The Maharashtra River Basin's Flood-Drought-Water Scarcity Nexus

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GRAPHICAL ABSTRACT

Abstract:

India's droughts and floods, which have affected 8 million hectares yearly since the 1950s, make future adaptation and mitigation plans necessary, as well as an awareness of potential changes. In order to address the growing issues of flood and drought events in urban settings, the study emphasizes the importance of comprehensive water management strategies that ensure both routine water needs and severe event readiness. This study article recommends including drought and flood considerations in building codes and urban planning regulations to boost urban water resilience. The paper provides workable solutions for developing water-sensitive urban design, rainwater collecting, greywater reuse programs, and decentralized water management systems

through a collection of case studies and strategy models. It also emphasizes the importance of teaching the population about the dangers of droughts and floods, water conservation methods, and emergency response procedures.

The recommendations place a lot of emphasis on the need for a variety of policies that encourage cooperation between stakeholders, including local and state governments, business owners, community leaders, and experts. The policy recommendations include requests for green infrastructure, building standards for flood-resistant homes, water conservation requirements, and climate-responsive legislation, among other subjects. By encouraging sustainable water use behaviors, these concepts aim to increase urban resilience and make cities better prepared to mitigate the consequences of drought and flooding. These recommendations can aid local and state governments in creating a culture of preparedness for catastrophes, protecting communities, and fostering urban water resilience. This case study looks at the intricate relationships between a specific Maharashtrian river's floods, droughts, and water scarcity.

Keywords:

Climate-responsive policies, Flood Draught Water Scarcity, urban water resilience, Risks, water conservation.

1) Introduction:

India experiences droughts and floods, characterized by low rainfall and dryness, impacting water availability, agriculture, and socio-economic activities. The frequency and intensity of these events have increased since the 1950s, affecting nearly 8 million hectares of land annually. India's drought and flood frequency has increased in recent decades, particularly in central humid regions and urban areas like Mumbai, Kolkata, and Chennai. Understanding future changes is crucial for developing effective adaptation and mitigation policies to address the adverse impacts on food and water security. (Mujumdar 2020).

These disasters have impacted the agricultural environment, water security, and socioeconomic stability. Regional variations in climate are not better recognized as global ones due to a few fundamental mechanisms and a dearth of local observational data(Flato 2013). Historical climate data shows a pattern of rising temperatures and altered precipitation levels across India, with studies by climatologists highlighting a significant increase in drought and flood events. Advanced modeling techniques highlight the need for proactive measures and the urgency of formulating adaptive strategies to mitigate the risk of extreme weather events. As we look towards the future, it is crucial to develop proactive measures to mitigate these risks.

The increasing frequency and severity of drought and flood events in urban areas need a deliberate focus on integrated water management approaches. This study explores the vital significance of developing and putting into practice strategies that strengthen urban resilience against extreme flood occurrences while simultaneously attending to normal water demands. Promoting the inclusion of drought and flood factors in construction standards and urban planning rules is the main goal of this research to improve urban water resilience in the process. The next sections will outline the importance of water-sensitive urban design, rainwater collecting, greywater reuse

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programs, and decentralized water management systems, along with practical solutions and case study.

1.1. Objectives of the study

The primary objective of this Research article is to thoroughly investigate and deal with the issues raised by India's rising frequency of floods and droughts, with an emphasis on metropolitan areas.

So the specific objectives for the research study are:

i. To analyze historical data and patterns to understand the dynamic nature of climate variability with a particular emphasis on the growing frequency and intensity of drought and flood occurrences in India
ii. To explore integrated water management strategies that strengthen urban resilience against extreme flood occurrences while concurrently addressing routine water demands.
iii. To investigate how to enhance urban water resilience by incorporating drought and flood factors into building standards and urban planning laws.
iv. To promote the incorporation of climate-responsive strategies that are able to manage the uncertainties associated with regular water requirements and catastrophic flood occurrences, as illustrated in Figure 1.
v. To emphasize the importance of decentralized water management systems, rainwater collecting, greywater reuse initiatives, and urban planning that considers water, and explores the interplay between drought, floods, and water scarcity to develop adaptive management approaches. The study also examines current water management, flood prevention, and drought preparedness policies in Maharashtra, identifying gaps and areas for collaboration.

