MHSH0189B006 - TARMAPARNI BRIDGE

Description	1st Year
YEAR OF INPUT	2026
DEPARTMENTAL BUDGET FOR PARTICULAR YEAR	100000.0
ESTIMATE FOR REHABILITATION FOR EACH BRIDGE	10000000.0
BRIDGE IDENTITY	
GABM Id	IND1-01
Length in meters	45
Total No. of Spans	4
Span Length	8
Latitude	15.9331
Longitude	74.1848
CLASSIFICATION	
Traffic Lane	2
Type of Road	2
Age of Bridge	58
Load Capacity	70000
Foundation Type	OPEN
BRIDGE STRUCTURAL RATING NUMBER [BSRN]	
Deck Rating	4
Superstructure	3
Substructure	3
Foundation	3
BRIDGE FUNCTIONAL RATING NUMBER [BFRN]	
Deck Geometry	3
Vertical Clearance	3
Waterway	4
ADT	3
SOCIO-ECONOMIC RATING NUMBER [SERN]	
Social Importance	3
Economic Growth	3
Alternate Route	3
Environment Impact	3
CAUSE MATRIX	
Impact (M1)	3
Abrasion (M2)	3
Erosion (M3)	3
Overload (M4)	3
Fatigue (M5)	3
Temperature (P1)	3
Shrinkage (P2)	3
Settlement (P3)	2
Chloride Attack (C1)	3
Sulphates (C2)	3
Carbonation (C3)	3
Alkali-Aggregate (C4)	3
Total of Cause Ratings	32
DATA FROM SHORT TERM STRUCTURAL HEALTH MONITORING	
SHM Change Rating	
Construction Cost Per KM	84444.444
Years Over Which Investment Is Spread	10
Conversion Ratio of Financial to Economic	0.9

MHSH0189B006 - TARMAPARNI BRIDGE

-Bridge is in severe distress

Description	1st Year
YEAR OF INPUT	2026
DEPARTMENTAL BUDGET FOR PARTICULAR YEAR	100000.0
ESTIMATE FOR REHABILITATION FOR EACH BRIDGE	10000000.0
RANKING AND PRIORITY	

1

13/01/2026

UBMS Research Group - 0478534118

Description	1st Year
50 Years Design Life	
Deterioration time in Years (DT/ BSL)	0.0
Median Service Life in Years (MSL)	0.0
Absolute Balance Service Life in years	0.0
100 Years Design Life	
Deterioration time in Years (DT/ BSL)	5.36
Median Service Life in Years (MSL)	36.65
Absolute Balance Service Life in years	1.29
Engineering Impact Index	3.2%
Financial Impact Index	14.66%
Sustainability Index	8.65%
Risk Index	0.89%
Final Cost	6.8500%
Wsum	150
Life Cycle Cost Analysis (LCCA)	
STANDARD IRR	13.61
ENHANCED IRR	45.27
CAUSE OF DISTRESS	MECHANICAL
CURRENT STATUS OF BRIDGE	-Bridge is in severe distress



GLOBAL ANALYTICS FOR BRIDGE MANAGEMENT TOOL

-Bridge is in severe distress

SERVICE LIFE EVALUATED-PRE SHM

DESIGNED SERVICE LIFE	BALANCE SERVICE LIFE	ABSOLUTE BALANCE SERVICE LIFE	MEDIAN SERVICE LIFE
50 Years	0.0	0.0	0.0
100 Years	5.36	1.29	36.65

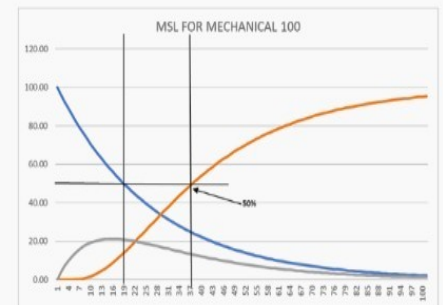
SERVICE LIFE EVALUATED-POST SHM

DESIGNED SERVICE LIFE	BALANCE SERVICE LIFE	ABSOLUTE BALANCE SERVICE LIFE	MEDIAN SERVICE LIFE
50 Years	0.0	0.0	0.0
100 Years	2.73	0.33	36.65

100 YEARS LIFE CYCLE COST ANALYSIS RESULTS

IRR(ONLY DIRECT IMPACT)	IRR(INCLUSIVE OF INDIRECT)
13.61%	45.27%

Engineering Impac	Financial Impact In	Sustainability Inde	Risk Index	Final Cost
0.800%	3.6650%	2.1625%	0.2225%	6.8500%



BRIDGE VULNERABILITY - RISK INDEX

	Vulnerability Index	Risk Index
EARTHQUAKE	0.005	0.002
FLOODING	0.016	0.009
CYCLONE	0.008	0.004
LANDSLIDE	0.008	0.004

Bridge Failure Result(Based on Historical Data)

	EARTHQUAKE	FLOODING	CYCLONE	LANDSLIDE
SHEAR FALIURE OF PIER	PROBABILITY OF BRIDGE COLLAPSE	PROBABLE BRIDGE COLLAPSE	PROBABILITY OF BRIDGE COLLAPSE	PROBABILITY OF BRIDGE SURVIVAL
SUPER STRUCTURE UNSEATING		PROBABILITY OF BRIDGE COLLAPSE	PROBABILITY OF BRIDGE COLLAPSE	
SUPER STRUCTURE SHEAR FALIURE	PROBABILITY OF BRIDGE COLLAPSE	PROBABILITY OF BRIDGE COLLAPSE	PROBABILITY OF BRIDGE COLLAPSE	

- Instructions
- Bridges
- Culvert
- Resilience
- Settings
 - Standard Cost
 - Export Data
 - Import Data
- Logout
- Resilience
- Settings
 - Standard Cost
 - Export Data
 - Import Data
- Logout



TARMAPARNI BRIDGE-08-01-2026

Adequacy Parameters

PARAMETERS	LANE ADEQUACY	ADT ADEQUACY	VERTICLE CLEARANCE ADEQUACY	SPAN LENGTH ADEQUACY	ADEQUACY FOR WATERWAY	ADEQUACY FOR OVERTOPPING
Status	BAD	BAD	BAD	BAD	BAD	OK

Social Parameters

PARAMETERS	AGE OF BRIDGE	SOCIAL IMPORTANCE	ECONOMIC GROWTH IMPORTANCE	CONNECTION BETWEEN 2 IMPORTANT CENTERS	ECONOMICAL GROWTH POTENTIAL	ALTERNATE ROUTE
Status	58	Not Critical	Not Critical	Critical	MODERATE	Critical

	SUGGESTED RECOMMENDATION
Is the bridge a candidate for reconstruction?	RI Recommended
Is providing Remedial Interventions feasible for this bridge?	BUOM
What will be the efficiency of remedial intervention provided?	RI Efficiency is 50%
Is there any special requirements essential due to age of the bridge?	Age is critical
Are there any critical issues with respect to age of the bridges which are essential to implement?	Age is super critical
What is the Incremental RI Cost taking into account the safety aspect diversion requirements speed and time lost considerations?	10675000.15
What is the increment in costing of RI due to very high BSRN not accounted in the design of RI?	No Increment Essential

-Bridge is in severe distress

Main Cause of deterioration	Principle of Remedical Intervention	Method of Rehabilitation/Repair
Impact	Concrete Restoration	Application of panels or plates for restoration
Abrasion	Structural Strengthening	Strengthening the concrete components by providing external Post or Pre-Stressing system
Erosion & Cavitation	Protection Against Ingress	Impregnation

BRIDGE STATUS and PROBABILITY OF FAILURE for all bridges is provided in [ANNEXURE](#)

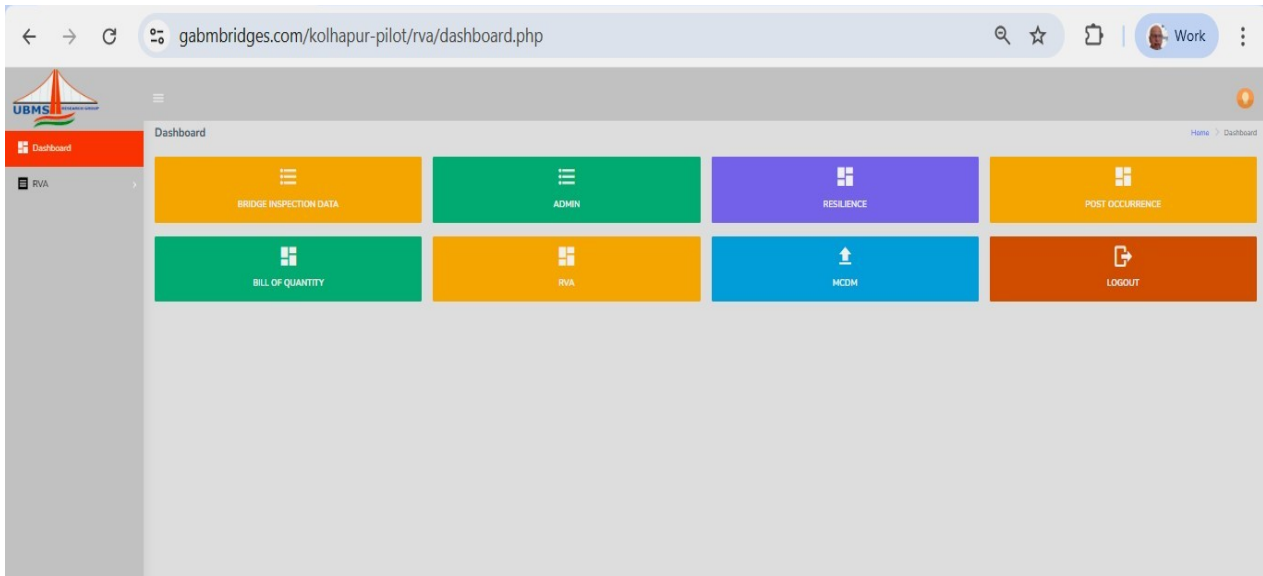
4.3 Maintenance History

Maintenance records were reviewed to understand the level of intervention carried out on each bridge over its service life. The records indicate a range of maintenance activities, from routine works such as joint sealing and minor repairs to major rehabilitation measures, including deck resurfacing and strengthening. In several cases, delayed maintenance and inadequate drainage upkeep have contributed to accelerated deterioration, particularly in flood-prone bridges. Maintenance history is therefore considered an important indicator of both current condition and future performance.

5. RISK AND VULNERABILITY ANALYSIS REPORT

5.1 Vulnerability Assessment

All the results from GABM are then imported on a ON-LINE portal named as Global Risk and Resilience Management System [**GARM**] for greater visibility by multiple departments / officials within the organization. This data is tailored for top level decision-making. Typical Screen of the GARM is as under:



Data is imported within the ADMIN module using the tab IMPORT DATABASE IMPORT. Once data is imported, the bridge results can be viewed under the BRIDGE INSPECTION HISTORICAL DATA.

Subsequently various functions can be performed. Typically BILL OF QUANTITIES module needs to be used first. Under this module, two functions are available. REHABILITATION BOQ and RESILIENCE ENHANCEMENT BOQ. Both the functions need to be utilized and BOQ for every bridges needs to be generated to compile the Estimates for Rehabilitation and Resilience Enhancement.

The second module to be used is the RISK AND VULNERABILITY ANALYSIS module. From among all the bridges on the database [15 in our case] proper RVA procedure needs to be incorporated to decide which of the bridges are critical and RVA is evaluated ONLY FOR THOSE CRITICAL BRIDGES. Bridges for which RVA is evaluated, are not available for Ranking and Prioritization under Multi-Criteria Decision-Making [MCDM] module. It is assumed that all critical bridges will essentially undergo rehabilitation and Resilience enhancement. We have evaluated RVA for all bridges assigned and hence have not conducted Ranking and Prioritization under MCDM. However typical MCDM results are generated prior to RVA analysis and the results are attached here in under



GENERATED FROM GABM
R & D BY UBMS RESEARCH GROUP

RESULTS FOR FUND OPTIMIZATION POST APPLICATION OF MULTI-CRITERIA DECISION-MAKING PROCESSES

Selected Bridge: 'MHDR0018B009', 'MHDR0053B014', 'MSH0130B004', 'MSH01 SOB007', 'MSH0189B003', 'MSH0192B008', 'MSH0192B012', 'MSH0201 B005', 'MSH0397B006', 'MHDR0039B01 0', 'MSH0189B002'

RESULT AS PER SIMPLE MULTI-ATTRIBUTE RATING TECHNIQUE [SMART]

RANK BRIDGES AND DETERMINE REHABILITATION POSSIBILITY

RANK OF THE BRIDGE	Bridge ID	Weighted Score	Rehabilitation Cost	Cumulative Cost	Rehabilitation Possible
1	MSH0189B002	3.1	35,104,000.00	35,104,000.00	YES
2	MSH0150B007	3.1	9,585,000.00	44,689,000.00	YES
3	MHDR0018B009	3.1	33,558,250.00	78,247,250.00	YES
4	MHDR0039B010	3.1	23,165,575.00	101,412,825.00	YES
5	MSH0189B003	2.95	60,471,250.00	161,884,075.00	YES
6	MSH0130B004	2.95	74,842,250.00	236,726,325.00	YES
7	MSH0201B005	2.95	68,571,250.00	305,297,575.00	NO
8	MSH0397B006	2.95	9,585,000.00	314,882,575.00	NO
9	MSH0192B008	2.95	58,446,250.00	373,328,825.00	NO
10	MSH0192B012	2.95	15,750,000.00	389,078,825.00	NO
11	MHDR0053B014	2.95	37,507,000.00	426,585,825.00	NO

REFINEMENT AS PER ANALYTICAL HIERARCHY PROCESS (AHP)

ASSIGNMENT OF BUDGET FOR RI

ASSIGNED RANK	BRIDGE ID	ESTIMATED COST	ASSIGNED BUDGET
1	MSH0189B002	35,104,000.00	26,328,000.00
2	MSH0150B007	9,585,000.00	7,188,750.00
3	MHDR0018B009	33,558,250.00	25,168,687.50
4	MHDR0039B010	23,165,575.00	17,374,181.25
5	MSH0189B003	60,471,250.00	45,353,437.50

6	MHSH0130B004	74,842,250.00	56,131,687.50
ASSIGNED RANK	BRIDGE ID	ESTIMATED COST	ASSIGNED BUDGET
7	MHSH0201B005	68,571,250.00	51,428,437.50
8	MHSH0397B006	9,585,000.00	7,188,750.00
9	MHSH0192B008	58,446,250.00	43,834,687.50
10	MHSH0192B012	15,750,000.00	11,812,500.00
11	MHDR0053B014	37,507,000.00	28,130,250.00

BRIDGE WISE EVALUATION FOR FEASIBILITY TO PROCEED WITH REHABILITATION AND RESILIENCE ENHANCEMENT(ALL FIGURES ARE IN MILLIONS)

RANKING AS PER MCDM	BRIDGE ID	REHAB COST	RESILIENCE COST	TOTAL OF R&R	BENEFIT DUE TO BRIDGE	FEASIBILITY TO UNDERTAKE R&R
1	MHSH0189B002	35	43	78	658	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
2	MHSH0150B007	10	17	27	424	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
3	MHDR0018B009	34	41	75	667	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
4	MHDR0039B010	23	16	39	926	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
						YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT

6	MHSH0130B004	75	20	95	1429	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
7	MHSH0201B005	69	22	91	1000	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
8	MHSH0397B006	10	19	28	424	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
9	MHSH0192B008	58	22	81	1111	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
10	MHSH0192B012	16	59	75	350	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT
11	MHDR0053B014	38	45	83	676	YES PROCEED FOR REHAB AND RESILIENCE ENHANCEMENT

FEASIBILITY OF ENHANCING BUDGET TO ENSURE STRUCTURAL AND RESILIENCE ADEQUACY (ALL FIGURES ARE IN MILLIONS)

Bridge vulnerability is assessed by integrating inspection condition ratings, observed material deterioration, and adequacy of original design relative to current hazard levels. Structural assessments consider the response of bridges under static loading as well as potential seismic demands. Particular attention is given to identifying possible failure mechanisms, such as pier instability during floods, excessive deck distress under increased traffic loads, and foundation vulnerability due to scour. The assessment also considers whether bridges meet modern design and detailing requirements, especially for seismic resistance, to determine their susceptibility to damage during extreme events.

5.2 Risk Analysis and Evaluation

Likelihood and Consequence

Risk analysis is carried out by combining hazard likelihood with bridge vulnerability and potential consequences. Hazard probability is estimated using historical occurrence data and regional hazard characteristics. Structural vulnerability is derived from inspection and analysis results, while functional importance reflects the role of the bridge within the transportation network. These factors are integrated to assign overall risk levels to individual bridges.

Results of Risk and Vulnerability Analysis were done for all bridges using the RVA module of GARM and the results are tabulated in the TABLE 2

TABLE 2

BRIDGE ID	RISK INDEX [RI]				RI for MCDM
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE	
MHSH0189B002	0.59	0.58	0.67	0.67	0.63
MHSH0189B003	0.62	0.6	0.69	0.69	0.65
MHSH00130B004	0.61	0.59	0.68	0.68	0.64
MHSH0201B005	0.58	0.57	0.66	0.66	0.62
MHSH0397B006	0.6	0.57	0.65	0.65	0.62
MHSH0150B007	0.6	0.57	0.65	0.65	0.62
MHSH0192B008	0.61	0.59	0.68	0.68	0.64
MHDR0018B009	0.59	0.58	0.67	0.67	0.63
MHDR0039B010	0.57	0.55	0.64	0.64	0.6
MHSH0192B011	0.6	0.58	0.67	0.67	0.63
MHSH0192B012	0.64	0.62	0.71	0.71	0.67
MHSH0195B013	0.6	0.57	0.65	0.65	0.62
MHDR0053B014	0.62	0.6	0.69	0.69	0.65
MHDR0037B015	0.6	0.58	0.67	0.67	0.63
MHSH0166B016	0.66	0.62	0.7	0.7	0.67

Risk and Vulnerability analysis for all bridges has been conducted. One important factor needs to be borne in mind, when the bridge is designated for Risk and Vulnerability Analysis in GARM than that Bridge is not available in the MCDM module. This is due to the fact that bridge which is critical needs to be attended first before assignment of ranking for non critical bridges.

Risk Prioritization

Based on the combined assessment, bridges are categorized into high, medium, and low risk groups. High-risk bridges are those with high hazard exposure, poor structural condition, and high functional importance. Medium-risk bridges require monitoring and planned intervention, while low-risk bridges are suitable for routine maintenance. This prioritization supports efficient allocation of resources and targeted mitigation planning.

5.3 Consequence Assessment

Direct Impacts

Direct consequences include physical damage to bridge components, repair and rehabilitation costs, and potential replacement expenses in severe cases. These impacts represent immediate financial and technical challenges following hazard events.

Indirect Impacts

Indirect impacts include traffic delays, loss of connectivity, disruption to emergency services, and broader economic and social losses. In flood or landslide scenarios, prolonged bridge closures can significantly affect regional mobility and access to essential services.

Criticality Assessment

Criticality assessment evaluates the strategic importance of each bridge within the transport network. Bridges serving major routes, urban centers, or emergency corridors are assigned higher criticality, increasing their overall risk significance.

5.4 Mitigation and Action Plan

Structural Measures

Structural mitigation measures include retrofitting and strengthening of vulnerable components, installation of scour protection works, and replacement or rehabilitation of deteriorated bearings and joints. These measures aim to enhance structural capacity and durability under extreme loading conditions.

Operational Measures

Operational strategies focus on improving preparedness and response, including emergency action planning, traffic diversion routes, and temporary load or access restrictions during extreme events. These measures reduce risk to users and maintain network functionality.

Monitoring and Review

A systematic monitoring and review framework is proposed, incorporating periodic inspections, condition reassessment, and sensor-based monitoring for critical bridges. Integration with early-warning systems for floods and extreme weather events is recommended to support timely decision-making and reduce damage.

6. DISCUSSION

6.1 Discussion on Bridge structural status:

Within GABM the structural status of the bridge is evaluated based on the input provided by the bridge inspection engineer. The analysis is performed based on standard protocol for determination of Balance service life and Absolute Balance service life [**BSL, ABSL**]. This evaluation is done for two scenarios based on the designed service life [**DSL**] [50 years or 100 years]. The BSL and ABSL evaluation depends on the age of the bridge. For bridges which are below 20% of their DSL the evaluation is done based on symptoms. Beyond that age limit up to 55% of DSL, the evaluation is based on Identified Cause of distress. Details of all Bridges are provided in ANNEXURE 2 where the **BRIDGE STATUS and FAILURE PROBABILITY** is highlighted

6.2 Discussion on Bill of Quantities evaluation.

Within GARM evaluation of Bill of Quantities for rehabilitation and enhancement of resilience is available. BOQ module enables users to prepare the estimates based on identified cause of distress. For every identified cause, the Principle's of rehabilitation is provided. This definition of principle is as per EN 1504. The user can define the quantity and the rate. For Resilience enhancement three causes for possible failure define the enhancement techniques. For each failure mode, one option to design the enhancement technique is also provided. Typical BOQ for rehabilitation and enhancement of resilience are provided in **ANNEXURE 4**.

6.3 RISK and VULNERABILITY ANALYSIS

The results of the risk and vulnerability assessment clearly indicate that flooding represents the dominant natural hazard affecting bridge infrastructure in Kolhapur District. The district's location within the Panchaganga river basin, combined with intense monsoon rainfall and upstream catchment influences from the Western Ghats, results in frequent high-flow conditions and prolonged inundation. Repeated exposure to flooding has led to recurring issues such as foundation scour, deterioration of substructure elements, and loss of serviceability due to submerged approaches.

The risk and vulnerability results gain further significance when interpreted in the context of quantified local hazard exposure and functional criticality of bridges within the regional transportation network. Historical flood records from the Panchganga river basin clearly demonstrate that bridge infrastructure in Kolhapur District is subjected to extreme and recurring hydraulic loading. During the 2021 flood event, the Panchganga river reached a peak level of 56'3" [17.2 M], exceeding the designated danger level by 13'3" [4.03 M],

resulting in widespread submergence of bridge decks and approach roads. Similarly, the 2019 flood event, characterized by cumulative rainfall of 2506 mm, and the 2021 event triggered by extreme short-duration rainfall exceeding 500 mm within two days, highlight the increasing intensity and variability of flood-inducing rainfall patterns.

These extreme events translated into substantial infrastructure losses, with damages to roads and bridges alone estimated at approximately ₹3289.51 crore during the 2019 floods. Such quantified hazard impacts reinforce the necessity of explicitly incorporating hazard intensity, duration, and recurrence into bridge risk assessment frameworks, rather than relying solely on structural condition indicators.

Functional criticality further amplifies the consequences of bridge vulnerability. Several bridges assessed under this study serve as critical mobility links, where service disruption directly affects regional connectivity and emergency response. For instance, the Shivaji Bridge to Kerle section along NH-166 experiences repeated submergence, leading to isolation of surrounding areas and severely constrained access for emergency services. During the 2021 flood event, disruptions to bridge connectivity contributed to mobility challenges across approximately 409 affected villages, underscoring that bridge failure extends beyond structural loss to societal and economic consequences.

The findings indicate that bridges with moderate structural distress can still exhibit high risk levels when located in flood-prone zones and assigned high functional importance. This observation validates the integrated Risk and Vulnerability Assessment (RVA) framework, which captures the combined influence of hazard exposure, structural vulnerability, and consequence severity. From a policy perspective, the results align closely with existing challenges identified by the Public Works Department (PWD), particularly the need to elevate approach roads, enhance scour protection measures, and prioritize resilience retrofitting for bridges in flood-prone corridors.

Overall, the discussion confirms that transitioning from conventional condition-based inspection to risk-based bridge management is essential for informed decision-making and climate adaptation planning. The integration of hazard quantification, functional criticality, and economic feasibility within the RVA framework provides a robust basis for prioritizing interventions and improving long-term infrastructure resilience in hazard-prone districts such as Kolhapur.

The analysis also highlights the significance of compound hazard interactions. Indirect impacts of cyclonic systems often intensify monsoon rainfall, thereby increasing both flood magnitude and the likelihood of landslides in western talukas. These cascading effects amplify overall risk, as bridges may be subjected to multiple stressors simultaneously, such as hydraulic loading, slope instability, and traffic disruption. While seismic hazard in Kolhapur is moderate, the presence of older bridges lacking modern seismic detailing increases vulnerability when combined with other hazards.

Conventional bridge inspections largely focus on visible structural distress and do not adequately account for hazard exposure, functional importance, or future climate-related risks. Dynamism in frequency and severity of natural hazard is also accounted within the analysis. In many cases, inspection data are not systematically integrated with historical hazard records, leading to **reactive** rather than **proactive** maintenance decisions. Evaluation of risk index for all bridges offers an insight into the need for immediate enhancement of resilience. Enhancement of resilience is a fund intensive process. MCDM within GARM provides a solution by comparing the cost involved with the total [Direct and Indirect] benefits. For each of the bridge, the benefits exceeds the total cost involved in rehabilitation and resilience enhancement.

All bridges have a risk index above 0.5 which is considered high risk and calls for immediate attention. Action recommended is to initiate and plan mitigation measures and to implement rehabilitation and resilience enhancement.

For every bridge, the ratio of Benefit vs Cost is positive indicating that during the life of the bridge, the cost incurred for enhancing resilience will be recovered fully.

The findings emphasis the need to adopt a risk-based bridge management approach that integrates hazard likelihood, structural vulnerability, and consequence assessment. Such an approach enables prioritization of interventions, efficient resource allocation, and improved resilience planning. Furthermore, the increasing frequency and intensity of extreme rainfall events associated with climate change underline the importance of incorporating climate adaptation considerations into bridge design, inspection, and maintenance strategies.

7. CONCLUSION

This study presents a comprehensive district specific risk and vulnerability assessment of bridge infrastructure in Kolhapur District under multiple natural hazards. By integrating historical hazard data, bridge inspection records, and semi-quantitative risk analysis techniques, the study provides a structured framework for evaluating bridge safety, performance, and resilience. The adopted methodology demonstrates how engineering condition data, when combined with hazard characteristics and consequence analysis, can provide a more realistic representation of infrastructure risk than conventional assessment approaches.

The **multi-hazard assessment** identifies flooding as the most critical and recurring threat to bridge infrastructure in Kolhapur District, primarily due to riverine flooding, high monsoon rainfall, and scour-related damage mechanisms. Landslides emerge as a significant secondary hazard, particularly in the western hilly regions where geomorphological conditions and intense rainfall increase slope instability. In addition, the district falls under Seismic Zone III, indicating moderate seismic risk, which, although less frequent, carries potentially severe consequences for structurally vulnerable bridges. Several bridges were classified as high risk owing to the combined effects of elevated hazard exposure, advanced structural deterioration, and high functional importance within the regional transportation network. The identification of medium- and low-risk bridges further enables a rational, phased approach to intervention, allowing authorities to allocate resources strategically while maintaining acceptable service levels across the network. The study also highlights that bridge vulnerability increases significantly when financial availability is constrained, underscoring the strong linkage between funding adequacy and infrastructure resilience.

One of the most significant outcomes of this pilot project is the explicit demonstration of the limitations of conventional condition-based inspection practices when applied in isolation. While routine inspections are essential for identifying visible deterioration and structural deficiencies, they do not adequately capture the influence of natural hazard frequency, intensity, spatial variability, and cascading consequences. By contrast, the multi hazard risk-based framework adopted in this study integrates inspection data with hazard history and consequence assessment, enabling a transition from **reactive maintenance toward proactive and prioritized risk-based management**. This shift is particularly crucial for climate adaptation planning in districts such as Kolhapur, where bridges are repeatedly exposed to natural hazards that are expected to intensify under changing climatic conditions.

Based on the assessment, the study recommends the adoption of risk-based prioritization frameworks, strengthening of flood and scour protection measures, incorporation of seismic considerations in retrofitting works, and enhancement of monitoring systems for critical bridges. The findings strongly support the adoption of risk-informed and resilience-oriented bridge management practices. The benefit–cost analysis conducted for all bridges included in the study indicates positive benefit–cost ratios, confirming that **investments in resilience enhancement, retrofitting, and protective measures are economically justified**. When both direct benefits, such as reduced repair costs and avoided structural failures, and indirect benefits, such as improved connectivity, reduced travel disruptions, and enhanced public safety, sustainable socio-economic growth are considered, the long-term economic returns significantly outweigh the initial investment costs.