To ensure routine water needs and sever flood event readiness it is important to analyse and design climate responsive policies is need of time. As shown in figure 1, climate responsive policies can be framed to handle uncertainties.

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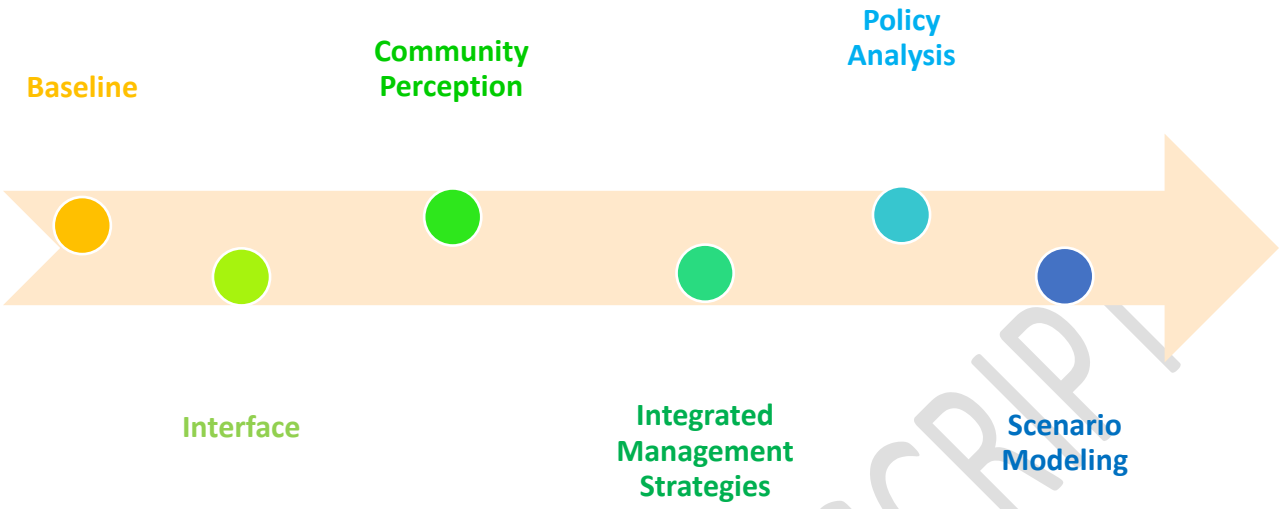

Figure 1: Climate Responsive Policies

Climate Responsive policies guidelines offered are as:

• **Baseline Assessment:** Analyze the selected river basin's hydrological and meteorological data thoroughly to discover previous instances of flooding and drought. Utilize the information at hand to calculate the amounts of precipitation, river discharge, groundwater levels, and reservoir capacity.

• **Interactions Analysis:** Look at how the occurrences of flood, drought, and water shortages interact with one another. Examine how floods may replenish reservoirs and groundwater, changing how much water is available when there is a drought. Alternatively, consider how soil compaction and increased flood risk might result from droughts.

• **Community Perception:** To learn how local communities, farmers, and water managers see floods, droughts, and water scarcity, conduct surveys and interviews with these groups of people. Insights about local coping mechanisms, folklore, and difficulties can be gained from this qualitative data.

• **Integrated Management Strategies:** Create integrated water management strategies in collaboration with stakeholders and local authorities. Examine the possibility of groundwater recharge systems, floodplain zoning, and water storage options to lessen the effects of both floods and droughts. Analyze the viability and efficiency of natural remedies, such as reforestation and wetland restoration.

• **Policy Analysis:** Look at the laws and rules in place for Maharashtra's water management, flood prevention, and drought preparedness. To address the linked concerns, identify the gaps and potential for policy integration and cooperation.