Spatial variability in risk and vulnerability across the district highlights the importance of using location-specific and context-sensitive data. The reliance on district-level datasets ensures that regional hazard characteristics, local construction practices, and network dependencies are accurately represented. The incorporation of AI-based analytical tools further strengthens the framework by accounting for the dynamism of hazard frequency and severity, allowing the assessment to reflect evolving risk conditions rather than static historical averages. Additionally, the integration of financial due diligence within the multi-criteria decision-making (MCDM) framework proves critical for realistic budgetary planning, as financial constraints directly exacerbate vulnerability and increase the overall risk index. **Financial crunch will increase the risk index as the vulnerability increases.**

At the policy and governance level, this study emphasizes the necessity of integrating risk and vulnerability assessments into existing bridge management systems and broader climate adaptation strategies. The outcomes demonstrate how risk-based prioritization frameworks can support evidence-based decision-making, improve transparency in resource allocation, and enhance coordination between engineering, disaster management, and planning authorities. As a pilot implementation, this study provides a scalable and transferable model that can be extended to other districts with similar hazard profiles. Ultimately, the adoption of such risk-informed approaches is essential for achieving long-term infrastructure resilience, ensuring public safety, and supporting sustainable regional development in Kolhapur District.

A key outcome of the study is the demonstrated importance of integrating hazard history with routine bridge inspections. Inspection

data alone are insufficient to capture true risk levels without considering hazard frequency, intensity, and potential consequences. **The findings support the transition toward risk-informed and resilience-oriented bridge management practices.**

ANNEXURE 1: Hazard History 1975 -2025

- **Flooding (1975–2025)**

Year	Event	Region / Place Affected	Description & Notes
1975	Major flood	Panchaganga River basin, Kolhapur city (low-lying wards)	Heavy monsoon rainfall caused river overflow and damage to agriculture and settlements.
1977	Moderate flooding	Riverbank villages along Panchaganga	Temporary inundation of agricultural land and access roads.
1978	Major flood	Kolhapur city, Hatkanangale, Shirol taluka	Prolonged rainfall led to extensive flooding across district floodplains.
1980	Moderate flooding	Panchaganga catchment villages	River crossed warning levels; minor infrastructure disruption.
1982	Moderate flooding	Rural Kolhapur, tributary zones	Short-duration flooding near minor streams.
1983	Major flood	Kolhapur city, Karvir taluka	Significant inundation of low-lying residential and commercial areas.
1986	Moderate flooding	Panchaganga tributaries	Heavy rainfall caused temporary overflow.
1988	Major flood	Western Kolhapur, riverine villages	Intense rainfall across Western Maharashtra led to flooding.
1990	Moderate flooding	Kolhapur city outskirts	River approached danger mark; precautionary measures taken.
1992	Moderate flooding	Urban Kolhapur (low-lying wards)	Urban waterlogging and minor river overflow.
1993	Major flood	Kolhapur district (Krishna basin)	Severe floods across Maharashtra; damage to housing and roads.
1995	Moderate flooding	Shirol, Hatkanangale taluka	Overflow at select river locations affected agriculture.
1998	Moderate flooding	Rural Kolhapur	Localized flooding in agricultural fields.
2000	Moderate flooding	Panchaganga floodplain	River discharge affected low-lying farmland.
2003	Moderate flooding	Kolhapur city, riverbank areas	Temporary inundation during intense rainfall spells.
2005	Major flood	Kolhapur district	Extreme monsoon rainfall across Maharashtra caused widespread flooding.

Year	Event	Region / Place Affected	Description & Notes
2007	Moderate flooding	Panchaganga River basin	River crossed warning level; local evacuations.
2010	Moderate flooding	Kolhapur city & suburbs	Short-duration flooding after heavy rainfall events.
2012	Moderate flooding	Urban low-lying zones	Waterlogging and drainage congestion.
2015	Major flood	Kolhapur city, Karvir taluka	Panchaganga overflowed; residential and commercial areas inundated.
2016	Moderate flooding	Kolhapur city, riverbank villages	River crossed warning mark; evacuations and road closures.
2019	Extreme flood	Kolhapur city, Shirol, Hatkanangale, Karvir	One of the worst floods on record; prolonged inundation, mass evacuation, infrastructure damage.
2020	Moderate flooding	Panchaganga basin	River crossed danger mark; NDRF deployment and precautionary evacuations.
2021	Severe flood	Entire Kolhapur district	Extreme rainfall caused widespread flooding and major relief operations.
2022	Minor flooding	Low-lying urban & rural areas	Localized flooding during heavy rainfall spells.
2023	Minor flooding	Kolhapur city floodplains	Seasonal waterlogging; mitigation-focused year.
2024	Moderate flooding	Panchaganga riverfront areas	River-level alerts, school closures, precautionary evacuation.
2025	Local flooding	Shirol, rural Kolhapur	Early monsoon rainfall caused agricultural land damage and local disruptions.

○ **Cyclones (Indirect Impact) (1975–2025)**

Year	Event	Region / Place Affected	Description & Notes
1977	Weak	District-wide	Remnant monsoon

Year	Event	Region / Place Affected	Description & Notes
	depression influence		depression caused increased rainfall.
1978	Indirect cyclone rainfall	Panchaganga basin	Excess rainfall linked to Bay of Bengal system.
1980	Indirect cyclone influence	Kolhapur district	Inland movement of low-pressure system caused heavy rainfall.
1982	Weak depression impact	Rural Kolhapur	Short-duration intense rainfall.
1983	Indirect cyclone rainfall	Kolhapur city & riverine villages	Enhanced monsoon rainfall linked to cyclonic circulation.
1986	Indirect system influence	Western Kolhapur	Rainfall intensification from offshore system.
1988	Indirect cyclone effect	District-wide	Heavy rainfall associated with Bay of Bengal cyclone remnants.
1990	Weak cyclone remnant	Panchaganga basin	Increased discharge due to inland depression.
1992	Indirect cyclone rainfall	Urban Kolhapur	Short-duration heavy rainfall and waterlogging.
1993	Indirect severe system	Kolhapur district	Strong depression enhanced rainfall during major Maharashtra floods.
1995	Indirect cyclone influence	Shirol & Hatkanangale	Rainfall intensification from offshore system.
1998	Indirect depression impact	Rural Kolhapur	Increased rainfall and river inflow.
2000	Weak cyclonic circulation	District-wide	Enhanced rainfall episodes.
2003	Indirect cyclone rainfall	Kolhapur city	Intense rainfall caused waterlogging.
2005	Indirect cyclone influence	Kolhapur district	Offshore Arabian Sea system enhanced monsoon rainfall.
2007	Weak cyclone remnant	Panchaganga basin	Rainfall intensification; minor flooding.
2010	Indirect cyclone rainfall	Urban Kolhapur	Heavy rainfall during cyclonic circulation event.
2012	Indirect	Low-lying urban zones	Short-duration heavy

Year	Event	Region / Place Affected	Description & Notes
	cyclone influence		rainfall.
2015	Indirect cyclone influence	Panchaganga basin	Enhanced rainfall during monsoon depression.
2016	Indirect system impact	Kolhapur city	Heavy rainfall associated with inland low-pressure system.
2019	Indirect cyclone rainfall	Entire district	Extreme rainfall partly attributed to strong monsoon systems; cyclone remnants contributed to basin saturation.
2020	Indirect cyclone influence (Nisarga)	Kolhapur district	Remnants of Cyclone <i>Nisarga</i> caused heavy rainfall and wind gusts inland.
2021	Indirect cyclone influence (Tauktae)	District-wide	Remnants of Cyclone <i>Tauktae</i> caused heavy rainfall and strong winds in parts of Kolhapur.
2023	Indirect cyclone rainfall	Kolhapur city & ghats	Remnant systems enhanced rainfall during monsoon.
2024	Indirect cyclone influence	District-wide	Low-pressure system from Bay of Bengal increased rainfall intensity.
2025	Indirect cyclone rainfall	Rural Kolhapur	Early monsoon depression caused heavy rainfall.

○ **Earthquake (1975–2025)**

Year	Event	Region / Place Affected	Description & Notes
1975	Minor earthquake	Southern Maharashtra region	Low-magnitude tremors felt; no reported damage in Kolhapur.
1977	Minor tremor	Kolhapur district	Weak tremors recorded in regional seismic networks.
1979	Minor earthquake	Western Maharashtra	Low-magnitude event; no structural damage.
1981	Minor tremor	Kolhapur district	Light tremors reported; felt by residents in isolated

Year	Event	Region / Place Affected	Description & Notes
			areas.
1983	Minor earthquake	Southern Maharashtra	Weak seismic activity; no reported damage.
1985	Minor earthquake	Western Maharashtra	Low-magnitude tremors; no major impacts.
1988	Minor tremor	Kolhapur district	Shallow-focus tremor; felt briefly.
1990	Minor earthquake	Southern Maharashtra	Low-intensity tremors; no damage reported.
1992	Moderate regional earthquake	Latur region (felt in Kolhapur)	Strong earthquake in Latur (M~6.3) felt in Kolhapur; no direct damage locally but increased seismic awareness.
1993	Aftershock effects	Kolhapur district	Weak aftershocks from Latur region felt lightly.
1995	Minor tremor	Kolhapur district	Low-magnitude event; no damage.
1998	Minor earthquake	Southern Maharashtra	Shallow tremor; no reported damage.
2000	Minor tremor	Kolhapur district	Felt briefly in rural areas.
2001	Moderate regional earthquake	Bhuj (felt in Kolhapur)	Bhuj earthquake (M~7.7) faintly felt in Kolhapur; no structural damage locally.
2003	Minor tremor	Kolhapur district	Weak seismic activity recorded.
2006	Minor tremor	Southern Maharashtra	Low-intensity event.
2008	Minor earthquake	Kolhapur district	Short-duration tremor; no damage.
2010	Minor tremor	Kolhapur district	Weak seismic event.
2012	Minor earthquake	Western Maharashtra	Low-magnitude tremor felt in parts of Kolhapur.
2015	Minor tremor	Kolhapur district	Weak seismic activity reported.
2017	Minor earthquake	Southern Maharashtra	Low-magnitude event; no damage.
2019	Minor tremor	Kolhapur district	Shallow tremor recorded by regional stations.
2021	Minor earthquake	Western Maharashtra	Weak tremor; no reported damage.
2023	Minor tremor	Kolhapur district	Low-magnitude seismic activity.

○ **Landslide (1975–2025)**

Year	Event	Region / Place	Description & Notes
1975	Monsoon-induced landslides	Gaganbawda	Heavy rainfall triggered slope failures affecting rural roads and bridge approaches
1978	Rainfall-triggered landslides	Radhanagari	Slope instability near forested hill roads; minor damage to approach embankments
1984	Localized landslides	Western Ghats belt	Saturated soils caused shallow landslides along ghat roads
1989	Monsoon slope failures	Gaganbawda	Disruption to road connectivity; temporary isolation of villages
1993	Landslides during intense monsoon	Radhanagari	Combined effect of rainfall and weakened slopes after floods
1998	Hill slope failures	Chandgad	Damage to retaining structures near bridge approaches
2003	Rainfall-induced landslides	Ajra	Soil slips affecting rural bridges and access roads
2005	Extreme monsoon landslides	Western talukas	Severe rainfall caused multiple landslides and road blockages
2009	Local slope instability	Gaganbawda	Minor landslides near culverts and small bridges
2013	Monsoon-triggered landslides	Radhanagari	Landslides affected approach roads and drainage systems
2015	Slope failures	Bhudargad	Heavy rainfall caused embankment erosion near bridges
2017	Landslides after prolonged rain	Gaganbawda	Temporary closure of hill roads and bridge access
2019	Major landslide activity	Western Kolhapur	Extreme rainfall year; multiple slope failures during district-wide flooding
2020	Cyclone-influenced landslides	Gaganbawda, Ajra	Cyclone Nisarga rainfall triggered slope instability
2021	Post-flood	Radhanagari	Saturated slopes failed after

Year	Event	Region / Place	Description & Notes
	landslides		prolonged flood conditions
2022	Localized landslides	Chandgad	Minor slope failures affecting rural connectivity
2023	Monsoon-related slope instability	Western Ghats region	Preventive closures implemented in landslide-prone zones
2024	Isolated landslides	Gaganbawda	Minor soil slips reported during intense rainfall
2025	Seasonal slope risk	Western talukas	Ongoing monitoring; no major damage reported

ANNEXURE 2 : LIST OF BRIDGES ASSIGNED FOR STUDY

Major Bridge list_Risk and Vulnerability Assessment

Sr . no	Division Name	Sub Division Name	Road Name	Road Category and No.	Name of Bridge	Name of River / Nala	Km
1	Executive Engineer, P.W. SOUTH DIVISION KOLHAPUR	P.W.SUB DIVISION BHUDARG AD	Kolhapur Parite Gargoti Gadhinglaj Naganwadi Chandgad Motanwadi Kakasgasde Bhadshi Road S.H. 189	SH-189	Kur Bridge	Vedganga River	42/950
2		P.W.SUB DIVISION CHANDG AD	Kolhapur Parite Gargoti Gadhinglaj Naganwadi Chandgad Motanwadi Kakasgasde Bhadshi Road S.H. 189	SH-189	Tarmarni Bridge (Near Chandgad)	Tarmarni River	135/240
3		P.W.SUB DIVISION CHANDG AD	Patne phata Patne to motanwadi road MDR 76	MDR-76	Patne Bridge	Tarmarni River	14/800
4		P.W.SUB DIVISION CHANDG AD	Chandgad Hindgaon Ibrahimpur Ajara Mahagaon Halkarni Road SH.2 01.	SH-201	Ibrahimpur Bridge	Ghatpabra River	5/600
5	Executive Engineer Special Project (P.W.) DIVISION	P.W.SUB DIVISION Shahuwadi	SH 191 to Nandgaon Ghungoor Khotwadi Pishavi Bambawade Sarud to District Border road State Highway No.397	SH-397	Sarud Bridge	Kadavi River	20/00
6		P.W.SUB DIVISION Shahuwadi	Vita Peth Malkapur Anuskura Pavas road State Highway No.50 Part-District border to Turukwadi Malkapur Anuskura to District Border	SH-150	Kadavi Bridge (Period)	Kadavi River	98/00
7		P.W.SUB DIVISION Panhala	Panhala Waghbil Borpadale Kodoli Wathar Hatkanangale Ichalkaranji	SH-192	Kodoli Bridge	Nala	19/600

	KOLHAPUR		to State border road State Highway No.192		e (Narsoba Nalla)		
8		P.W.SUB DIVISION Gaganbawada	SH 177 to Koparde Padal Majgaon Porle to join SH 191 road Major District Road 18	MDR 18	Majgaon Bridge	Kasari River	9/800
9		P.W.SUB DIVISION Gaganbawada	SH 177 to Parakhandale Akurde Harpawade Gavashi Dhundawade Jargi Gariwade Gaganbawada to join SH 177 road Major District Road 39	MDR 39	Goth Bridge	Kumbhi River	0/700
10		P.W.SUB DIVISION HATKANGALE	Panhala Waghbel Borephadale Watre turn Wadgaon Hatkangale Ichalkaranji Shirdwad Shiwanakwadi to State Border State Highway No.192.	SH -192	Vathar Briad ge	Vathar Local nala	31/730
11	Executive Engineer, P.W. DIVISION KOLHAPUR	P.W.SUB DIVISION HATKANGALE	Panhala Waghbel Borephadale Watre turp Wadgaon Hatkangale Ichalkaranji Shirdwad Shiwanakwadi to State Border State Highway No.192.	SH-192	Ichalkar anji Old Bridge	Panch gan ga Rive r	63/900
12		P.W.SUB DIVISION KAGAL	S.H.No.178 to Nidhori Ghorabe Kagal Sangaon Yelgud Radal Rangoli Herwad to join SH 153 State Highway No.195	SH-195	Sidhn erli Bridg e	Dudhg ang a Rive r	20/150
13		P.W.SUB DIVISION KAGAL	Road starts from State Highway No. 189 to Hasur Kapashi Alabad to join MDR 54, MDR. No. 53	MDR-53	Kaps hi Brid ge	Chikotr a River	0/600
14		P.W.SUB DIVISION	Road starts from MDR 29 to Shirol D. Bachani Sadoli. Haladi Kurdu Ispurli	MDR-	Haladi Bridge	Bhogawati Rive	6/900

		DIVISION N KARVEE R	Nagaon Nandgaon Akondi Vhannur to join SH 195 at Pimpalgaon Chowk., MDR No. 37	37		r	
15		N H division		SH 0166	BALING E BRIDGE		

BRIDGE STATUS AND PROBABILITY OF FAILURE

1: Bridge 1: Kur Bridge

MHSH0189B002

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR				

FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.59	0.58	0.67	0.67
BRIDGE STATUS	BSL= 5.31	ABSL=1.06	STATUS IS SEVERE	



2: Bridge 2: TARMAPARNI Bridge

MHSH0189B003

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.62	0.60	0.69	0.69
BRIDGE STATUS	BSL= 5.36	ABSL=1.29	STATUS IS SEVERE	



3: Bridge 3: PATNE Bridge MSH0130B004

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.61	0.59	0.68	0.68
BRIDGE STATUS	BSL= 5.36	ABSL=1.29	STATUS IS SEVERE	



4: Bridge 4: IBRAHIMPUR Bridge

MHSH0201B005

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.58	0.57	0.66	0.66
BRIDGE STATUS	BSL= 6.31	ABSL=2.59	STATUS IS SEVERE	



5: Bridge 5: SARUD Bridge

MHSH0397B006

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.6	0.57	0.65	0.65
BRIDGE STATUS	BSL= 6.41	ABSL=1.86	STATUS IS SAFE	



6: Bridge 6: KADAVI Bridge MSH0150B007

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.60	0.57	0.65	0.65
BRIDGE STATUS	BSL= 5.36	ABSL=1.39	STATUS IS SAFE	



7: Bridge 7: KADOLI Bridge

MHSH0192B008

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	SAFE	SAFE	SAFE	SAFE
SUPER STRUCTURE UNSEATING	SAFE	SAFE	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	SAFE	SAFE	SAFE	SAFE
RISK INDEX	0.61	0.59	0.68	0.68
BRIDGE STATUS	BSL= 6.32	ABSL=1.83	STATUS IS SEVERE	



8: Bridge 8: MAJGAON Bridge

MHDR0018B009

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	SAFE	SAFE	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.59	0.58	0.67	0.67
BRIDGE STATUS	BSL= 6.31	ABSL=2.9	STATUS IS SEVERE	



9: Bridge 9: GOTHE Bridge

MHDR0039B010

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.57	0.55	0.64	0.64
BRIDGE STATUS	BSL= 8.0	ABSL=4.4	STATUS IS SAFE	



10: Bridge 10: VATHAR Bridge

MHSH0192B011

FAILURE PROBABILITY

	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.60	0.58	0.67	0.67
BRIDGE STATUS	BSL= 8.00	ABSL=2.88	STATUS IS SAFE	



**11: Bridge 11: ICHALKARANJI OLD Bridge
MHS0192B012**

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.64	0.62	0.71	0.71
BRIDGE STATUS	BSL= 5.36	ABSL=1.23	STATUS IS SEVERE	



12: Bridge 12: SIDHNERLI Bridge

MHSH0195B013

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.60	0.57	0.65	0.65
BRIDGE STATUS	BSL= 5.36	ABSL=1.34	STATUS IS SEVERE	



13: Bridge 13: KAPSHI Bridge

MHDR0053B014

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.62	0.60	0.69	0.69
BRIDGE STATUS	BSL= 5.36	ABSL=1.34	STATUS IS SEVERE	



14: Bridge 14: HALADI Bridge

MHDR0037B015

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.60	0.58	0.67	0.67
BRIDGE STATUS	BSL= 6.31	ABSL=1.77	STATUS IS SAFE	



15: Bridge 15: BALINGE Bridge MSH0166B016

FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.66	0.62	0.70	0.70
BRIDGE STATUS	BSL= 6.31	ABSL=1.51	STATUS IS SAFE	

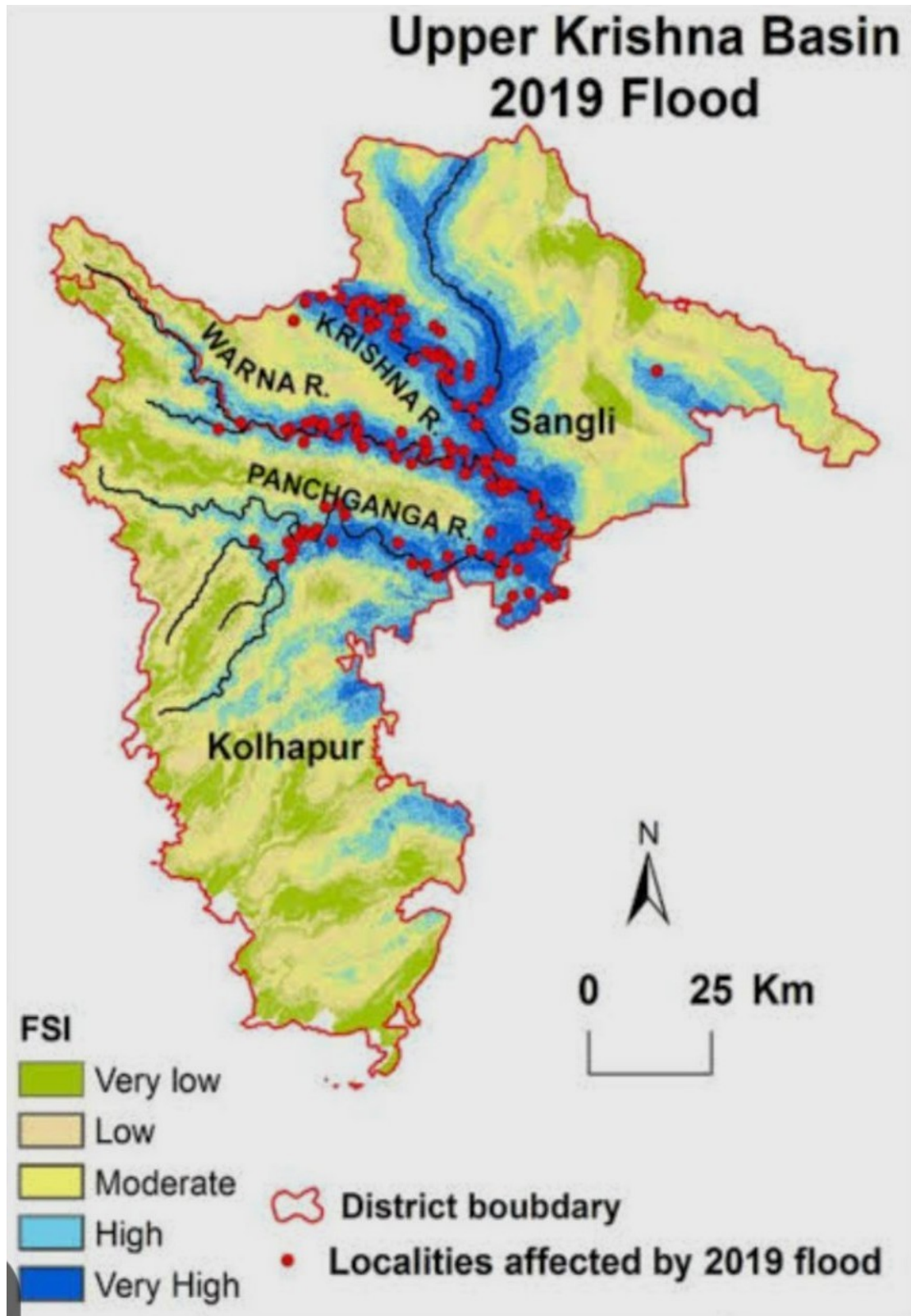


**ANNEXURE 3: MAPS FROM OTHER SOURCES
[COPYRIGHT REST WITH ORIGINAL CREATOR]**

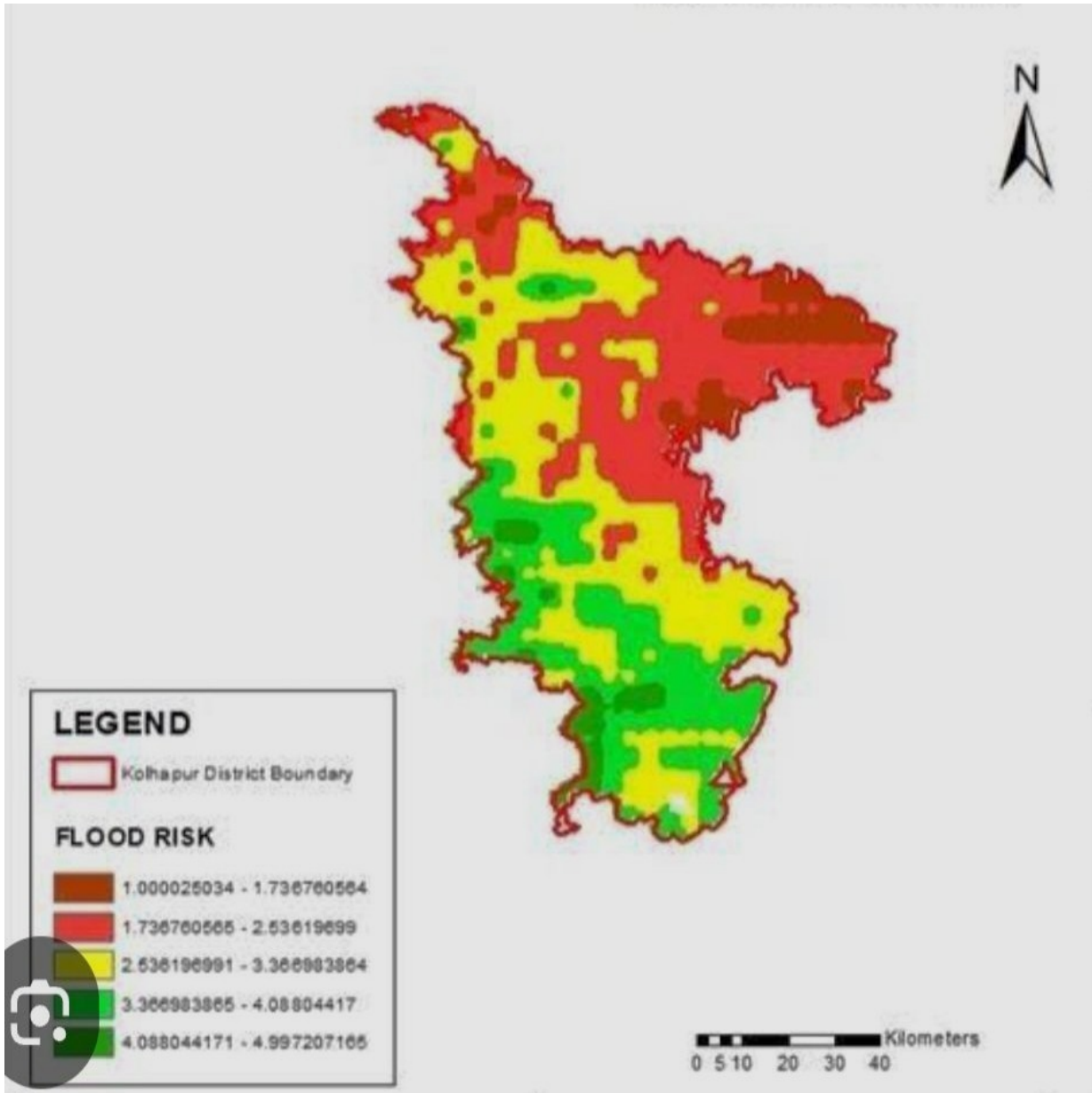
KOLHAPUR DISTRICT WITH RIVERS



FLOOD MAP 2019



FLOOD MAP 2021



BRIDGE LOCATION MAP



ANNEXURE 4: REPORTS FROM GABM & GARM

BILL OF QUANTITIES (BOQ) FOR MSH0201B005



GENERATED FROM GABM - R & D BY UBMS RESEARCH GROUP

[Print BOQ](#)

[← Back to List](#)

Bridge Name	MSH0201B005		
Latitude	15.98	Longitude	74.19
Inspection Date	13-Jun-2026	Engineer Name	MT
Bridge Length	50	No Of Lanes	2
Distress Severity	4	Total Rehabilitation Cost	68571250.00