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• **Scenario Modeling:** To simulate the effects of various flood and drought scenarios under changing climatic conditions, use sophisticated hydrological modeling and scenario analysis. Analyze how well the suggested solutions do at boosting resilience and lowering vulnerability.

1.2.Scope of the Study

The research's scope is defined by a thorough examination of the opportunities and problems brought about by India's rising frequency of floods and droughts, with a focus on how these disasters affect metropolitan areas. The research covers a wide range of topics and includes the following crucial areas:

1.2.1. Geographical Scope:

The study is focused on specific regions of India and seeks to examine trends, past information, and vulnerability classifications at the district level, with an emphasis on the effects of climate change. The state of Maharashtra is the main focus of the investigation, and certain areas are examined. Large cities are highlighted, with Mumbai being used as a case study because of its noteworthy vulnerability to floods and droughts. The specified region exhibits a notable sensitivity to climatic events, as underscored by the ranking of large deficient rainfall in Maharashtra in proportion to its population, distinguishing it from other states in India.

1.2.2. Temporal Scope:

This research conducts a thorough analysis of climate data from the 1970s to the present, covering the last five decades. It explores historical patterns and trends of drought and flood incidents. Data analyzed and compiled totally based on secondary data in form of government reports, historical news analysis and existing articles. In addition, the study broadens its scope to include future estimates in an effort to predict possible modifications to these weather phenomena.

1.2.3. Analytical Scope:

The research focuses on strategies and policies to improve urban water resilience against extreme floods and routine water demands. It examines water-sensitive urban design, rainwater collection, greywater reuse programs, and decentralized water management systems. The study also analyzes existing policies and regulations in Maharashtra, identifying gaps and potential areas for policy integration. The research collaborates with stakeholders, including local and state governments, business owners, community leaders, and experts, to understand their perspectives and develop integrated water management strategies by using existing data in form of literature and published reports. Sophisticated hydrological modeling and scenario analysis are suggested to simulate flood and drought scenarios under changing conditions. The research also explores educational

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initiatives to raise awareness about droughts and floods, promote water conservation methods, and enhance emergency response procedures.

2) Literature Review:

The Study (Kholod 2021, Jain SK 2023) discusses the unsustainable resource utilization in water-energy-food-ecosystem (WEFE) sectors in India, recommending a WEFE nexus-based approach and calls for future research to address these challenges. India and South Asian nations face challenges in supplying food, water, and energy to a growing population, hindering Sustainable Development Goals achievement due to inadequate sectoral coordination and policy incentives. (Rakitskaya, K., 2021, Golam R. 2016). Over the last two decades, flood and drought research has progressed beyond hydrology to interdisciplinary techniques (Fashi S. 2021, Savelli E. 2022, Wilby R. L. 2019). Climate change vulnerabilities are addressed through novel study designs aimed at resource conservation and long-term use (Katyaini 2021). Kartuz(2022) The systematization of impediments in the FWE nexus PSIR framework increases understanding by stressing nexus-thinking in complex real-world issues, according to research. To understand the inter-sectoral connections and implications of water resources, India need a comprehensive resource inventory. There is a need for reliable data on hydro-climate factors, infrastructure, aquifer systems, land use, energy production, and water consumption patterns. It is important to compile current datasets at better geographical and temporal resolutions (Madhusoodhanan CG-2016, Hasan Volkan O. 2020). The article (Philip J. W.-2020) highlights the need of implementing a multi-risk, holistic approach to water-related disaster risk management, such as exploring flood and drought interactions, reducing climate change implications, and integrating DRR, climate change adaptation, and SDGs. Risk reduction plans often focus on one extreme of the hydrological cycle, neglecting links across spatial scales and tradeoffs, requiring a comprehensive approach. Natural catastrophe impacts were examined in regions and states, demonstrating differences in distribution and impact Amarasinghe U. (2020). Agriculture and other businesses must adapt, with future research focusing on spatial resolution (Kong 2022). The research Irbik E. (2022) explores the link between water, migration, and gender, concluding that current solutions to water sustainability and resource inefficiency are insufficient. It argues for a broader approach to equitable, fair, and sustainable development, as well as tackling gender imbalances and achieving the SDGs. Sustainable water management, human well-being, ecosystem services, flood risk mitigation, and biodiversity all depend on urban green spaces, which need for a knowledge of hydrological, environmental, socioeconomic, and managerial circumstances(Ferreira et al 2021, Vollmer, D. et al 2022). Mumbai's flood of 2005 exposed its vulnerability to heavy precipitation and climate change, necessitating integrated adaptation measures like drainage system upgrades, insurance, spatial planning, and public risk awareness. (Gupta K. 2007, Hallegatte, S. et al. 2010). The study of Chetan Kumar S.(2021) found that the frequency and intensity of drought and floods are increasing due to climate change, although the total number of flood and drought events is not rising at the same time; 51.97% of grid points indicate rising monthly Standardized Weighted Average of Precipitation values. Extreme rainfall is predicted to intensify in central and western Indian River basins, with greater increases after 2040s. The frequency of extremes will dominate