General Items Applied Prior to Start of Rehabilitation

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To design and provide approach to all such identified areas and to ensure total approachability for the entire bridge structure. To design and install support mechanism/system to ensure load transfer from superstructure and deck elements.	Sq. meter	200.00	200.00	200.00	200,000.00
2	Remove decessed concrete from all identified distress area including crack surfaces. Cleaning of exposed surfaces by appropriate mechanism/system. Ensure all exposed rebars are cleaned and rust removed.	Sq. meter	700.00	700.00	100.00	70,000.00
3	To apply appropriate bonding agents for concrete surfaces, rust inhibition coat for exposed rebar/ steel surfaces. Ensure proper curing time.	Sq. meter	700.00	700.00	200.00	140,000.00
4	To identify areas which require fresh concrete/micro concrete. To design and create formwork for all such areas.	Lump sum	1.00	1.00	2,000,000.00	2,000,000.00
5	To design the quality control systems for all items of work, define the frequency, type of test, acceptance criteria. To submit the same to appropriate authority for their approval. To apply this approved quality control system during the entire rehabilitation program.	Lump sum	1.00	1.00	20,000.00	20,000.00
6	To design and get approval for all such situations with respect to safety of workers and protection of other people in the vicinity of rehabilitation area.	Lump sum	1.00	1.00	70,000.00	70,000.00
7	To design and develop alternate route for traffic diversion. Maintain this diversion to ensure smooth traffic movement during the entire rehabilitation program.	Lump sum	1.00	1.00	1,000,000.00	1,000,000.00
8	Structural Assessment, inspection and identification / mapping of distress area	Lump sum	1.00	1.00	70,000.00	70,000.00
Sub-Total (Prior to Start):						₹ 5,000,000.00

General Items Applied Post Completion of Rehabilitation

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To provide appropriate protective coating for the entire bridge surface. Ensure that the surface is properly finished, cured and prepared for protective coating application. Such preparation will entail surface leveling and finishing.	Lump sum	120.00	120.00	1,000.00	120,000.00
2	To design and get approval for all test methodologies, frequencies and acceptance criteria for post rehabilitation work. This testing will ensure to have load capacity evaluation and shall be performed prior to opening the bridge for regular traffic.	Lump sum	1.00	1.00	10,000.00	10,000.00
3	To design and provide concrete mix for all such areas which require fresh concrete.	Lump sum	1.00	1.00	20,000.00	20,000.00
Sub-Total (Post Completion):						₹ 170,000.00

Method Based Items - Section #1

Cause Matrix:
FATIGUE

Principle:
Structural strengthening

Method:
Surface panel / plates for strengthening
(Application/bonding/external sections)

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To design and provide approach to all such identified areas and to ensure total approachability for the entire bridge structure. To design and install support mechanism/system to ensure load transfer from superstructure and deck elements.	Sq. meter	200.00	200.00	200.00	200,000.00
2	Remove deformed concrete from all identified distress area including crack surfaces. Cleaning of exposed surfaces by appropriate mechanism/system. Ensure all exposed rebars are cleaned and rust removed.	Sq. meter	120.00	120.00	100.00	120,000.00
Section #1 Total:						₹ 320,000.00

Method Based Items - Section #2

Cause Matrix:
OVERLOAD

Principle:
Concrete Restoration

Method:
Surface panel / plates for restoration
(Application/bonding/external sections)

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To apply appropriate bonding agent for concrete surfaces, rust inhibition coat for exposed rebar/ steel surfaces. Ensure proper curing time.	Sq. meter	120.00	120.00	200.00	240,000.00
2	To identify areas which require fresh concrete/micro concrete. To design and create formwork for all such areas.	Lump sum	1.00	1.00	2,000,000.00	2,000,000.00
Section #2 Total:						₹ 2,240,000.00

Cause Matrix:
OVERLOAD

Principle:
Concrete flexuration

Method:
Surface panel / plates for restoration
(Application/bonding/external sections)

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To apply appropriate bonding agent for concrete surfaces, run initiation coat for exposed rebar/ steel surfaces. Ensure proper curing time.	Sq. meter	125.00	125.00	288.00	36,000.00
2	To identify areas which require fresh concrete/micro concrete. To design and create formwork for all such areas.	Lump sum	1.00	1.00	2,000,000.00	2,000,000.00
Section #2 Total:						₹ 2,036,000.00

Method Based Items - Section #3

Cause Matrix:
AGGRESSION BY CHLORIDES

Principle:
Protection against Ingress

Method:
Coating to improve physical resistance

S.No	Items of Work (Description)	Unit of Measurement	Observed Quantity	Area/Vol for Rehab	Rate per Unit (₹)	Amount (₹)
1	To design the quality control systems for all items of work, define the frequency, type of test, acceptance criteria. To submit the same to appropriate authority for their approval. To apply this approved quality control system during the entire rehabilitation program.	Lump sum	1.00	1.00	20,000.00	20,000.00
2	To design and get approval for all such situations with respect to safety of workers and protection of other people in the vicinity of rehabilitation area.	Lump sum	1.00	1.00	12,000.00	12,000.00
3	To design and develop alternate route for traffic diversion. Maintain this diversion to ensure smooth traffic movement during the entire rehabilitation program.	Lump sum	1.00	1.00	2,000,000.00	2,000,000.00
Section #3 Total:						₹ 2,032,000.00

All Method Based Items Total: ₹ 5,825,000.00

BOQ FOR ENHANCING RESILIENCE

RESILIENCE ENHANCEMENT BOQ FOR MSH0201B005



GENERATED FROM GABM - R & D BY UBMS RESEARCH GROUP

Bridge Name	MSH0201B005		
Latitude	15.986	Longitude	74.192
Inspection Date	13-Jan-2026	Engineer Name	SJ
Bridge Length	50	No Of Lanes	2
Distress Severity	4	Total Resilience Cost	₹ 22,430,000.00

Resilience Enhancement - Section #1

Cause Matrix:

Against Shear Failure of Substructure

Principle:

Design and Provide required systems

S.No	Items of Work	Item Description	Unit	Observed Qty	Rate/Unit (₹)	Amount (₹)
1	Identify member needing increased shear capacity		50.00	100,000.00	5,000,000.00	
2	Design of systems required to increase shear capacity of substructure elements.		1.00	50,000.00	50,000.00	
3	Provide the designed system		1.00	6,000,000.00	6,000,000.00	
4	Load capacity check by testing.		1.00	100,000.00	100,000.00	
Section #1 Total:						11,150,000.00 ₹

Resilience Enhancement - Section #2

Cause Matrix:

Against the Toppling of the Superstructure

Principle:

Design and Provide required systems

S.No	Items of Work	Item Description	Unit	Observed Qty	Rate/Unit (₹)	Amount (₹)
1	Identify member likely to topple		6.00	15,000.00	90,000.00	
2	Design of systems required to avoid toppling of elements.		1.00	750,000.00	750,000.00	
3	Provide the designed system		6.00	150,000.00	900,000.00	
4	Load capacity check by testing.		1.00	100,000.00	100,000.00	
5	Design and provide lateral restraints to main girder or main beams in superstructure		3.00	500,000.00	1,500,000.00	

S.No	Items of Work	Item Description	Unit	Observed Qty	Rate/Unit (₹)	Amount (₹)
Section #2 Total:						₹ 3,340,000.00

Resilience Enhancement - Section #3

Cause Matrix:

Against overturning of Superstructure

Principle:

Design and Provide required systems

S.No	Items of Work	Item Description	Unit	Observed Qty	Rate/Unit (₹)	Amount (₹)
1	Identify member likely to topple		6.00	15,000.00	90,000.00	
2	Design of systems required to avoid toppling of elements.		1.00	250,000.00	250,000.00	
3	Provide the designed system		6.00	1,000,000.00	6,000,000.00	
4	Load capacity check by testing.		1.00	100,000.00	100,000.00	
5	Design and provide lateral restraints to main girder or main beams in superstructure		3.00	500,000.00	1,500,000.00	
Section #3 Total:						₹ 7,940,000.00

All Resilience Enhancement Items Total: ₹ 22,430,000.00

ARTICLE 2:
EVALUATION OF RISK AND VULNERABILITY
OF BRIDGES IN KOLHAPUR DISTRICT

ARTICLE 2: EVALUATION OF RISK AND VULNERABILITY OF BRIDGES IN KOLHAPUR DISTRICT

Sachidanand Joshi¹, Dr. Prasad Sankpal², Mayuri Tundalwar¹,
Sreenath Menon¹

1: UBMS Research Group

2: Kolhapur District Disaster Management Authority

ABSTRACT:

Bridges in Kolhapur District are essential components of the transportation network, enabling regional connectivity, supporting economic activities, and ensuring access for emergency and disaster response services. The district's geographical setting at the foothills of the Western Ghats, combined with a tropical monsoon climate, exposes bridge infrastructure to recurring natural hazards such as floods, landslides, and moderate seismic activity. Repeated flood events in past decades have demonstrated that bridges are frequently subjected to prolonged submergence, high hydraulic forces, debris impact, and foundation scour, leading not only to structural distress but also to significant loss of serviceability. Many bridges in the district are ageing and were constructed prior to the adoption of modern design, hydraulic, and seismic standards, further increasing their vulnerability under multi-hazard conditions. Past natural hazards occurrence in the district have shown that failure or disruption of few critical bridges can severely affect mobility, emergency response, and regional economic stability. In this context, conventional condition-based inspection practices alone are inadequate to capture the true level of vulnerability and resultant risk. A comprehensive Risk and Vulnerability Analysis [RVA] is therefore necessary to integrate hazard exposure, bridge condition, functional importance, and potential consequences. This paper presents results of RVA conducted to support informed decision-making, prioritization of interventions, and enhancement of long-term resilience of bridge infrastructure in Kolhapur District.

1. Introduction:

Risk and Vulnerability Analysis of selected bridges in Kolhapur District, undertaken by UBMS Research Group [URG] & Global Bridge Management Systems Pty, Australia in coordination with the Kolhapur District Disaster Management Authority [DDMA] and the Public Works Department (PWD). The assessment focuses on bridges located in various river basins in Kolhapur, which were repeatedly affected by natural hazards, particularly floods. The selection of bridges was done to induce diversity in terms of location, geometry and road type.

Bridges are critical elements of transportation networks, and their failure or loss of serviceability can lead to significant economic losses, disruption of emergency services, and reduced regional connectivity.

In disaster-prone regions such as Kolhapur, the reliable performance of bridges is essential for both routine mobility and effective disaster response.

Meteorological character of Kolhapur District

Kolhapur District is located at the eastern foothills of the Western Ghats and experiences a tropical monsoon climate characterized by intense seasonal rainfall. The district's location within multiple river basin, combined with intense monsoon rainfall and upstream catchment influences from the Western Ghats, results in frequent high-flow conditions and prolonged inundation. Repeated exposure to flooding has led to recurring issues such as foundation scour, deterioration of substructure elements, and loss of serviceability due to submerged approaches. Presence of multiple river systems and its tributaries make the district highly susceptible to river flooding. Kolhapur District has been exposed to a complex multi-hazard environment. Our study focused on observations over the last five decades (1975–2025), including recurrent flooding, cyclone-influenced extreme rainfall, landslides, and moderate seismic activity. Historical flood events in 1975, 1978, 1993, 2005, 2019, and 2021 have repeatedly exposed bridge infrastructure to prolonged submergence, high hydraulic forces, debris impact, and foundation scour.

In addition to flooding, Landslides are particularly common in the western talukas due to steep slopes and weathered rock formations. Many roads in these talukas were damaged during previous events of heavy rain. The district is indirectly affected by cyclonic systems originating in the Arabian Sea and Bay of Bengal, which intensify rainfall and trigger secondary hazards such as landslides. The district falls under Seismic Zone III, indicating moderate earthquake risk. These multiple hazards create a complex risk environment for bridge infrastructure. Many past events have shown susceptibility of one occurrence resulting in multiple hazards. Flooding and Landslides have occurred simultaneously in 2019 and 2021. While floods dominate regional risk, events such as Cyclone Nisarga (2020) intensified rainfall over Western Ghats catchments and triggered landslides that disrupted bridge approaches and connectivity. Past earthquakes have highlighted vulnerabilities in ageing bridges constructed prior to modern seismic standards, particularly when combined with flood-induced deterioration. Major monsoon events in 2019 and 2021 further demonstrated the occurrence of compound hazards, with flooding and landslides affecting bridges simultaneously. Incorporating this long-term hazard history ensures that vulnerability indices and risk rankings are firmly grounded in verified regional data rather than theoretical assumptions.

The need for risk and vulnerability analysis gain further significance when interpreted in the context of quantified local hazard exposure

and functional criticality of bridges within the regional transportation network. Historical flood records from the river basin clearly demonstrate that bridge infrastructure in Kolhapur District is subjected to extreme and recurring hydraulic loading. During the 2021 flood event, the Panchganga river reached a peak level of 56'3" [17.2 M], exceeding the designated danger level by 13'3" [4.03 M], resulting in widespread submergence of bridge decks and approach roads. Similarly, the 2019 flood event, characterized by cumulative rainfall of 2506 mm, and the 2021 event triggered by extreme short-duration rainfall exceeding 500 mm within two days, highlight the dynamism in frequency and severity of rain-induced floods.

These extreme events translated into substantial infrastructure losses, with damages to roads and bridges alone estimated at approximately ₹3289.51 crore during the 2019 floods. Such quantified hazard impacts reinforce the necessity of explicitly incorporating hazard intensity, duration, and recurrence into bridge risk assessment frameworks, rather than relying solely on structural condition indicators. **Table 1** enumerates few climate-related historical moments in the Kolhapur district.

**Table 1
Flood Events in Kolhapur District (1975–2025)**

Year	Event Type	Region / Place Affected	Key Impacts
1975	Major flood	Panchaganga basin, Kolhapur city	River overflow after heavy monsoon rainfall; agricultural and settlement damage.
1993	Major flood	Krishna basin, district-wide	Severe flooding across Maharashtra; road and housing damage.
2019	Extreme flood	Kolhapur city, Shirol, Hatkanangale, Karvir	One of the worst floods on record; prolonged inundation, mass evacuation, infrastructure loss.
2021	Severe flood	Entire district	Extreme rainfall triggered widespread flooding and major relief operations.

Cyclone-Influenced Events (Indirect) (1975–2025)

Year	Event	Region / Place Affected	Key Impacts
1975	Indirect monsoon-depression rainfall	District-wide	Increased rainfall associated with remnant systems affecting river flows.
2020	Cyclone Nisarga remnants	Kolhapur district	Heavy rainfall and wind gusts inland triggered landslides and flooding.
2021	Cyclone Tauktae remnants	District-wide	Rainfall intensification and wind effects exacerbated flood conditions.

Earthquake Events Affecting Kolhapur (1975–2025)

Year	Event	Region / Place Affected	Key Impacts
1992	Latur earthquake (felt)	Latur region / Kolhapur	M~6.3 earthquake felt; raised seismic awareness though no direct damage locally.
2001	Bhuj earthquake (felt)	Gujarat / Kolhapur	M~7.7 event faintly felt; no local structural damage reported.
2021	Minor earthquake	Western Maharashtra	Weak tremor; highlighted persistent moderate seismic exposure.

Landslide Events in Kolhapur District (1975–2025)

Year	Event	Region / Place	Key Impacts
1975	Monsoon-induced landslides	Gaganbawda	Slope failures damaged rural roads and bridge approaches.
2019	Major landslide activity	Western Kolhapur	Extreme rainfall caused district-wide slope failures during floods.
2020	Cyclone-influenced landslides	Gaganbawda, Ajra	Cyclone Nisarga rainfall triggered slope instability near bridges.

2. Objectives of RVA study

The primary purpose of this study is to assess the risk and vulnerability of bridges assigned by district PWD under multiple natural hazards, including floods, indirect cyclone impacts, landslides, and earthquakes. The scope covers bridges of varying age, design, material, and functional importance across state highways and major district roads, using historical data spanning 1975–2025.

Key objectives include:

- VI. Identification of dominant hazards,
- VII. Assessment of structural Functional, and socio-economic vulnerability,
- VIII. Evaluation of risk index through integration of hazard likelihood and consequences.
- IX. Prioritization of bridges for mitigation and resilience enhancement.
- X. RVA also provide technical inputs to support policy decisions and disaster preparedness planning.

4. METHODOLOGY:

Risk and Vulnerability Analysis Framework

Typically RVA framework integrates hazard exposure, structural vulnerability, and consequence assessment to determine overall risk. Risk is defined as the combined effect of hazard likelihood and the severity of its impacts. A bridge exposed to frequent hazards may still pose lower risk if it is structurally sound and of low functional importance, whereas an ageing, deteriorated bridge carrying critical

traffic may represent high risk even under moderate hazard conditions. Most bridges assessed in this study are more than fifty to seventy years old and are considered ageing, with many constructed prior to modern design and seismic standards. Age-related deterioration, combined with repeated exposure to floods and increasing traffic loads, significantly influences vulnerability and risk levels.

Methodology and Analytical Tools

The methodology follows a structured sequence of hazard identification, vulnerability assessment, risk analysis, and prioritization. Hazard identification is based on historical records, hazard zoning, and regional studies. Vulnerability assessment uses bridge inspection data, condition ratings, observed distress, design adequacy, and maintenance history, considering three critical parameters namely structural, functional, and socio-economic aspects. A semi-quantitative scoring and ranking approach is adopted due to limitations in detailed probabilistic data. Advanced decision-support systems, including the Global Analytics for Bridge Management [**GABM**] and Global Analytics for Risk and Resilience Management [**GARM**], are used to integrate data and support multi-criteria decision-making.

The Risk and Vulnerability Analysis undertaken in this study is supported by advanced digital decision-support platforms, namely Global Analytics for Bridge Management (GABM) and Global Analytics for Risk and Resilience Management (GARM). These tools enable a systematic, data-driven assessment that extends beyond conventional manual inspection-based approaches.

GABM is primarily employed to evaluate the **structural vulnerability** of bridges by integrating inspection data, bridge geometry, age, material condition, deterioration trends, and functional performance indicators. The platform processes bridge-specific inputs to determine baseline vulnerability, remaining service life, and failure susceptibility under various hazard scenarios. This analysis establishes the structural and functional condition state of each bridge, forming the foundation for risk evaluation.

GARM builds upon the outputs of GABM by incorporating **hazard likelihood, consequence assessment, and resilience parameters** within a unified risk framework. The platform enables multi-hazard risk assessment by combining vulnerability indices with hazard frequency and severity, and further supports decision-making through a Multi-Criteria Decision-Making (MCDM) module. This integrated technological workflow allows the transition from condition-based assessment to **risk- and resilience-oriented bridge management**.

The application of GABM and GARM in this pilot study demonstrates a **technology-enabled assessment framework**, where analytical rigor, consistency, and transparency are achieved through structured data integration and automated evaluation. This approach represents a shift from subjective, inspection-driven judgments toward objective, repeatable, and scalable infrastructure risk assessment.

The flow of data within the framework essentially relies on input of basic bridge geometry [BG], geospatial data [GS], identified ranking for structural status, functional adequacy and socio-economic impact, and historical data related to hazards impacting the region. This data is analysed within GABM to provide results which form the input to GARM. Within GARM this results are further analysed for Risk and Vulnerability assessment, definition of remedial measures required to generate the estimates for both rehabilitation and resilience enhancement. The results of RVA and estimates are then processed in multi-criteria decision-making module of GARM to provide solution that results in fund optimization and allocation.

This integrated dataset is first analysed within the GABM. Application processes bridge-specific information to evaluate current structural condition, deterioration trends, functional performance, and baseline vulnerability.

RVA essentially requires details of the zone in which the bridge is located since the natural hazards are specific to the geography/location of the bridge. Risk index evaluation is done using four factors:

1. The Structural Vulnerability factor [SVF] depends on the age of the bridge [A], material condition [MC] and design of the bridge [DP] apart from the Bridge Structural Rating Number. The mean of the BSRN is modified to account for the age of the bridge and the material condition for a specific design philosophy.

$$\mathbf{SVF} = f [A, MC, DP] \dots \mathbf{1}$$

2. The functional importance factor [SIF] depends on the values assigned during inspection to the Functional parameters, namely the Bridge geometry [BG], Bridge vertical clearance [VC], Waterway adequacy [WA], and average daily traffic [DT] on the bridge.

$$\mathbf{SIF} = f [BG, VC, WA, DT] \dots \mathbf{2}$$

3. Socio-economic importance [SEIF] of the bridge contributes to the definition of vulnerability and hence to the evaluation of the risk index. Parameters like social importance [SI], Economic growth potential [EGP] due to the bridge, Environmental impact [EI] contributed by the bridge.

$$\mathbf{SEIF} = f [SI, EGP, EI] \dots \mathbf{3}$$

4. Bridge Importance Factors [BIF] decided by the importance of the

bridge in evacuation and rescue [C_r] operations. This factor is critically determined by the traffic on the bridge [DT] and the alternate route parameter [AR], which determines how much more time the vehicle needs to travel in the absence of the bridge.

$$\mathbf{BIF} = f [C_r, DT, AR] \dots \quad \mathbf{4}$$

All the above factors are modified as per the regional hazard frequency [F] and severity dynamics [S].

$$\mathbf{RF} \propto F, S \dots \quad \mathbf{5}$$

Finally, all these five factors are used to determine the fraction assignment [$RHFA$]

$$\mathbf{RHFA} = f (SVF, SIF, SEIF, BIF) + f (RF) \dots \quad \mathbf{6}$$

from which the weighted RVA score for the bridge is evaluated.

$$\mathbf{RS} = RFr + RHFAr \dots \quad \mathbf{7}$$

The summation of all four scores determines the Risk score, which is then used to assign the risk index based on the zone in which the bridge is located.

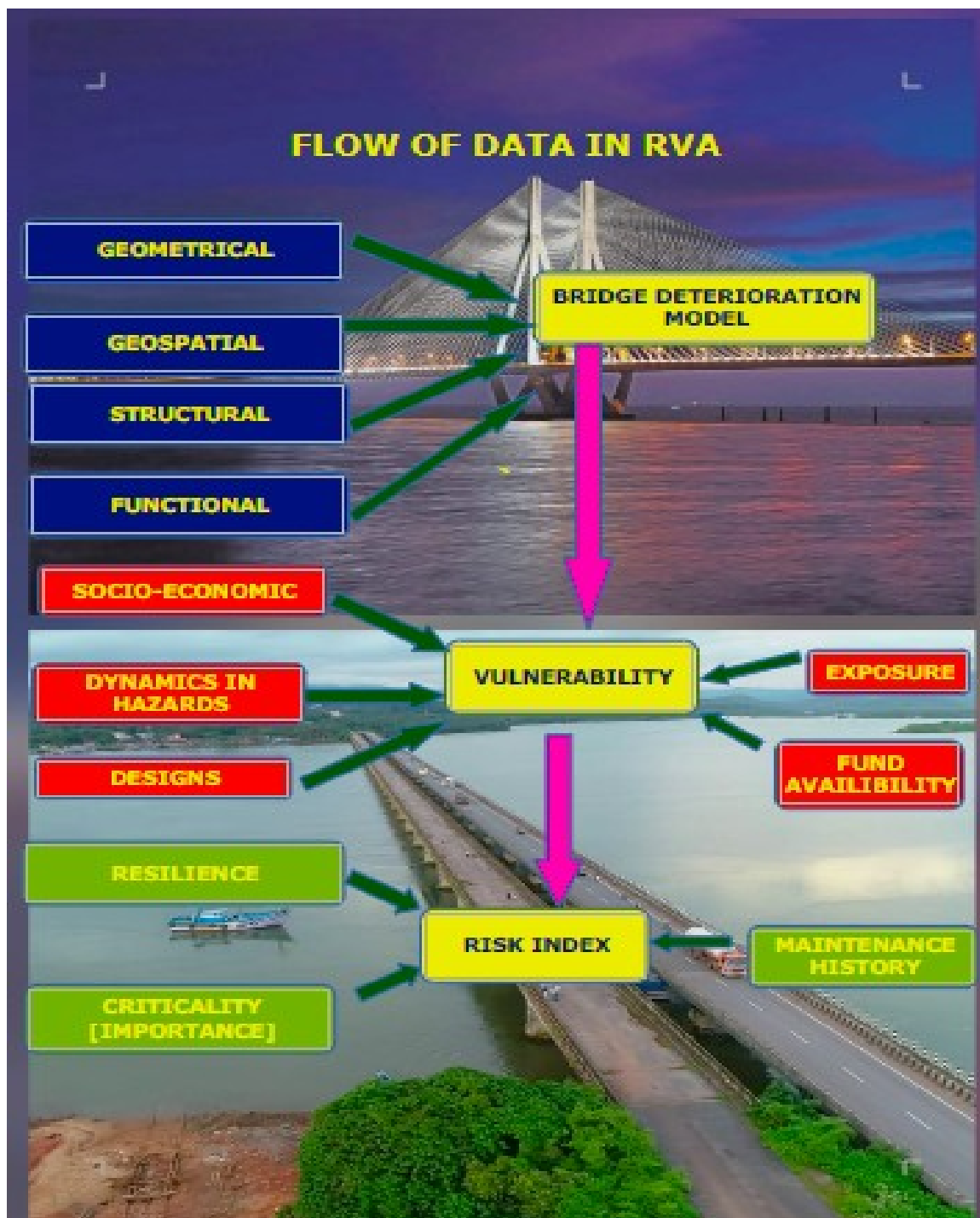
$$\mathbf{RI} = RS / \max[RHFA] \dots \quad \mathbf{8}$$

Such an evaluation procedure ensures that all critical factors which impact the vulnerability and risk are integrated in the evaluation of the risk index. The results from GABM are then transferred to the GARM, where advanced risk and vulnerability assessments are performed. Within GARM, hazard likelihood is combined with bridge vulnerability and consequence parameters to estimate overall risk levels. This stage also enables identification of dominant risk drivers and potential failure mechanisms under different hazard scenarios. Risk analysis integrates hazard likelihood with vulnerability and consequence indicators to determine overall risk levels. Due to limitations in detailed probabilistic data, a semi-quantitative scoring and ranking approach is adopted to ensure consistency and comparability across the bridge inventory. Based on the risk assessment outcomes, GARM supports the definition of appropriate remedial and mitigation measures.

A key strength of the study lies in the integration of cost, benefit, and prioritization analysis through the Multi-Criteria Decision-Making [**MCDM**] framework embedded within GARM. Unlike traditional risk assessments that stop at risk classification, the present framework extends to evaluating the feasibility and justification of rehabilitation and resilience enhancement measures.