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the Indus and upper Ganga basins, making these areas vulnerable. Long-term adaptation strategies are needed to reduce hydroclimate vulnerability (Chaubey, P. K and Mall R. K. 2023, Krishnan R. et al 2020).

3) Research Methodology

This study examines Maharashtra's urban resilience, water management, and climatic variability using a multifaceted research technique. It gathers historical climatic data, categorizes susceptibility, and aggregates socioeconomic and demographic information. The study evaluates the efficacy of water management and examines case study Mumbai's particular vulnerabilities. Statistical analysis is used to identify patterns and trends in quantitative data (secondary data), while thematic analysis extracts key themes related to urban water resilience in Mumbai. The synthesis of both quantitative and qualitative findings is crucial for drawing meaningful conclusions. The goal of the research effort is to offer evidence-based suggestions for improving urban water resilience and lessening the effects of floods and drought.

4) Research Case and Data Analysis

The research entails an in-depth examination and adoption analysis of urban water resilience, focusing on a case study of Mumbai City. Further extends the specific areas of study which include integrated urban planning, community engagement, flood early warning systems, demonstration projects, and public awareness campaigns. These approaches are scrutinized in the following manner:

4.1. Case Study: Urban Water Resilience and Adaptation in Mumbai, Maharashtra

The purpose of this case study is to evaluate Mumbai, Maharashtra's urban context's resistance to floods, droughts, and water scarcity. The study will look at ways to boost adaptability and improve urban water management.

Case Approach:

The urban infrastructure and communities of Mumbai's urban areas for susceptibility to floods, droughts, and water scarcity Analysis. This focuses to analyze the possible effects on public health, transportation, and key services.

Maharashtra and India have seen a marked rise in drought and high flood occurrences over the past 50 years, suggesting a changing climate and greater susceptibility to weather extremes. Maharashtra has seen 102 drought occurrences in the past 20 years, with 79 of those happening between 2010 and 2019(IANS 2021, Chatterjee B. 2020). 310 severe weather occurrences occurred after 2005, underscoring the complexity of climate-related issues as shown in table no.1. These patterns demonstrate Maharashtra's and India's susceptibility to severe droughts and floods, which can have an adverse effect on infrastructure, agriculture, water supplies, and social cohesion.

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These trends are significantly influenced by climate change and unpredictability, and reducing their effects requires the implementation of adaptation plans, environmentally friendly water management techniques, and robust infrastructure.

Table 1: Past 50 Years Data

Time Frame	Parameter	Maharashtra	India
1970-2019 (50 Years)	Drought Events	Seven-fold increase	250 events
1970-2019 (50 Years)	Extreme Flood Events	Six-fold increase	250 events
2000-2019 (Last Two Decades)	Drought Events	102 events (79 in 2010-2019)	05 major events
After 2005	Extreme Weather Events (Droughts, Floods, Cyclones, Compounding Events)	30+ events	310 events

(Source: Compiled by Researcher based on Secondary Data Source IANS 2021, Chatterjee B. 2020, PWC report)