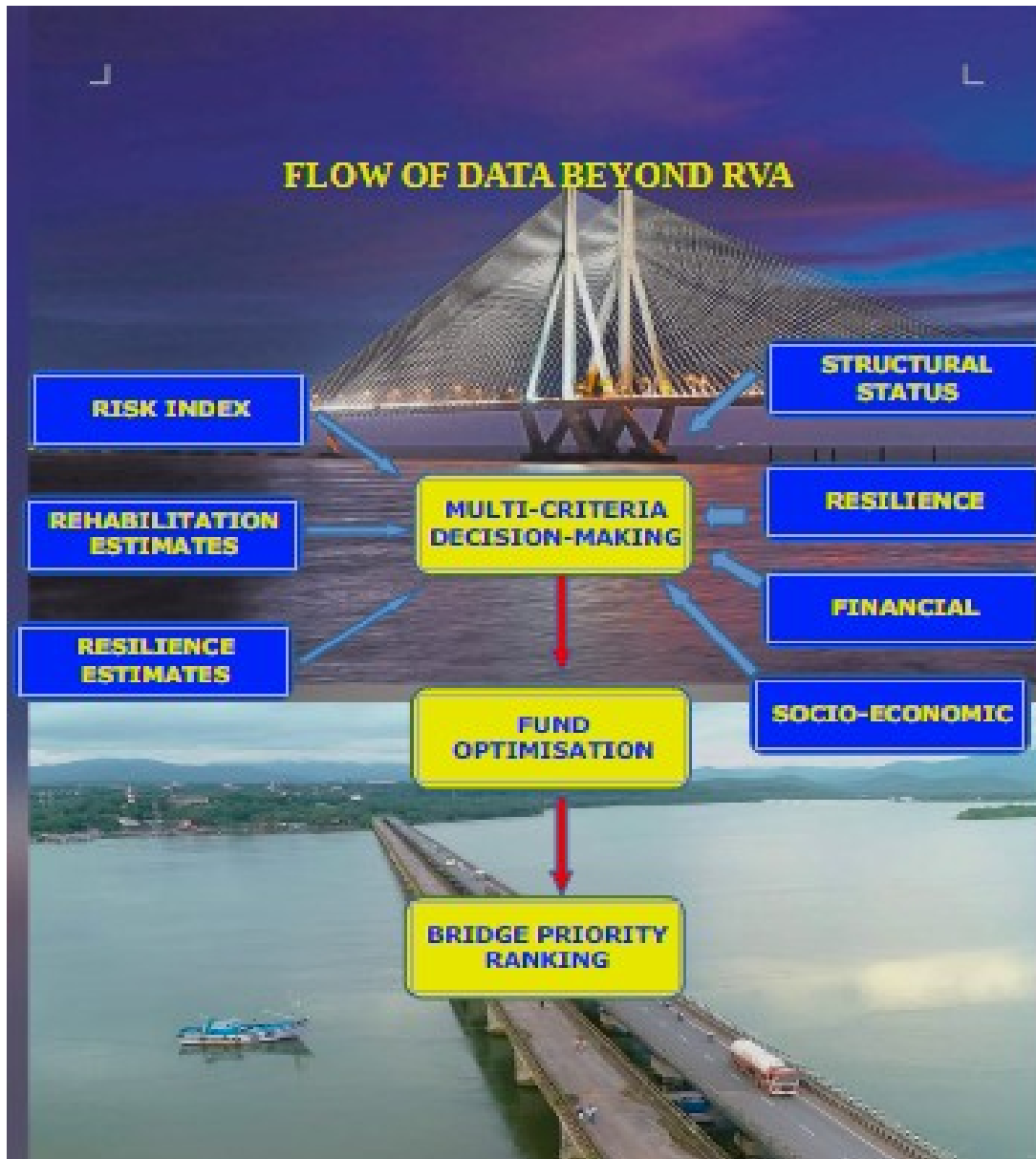
The MCDM module evaluates competing factors—including risk reduction potential, structural condition, functional importance, socio-economic impact, and estimated rehabilitation and resilience costs—to prioritize interventions across the bridge inventory. This enables identification of measures that offer the maximum benefit

relative to investment, ensuring optimized allocation of limited financial resources.



These may include structural rehabilitation actions such as strengthening, scour protection, or bearing replacement, as well as resilience enhancement measures such as improved drainage, slope stabilization, monitoring systems, and operational preparedness strategies. Cost estimates for both rehabilitation and resilience measures are generated to support economic evaluation. The results

of the Risk and Vulnerability Analysis, along with associated cost estimates, are processed within the Multi-Criteria Decision-Making [MCDM] module of GARM.



This module evaluates multiple competing factors—including risk reduction potential, cost, structural condition, functional importance, and socio-economic impact—to prioritize interventions. The outcome is an optimized solution that supports efficient fund allocation, maximizes risk reduction benefits, and ensures transparent and justifiable decision-making for bridge management and resilience planning. The bridges are prioritized into high, medium, and low risk categories to support decision-making related to inspection, retrofitting, monitoring, and disaster preparedness planning.

5. RESULTS OF THE STUDY:

While the primary focus of this paper is the development and application of a comprehensive Risk and Vulnerability Assessment [RVA] framework, the pilot study generated detailed, bridge-specific risk outputs for fifteen critical bridges in Kolhapur District. To strengthen the linkage between the proposed framework and real-world outcomes, selected bridge-level results are summarized and presented. Table 1.0 presents a representative summary of Assigned Rank and Risk Index [RI] values for key bridges identified during the assessment. The Kur Bridge [MHS0189B002] and Tamraparni Bridge [MHS0189B003] are highlighted due to their consistently high-risk classification across multiple hazard scenarios.

The Kur Bridge exhibits a severe structural status, with elevated failure probabilities under flooding and earthquake hazards. High hydraulic exposure, ageing structural components, and significant functional importance contribute to its high composite risk index. Similarly, the Tamraparni Bridge demonstrates a severe risk profile, driven by repeated flood exposure, susceptibility to scour, and high consequence of service disruption. These bridge-specific results confirm that structures with moderate to severe deterioration can exhibit disproportionately high risk when located in hazard-prone zones and assigned critical functional roles within the transportation network. The inclusion of such results demonstrates the ability of the RVA framework to translate analytical outputs into actionable, bridge-level insights, supporting prioritization of interventions and resource allocation.

Summary Table for Results Section (Table 1.0)

BRIDGE ID	BRIDGE NAME	STATUS / CAUSE	Hazard Dominance	BSL	ABSL
MHS0189B002	KUR BRIDGE	Severe / Mechanical	Flooding, Earthquake	5.31	1.06
MHS0189B003	TARMAPARNI BRIDGE	Severe / Mechanical & Chemical	Flooding, Earthquake	5.36	1.29
MHS0192B008	KODOLI BRIDGE	Severe / Mechanical & Chemical	Flooding	6.32	1.83
MHDR0018B009	MAJGAON BRIDGE	Severe / Mechanical & Chemical	Flooding, Earthquake	6.31	2.9
MHS0192B012	ICHALKARANJI OLD BRIDGE	Severe / Mechanical & Chemical	Flooding	5.36	1.23

Results of Risk and Vulnerability Assessment

Flooding is identified as the dominant hazard influencing bridge risk in Kolhapur District. While many bridge superstructures remain structurally intact during floods, loss of serviceability frequently occurs due to submergence or damaged approaches, scour around foundations, and deterioration of substructure elements. Landslides

mainly affect bridge approaches and embankments in western regions, leading to functional failure despite structural adequacy. The assessment also reveals that indirect cyclone impacts exacerbate flood and landslide risks, creating compound hazard scenarios. Although seismic hazard is moderate, older bridges lacking modern seismic detailing remain vulnerable, particularly when combined with other hazards.

Risk Classification and Prioritization

Based on the integrated risk assessment, bridges are categorized into high, medium, and low risk groups. High-risk bridges are characterized by high hazard exposure, advanced structural deterioration, and high functional importance within the transport network. Medium-risk bridges require planned interventions and enhanced monitoring, while low-risk bridges can be managed through routine maintenance. This prioritization enables efficient allocation of limited resources and targeted mitigation planning. Most of the bridges were classified as High-risk bridges.

Limitations of BMS and urgent need for Risk-Based Management

The study highlights limitations in conventional bridge inspection practices, which primarily focus on visible structural distress and do not adequately incorporate hazard exposure, functional criticality, or future climate risks. As a result, maintenance decisions are often reactive rather than preventive. The findings emphasize the need for a risk-based and resilience-oriented bridge management approach that integrates historical hazard data, vulnerability assessment, and consequence analysis. Such an approach is increasingly important in the context of climate change, which is expected to increase the frequency and intensity of extreme rainfall events.

Within GABM the structural status of the bridge is evaluated based on the input provided by the bridge inspection engineer. The analysis is performed based on standard protocol for determination of Balance service life and Absolute Balance service life [**BSL, ABSL**]. The BSL and ABSL evaluation depends on the age of the bridge. For bridges which are below 20% of their DSL the evaluation is done based on symptoms. Beyond that age limit up to 20% of DSL, the evaluation is based on Identified Cause of distress. For the purpose of this study, bridges are classified as ageing when their in-service age exceeds 50% of their Designed Service Life [DSL]. In the absence of original design documentation for older structures, a baseline DSL of 50 years is assumed for all bridges constructed prior to 1990, consistent with prevailing design practices at the time.

Based on this criterion, all fifteen bridges assessed in the pilot study fall within the ageing category, having surpassed half of their assumed service life. This uniform classification provides a technical justification for the selection of the bridge sample, ensuring that the

analysis focuses on structures most likely to exhibit cumulative deterioration, outdated design provisions, and heightened vulnerability under multi-hazard conditions. By explicitly defining ageing in terms of DSL exceedance, the study establishes a transparent and reproducible basis for inventory screening, while linking bridge age directly to structural vulnerability and risk evaluation within the RVA framework.

Typical results of each bridge is shown as under:

Bridge 1: Kur Bridge MSH0189B002

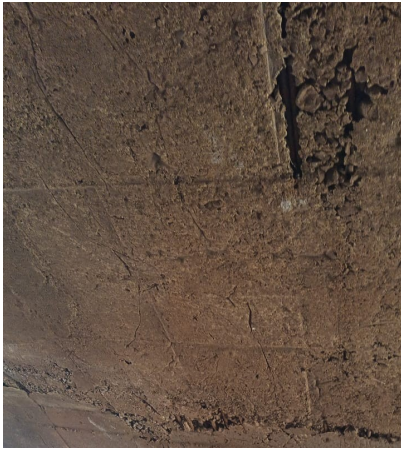
FAILURE PROBABILITY				
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE
SHEAR FAILURE OF PIER	FAIL	FAIL	SAFE	FAIL
SUPER STRUCTURE UNSEATING	FAIL	FAIL	SAFE	SAFE
SUPER STRUCTURE SHEAR FAILURE	FAIL	FAIL	SAFE	FAIL
RISK INDEX	0.59	0.58	0.67	0.67
BRIDGE STATUS	BSL= 5.31	ABSL=1.06	STATUS IS SEVERE	



Bill of Quantities evaluation.

Within GARM evaluation of Bill of Quantities for rehabilitation and enhancement of resilience is available. BOQ module enables users to prepare the estimates based on identified cause of distress. For every identified cause, the Principle's of rehabilitation is provided. This definition of principle is as per EN 1504. The user can define the quantity and the rate. For Resilience enhancement three causes for possible failure define the enhancement techniques. For each failure

mode, one option to design the enhancement technique is also provided. Few images of the type of distress are as under:



RISK and VULNERABILITY ANALYSIS:

The results of the risk and vulnerability assessment clearly indicate that flooding represents the dominant natural hazard affecting bridge infrastructure in Kolhapur District. Functional criticality further amplifies the consequences of bridge vulnerability. Several bridges assessed under this study serve as critical mobility links, where service disruption directly affects regional connectivity and emergency response. For instance, the Shivaji Bridge to Kerle section along NH-166 experiences repeated submergence, leading to isolation of surrounding areas and severely constrained access for emergency services. During the 2021 flood event, disruptions to bridge connectivity contributed to mobility challenges across approximately 409 affected villages, underscoring that bridge failure extends beyond structural loss to societal and economic consequences.

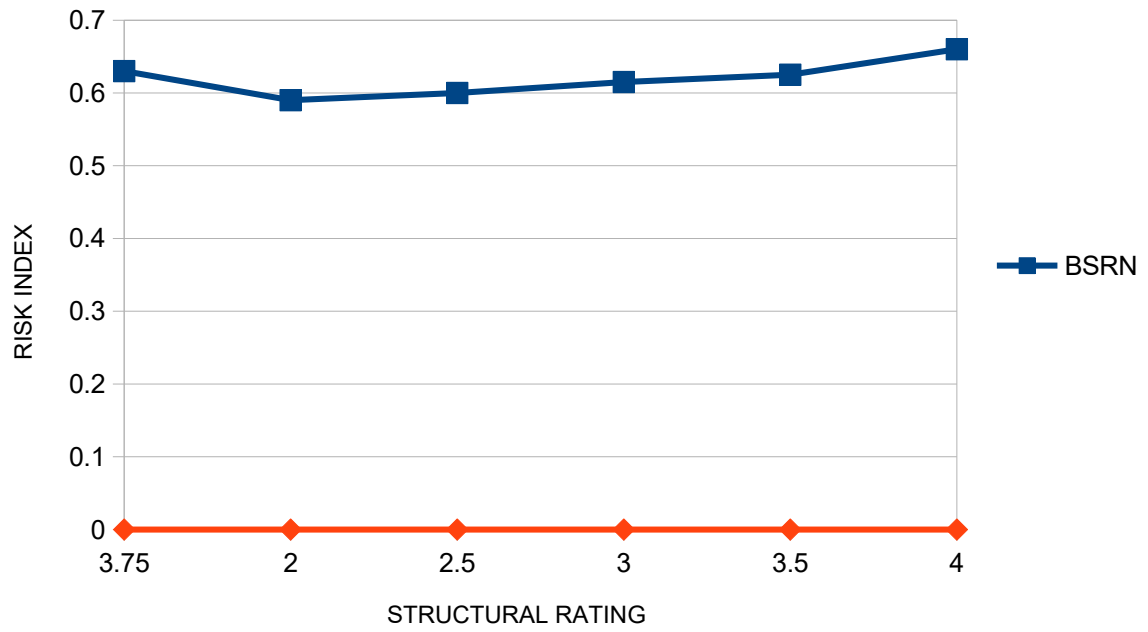
BRIDGE ID	RISK INDEX [RI]				RI for MCDM
	FLOODING	CYCLONE	LANDSLIDE	EARTHQUAKE	
MHSH0189B002	0.59	0.58	0.67	0.67	0.63
MHSH0189B003	0.62	0.6	0.69	0.69	0.65
MHSH00130B004	0.61	0.59	0.68	0.68	0.64
MHSH0201B005	0.58	0.57	0.66	0.66	0.62
MHSH0397B006	0.6	0.57	0.65	0.65	0.62
MHSH0150B007	0.6	0.57	0.65	0.65	0.62
MHSH0192B008	0.61	0.59	0.68	0.68	0.64
MHDR0018B009	0.59	0.58	0.67	0.67	0.63
MHDR0039B010	0.57	0.55	0.64	0.64	0.6
MHSH0192B011	0.6	0.58	0.67	0.67	0.63
MHSH0192B012	0.64	0.62	0.71	0.71	0.67
MHSH0195B013	0.6	0.57	0.65	0.65	0.62
MHDR0053B014	0.62	0.6	0.69	0.69	0.65
MHDR0037B015	0.6	0.58	0.67	0.67	0.63
MHSH0166B016	0.66	0.62	0.7	0.7	0.67

The findings indicate that bridges with moderate structural distress can still exhibit high risk levels when located in flood-prone zones and assigned high functional importance. This observation validates the integrated Risk and Vulnerability Assessment (RVA) framework, which captures the combined influence of hazard exposure, structural vulnerability, and consequence severity. From a policy perspective, the results align closely with existing challenges identified by the Public Works Department (PWD), particularly the need to elevate approach roads, enhance scour protection measures, and prioritize resilience retrofitting for bridges in flood-prone corridors. The integration of hazard quantification, functional criticality, and economic feasibility within the RVA framework provides a robust basis for prioritizing interventions and improving long-term infrastructure resilience in hazard-prone districts such as Kolhapur.

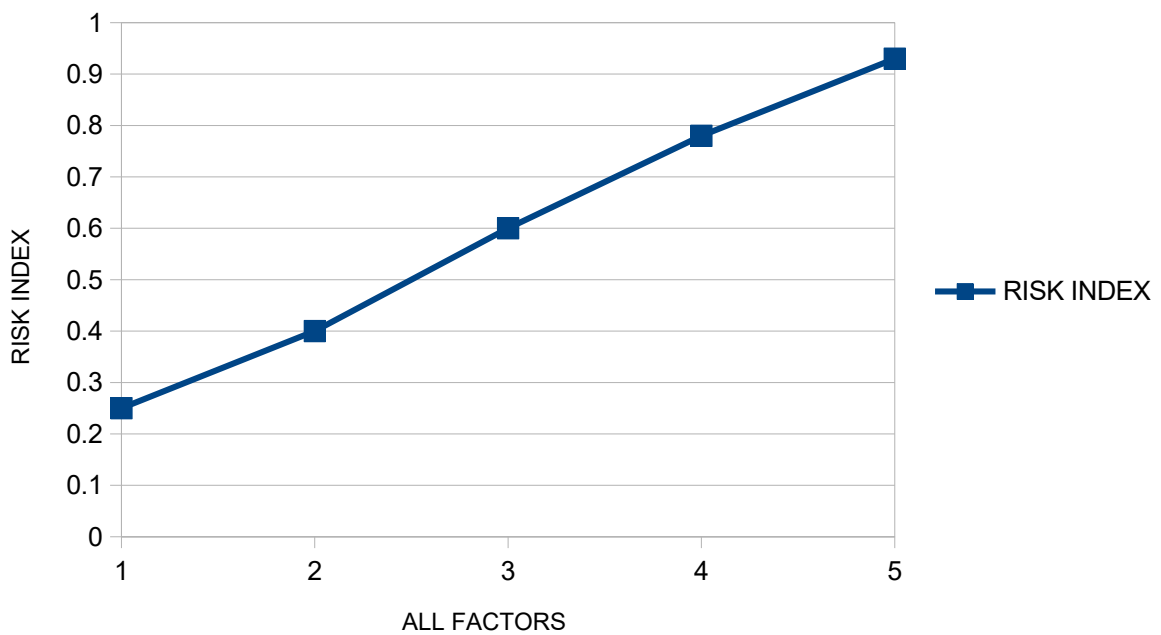
The analysis also highlights the significance of compound hazard interactions. Indirect impacts of cyclonic systems often intensify monsoon rainfall, thereby increasing both flood magnitude and the likelihood of landslides in western talukas. These cascading effects

amplify overall risk, as bridges may be subjected to multiple stressors simultaneously, such as hydraulic loading, slope instability, and traffic disruption. While seismic hazard in Kolhapur is moderate, the presence of older bridges lacking modern seismic detailing increases vulnerability when combined with other hazards.

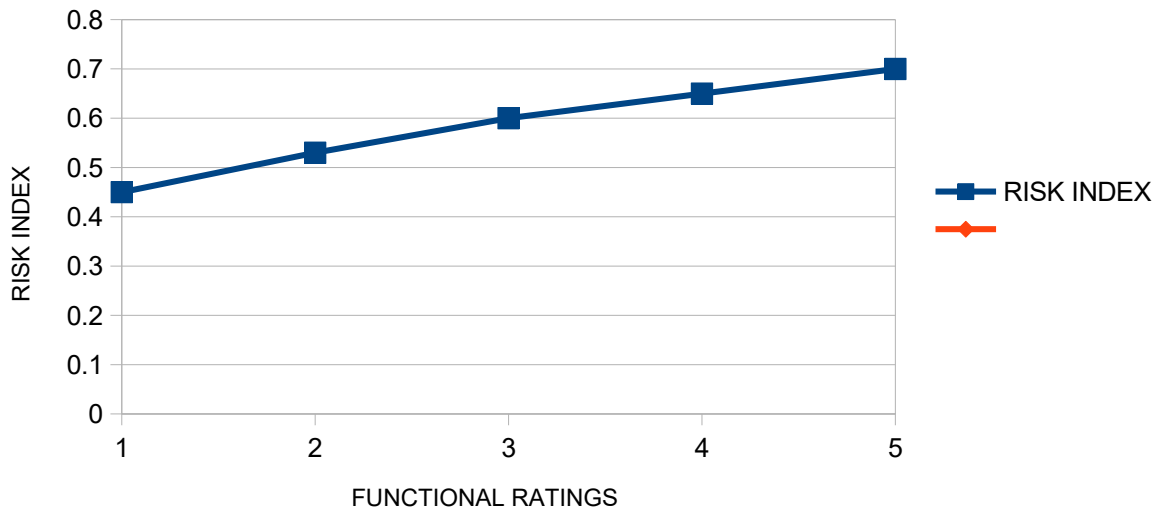
VARIATION OF RISK INDEX WITH STRUCTURAL RATINGS



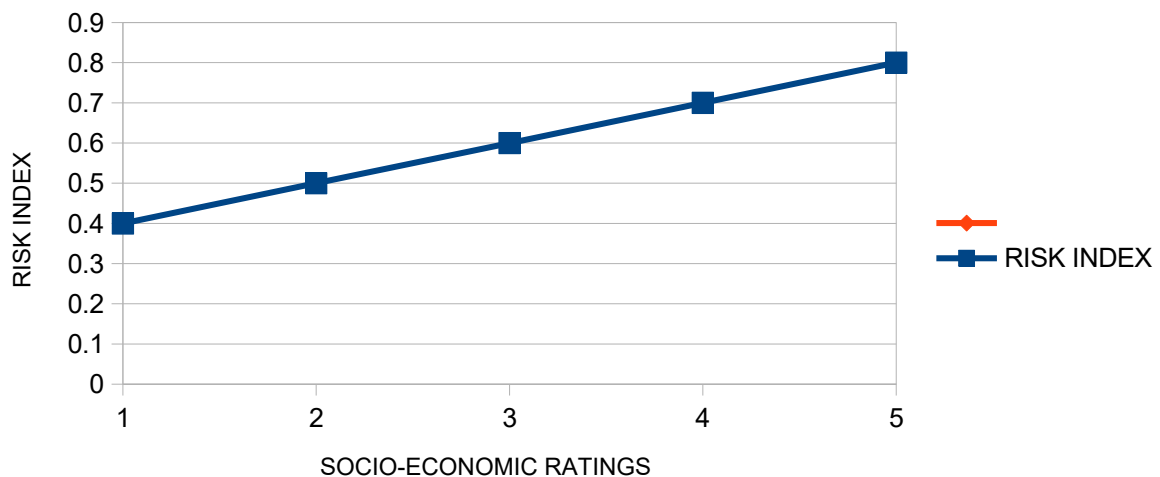
VARIATION OF RISK INDEX WITH ALL FACTORS



VARIATION OF RISK INDEX WITH INCREASING FUNCTIONAL RATINGS



VARIATION OF RISK INDEX WITH INCREASING SOCIO-ECONOMIC RATINGS



Description of the variations

1) Variation of Risk Index with Structural Ratings

The Risk Index shows only minor variation across different structural ratings, remaining within a narrow range. A gradual increase is observed as structural ratings increase in the value of risk index at higher values. This confirms that structural condition alone does not strongly govern overall risk in the present assessment. Other contributing parameters therefore play an important role in shaping final risk levels.

2) Variation of Risk Index with All Factors

When all contributing factors are considered together, the Risk Index increases sharply and consistently. The progressive rise reflects the

cumulative effect of structural, functional, and socio-economic components. This trend highlights the sensitivity of the overall risk framework to multi-parameter integration. It confirms the importance of holistic evaluation in bridge prioritization.

3) Variation of Risk Index with Functional Ratings

The Risk Index increases steadily with higher functional ratings, indicating a positive correlation between service importance and risk. Bridges carrying greater traffic volumes or serving key routes tend to exhibit higher risk values. This pattern underscores the role of operational significance in determining vulnerability. Functional performance therefore emerges as a major driver in risk-based ranking.

4) Variation of Risk Index with Socio-Economic Ratings

A clear upward trend is observed between socio-economic ratings and the Risk Index. Bridges that support critical economic activities and community connectivity show progressively higher risk values. This reflects the amplified consequences of failure in socially and economically important corridors. Socio-economic relevance is thus a **decisive factor** in risk prioritization and investment planning.

Conventional bridge inspections largely focus on visible structural distress and do not adequately account for hazard exposure, functional importance, or future climate-related risks. Dynamism in frequency and severity of natural hazard is also accounted within the analysis. In many cases, inspection data are not systematically integrated with historical hazard records, leading to reactive rather than proactive maintenance decisions. Overall, the study confirms that transitioning from conventional condition-based inspection to risk-based bridge management is essential for informed decision-making and climate adaptation planning.

Evaluation of risk index for all bridges offers an insight into the need for immediate enhancement of resilience. Enhancement of resilience is a fund intensive process. MCDM within GARM provides a solution by comparing the cost involved with the total [Direct and Indirect] benefits. For each of the bridge, the benefits exceeds the total cost involved in rehabilitation and resilience enhancement.

All bridges have a risk index above 0.6 which is considered high risk and calls for immediate attention. Action recommended is to initiate and plan mitigation measures and to implement rehabilitation and resilience enhancement. For every bridge, the ratio of Benefit vs Cost is positive indicating that during the life of the bridge, the cost incurred for enhancing resilience will be recovered fully.

The findings emphasis the need to adopt a risk-based bridge management approach that integrates hazard likelihood, structural vulnerability, and consequence assessment. Such an approach

enables prioritization of interventions, efficient resource allocation, and improved resilience planning. Furthermore, the increasing frequency and intensity of extreme rainfall events associated with climate change underline the importance of incorporating climate adaptation considerations into bridge design, inspection, and maintenance strategies.

6. CONCLUSION AND STRATEGIC RECOMMENDATIONS

The study concludes that integrated risk and vulnerability assessment provides a robust framework for improving bridge management in Kolhapur District. Flooding is identified as the most critical hazard, followed by landslides in western regions and moderate seismic risk. Several bridges are classified as high risk and require priority attention. Key recommendations include strengthening flood and scour protection measures, incorporating seismic considerations in retrofitting works, improving maintenance and drainage practices, and enhancing monitoring systems for critical bridges. At the policy level, embedding RVA outcomes into bridge management systems and climate adaptation planning is essential to ensure long-term infrastructure resilience.

A comprehensive report detailing the findings was submitted to the District Disaster Management Authority. The key outcomes of the pilot study are summarized below:

- A) Multi-hazard analysis identified flooding as the primary hazard and landslides as the secondary hazard affecting the bridge network;
- B) All assessed bridges were found to exhibit a very high risk index;
- C) The analysis underscored the need for a strategic shift from the prevailing reactive approach to a proactive framework focused on rehabilitation and resilience enhancement, enabling prioritized and risk-based bridge management;
- D) The investment required for rehabilitation and resilience enhancement was substantiated through a detailed cost–benefit analysis;
- E) Financial availability was observed to have a direct and significant influence on vulnerability levels; and
- F) The findings strongly support a transition toward risk-informed and resilience-oriented bridge management practices.

This study presents a comprehensive district specific risk and vulnerability assessment of bridge infrastructure in Kolhapur District under multiple natural hazards. By integrating historical hazard data, bridge inspection records, and semi-quantitative risk analysis techniques, the study provides a structured framework for evaluating bridge safety, performance, and resilience. The adopted methodology demonstrates how engineering condition data, when combined with

hazard characteristics and consequence analysis, can provide a more realistic representation of infrastructure risk than conventional assessment approaches.

The multi-hazard assessment for Kolhapur District identifies flooding as the primary threat to bridge infrastructure, followed by landslides and moderate seismic risk. Bridges are classified by risk level, enabling phased interventions and strategic resource allocation. The study emphasizes the limitations of condition-based inspections alone and advocates for a multi-hazard, risk-based framework integrating hazard history and consequence assessment for proactive management and climate adaptation. Recommendations include risk-based prioritization, enhanced protection measures, seismic retrofitting, and improved monitoring. Benefit-cost analysis confirms the economic justification for resilience investments. The study highlights the importance of location-specific data, AI-based analytical tools, and financial due diligence. Integrating risk assessments into bridge management and climate adaptation strategies is crucial for evidence-based decision-making and resource allocation. The study provides a scalable model for other districts, emphasizing the need for risk-informed approaches to achieve long-term infrastructure resilience and sustainable regional development. Integrating hazard history with routine inspections is key to accurately assessing risk. By explicitly accounting for benefit due to bridge serviceability and long-term resilience gains, the framework moves beyond risk identification to support evidence-based investment decisions. The inclusion of cost-benefit considerations ensures that recommended interventions are not only technically necessary but also economically viable, reinforcing the practical relevance of the study for policy makers and infrastructure agencies.

Routine inspections are essential for identifying visible deterioration and structural deficiencies, they do not adequately capture the influence of natural hazard frequency, intensity, spatial variability, and cascading consequences. By contrast, the multi hazard risk-based framework adopted in this study integrates inspection data with hazard history and consequence assessment, enabling a transition from reactive maintenance toward proactive and prioritized risk-based management. This shift is particularly crucial for climate adaptation planning in districts such as Kolhapur, where bridges are repeatedly exposed to natural hazards that are expected to intensify under changing climatic conditions.

The reliance on district-level datasets ensures that regional hazard characteristics, local construction practices, and network dependencies are accurately represented. The incorporation of AI-based analytical tools further strengthens the framework by accounting for the dynamism of hazard frequency and severity,

allowing the assessment to reflect evolving risk conditions rather than static historical averages.

At the policy and governance level, this study emphasizes the necessity of integrating risk and vulnerability assessments into existing bridge management systems and broader climate adaptation strategies.

A key outcome of the study is the demonstrated importance of integrating hazard history with routine bridge inspections. Inspection data alone are insufficient to capture true risk levels without considering hazard frequency, intensity, and potential consequences. The findings support the transition toward risk-informed and resilience-oriented bridge management practices.

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