2002 and 2015 were the unluckiest years in the previous 20 years due to extensive droughts that affected 65 crore and 43 crore people worldwide, respectively, with 30 crore people being affected in India alone (Sharma S. 2021). India's droughts have lessened the severity of fatalities, but they also raise questions about agriculture and rural livelihoods, especially in areas like Ahmednagar and Aurangabad (CEEW 2020). The Maharashtra government implemented programs like the Agricultural Debt Waiver and Debt Relief Scheme in 2008 and the Chhatrapati Shivaji Maharaj Shetkari Sanman Yojana in 2017, aimed at addressing agricultural issues like drought. In 2017, 89 lakh farmers received a ₹35,000 billion agricultural loan forgiveness, and in 2022, the administration provided INR 1 lakh to farmer households (PWC report, 2023).

Table 2: District-wise Vulnerability Classification and Climate Impacts in Maharashtra

Sr. No.	**Number of Districts affected**	**% of Total Districts**	**Impact**	**Cropped Area**
1	01	2.78%	Most Vulnerable	10%
2	11	30.56%	Highly Vulnerable	30%
3	14	38.89%	Moderately Vulnerable	37%
4	09	24.32%	Less Vulnerable	23%
Total	**37**			100%

(Source: Compiled by Researcher based on Secondary Data Source IANS 2021, Chatterjee B. 2020)

Due to its distinct geographical and socio-economic features, Mumbai, one of the largest and most populous cities in India, is particularly vulnerable to hydrological extremes including floods, droughts, and water scarcity. This research looks at how vulnerable Mumbai's urban infrastructure and neighborhoods are to these problems and assesses how they can affect vital services, transportation, and public health.

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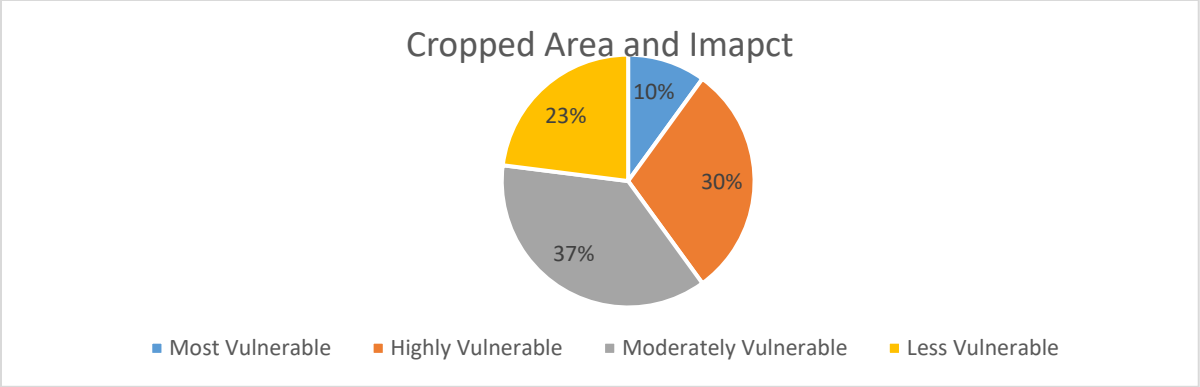

Figure 2: Climate Impacts in Maharashtra on Cropped area

Three categories as depicted in table no.2, represent the distribution of vulnerability in Maharashtra: Most Vulnerable (1.78%), Highly Vulnerable (11.56%), Moderately Vulnerable (38.89%), and Less Vulnerable (25.00%). With 2.78% of the total cultivated land, the most vulnerable district is probably going to experience serious climate-related difficulties. Ten percent of Maharashtra's total agricultural area is impacted by this district. At thirty percent of the total cropped area, the most susceptible district, which consists of eleven districts, has a major effect on cropped areas. At 37% of the total cropped area, the 14 districts that make up the moderately susceptible district have a significant influence on cultivated areas as depicted in figure no.2. With 11 districts, or 23% of the total cultivated area, the less susceptible district nonetheless has a significant influence on cropped areas. This emphasizes the necessity of focused approaches in planning for agriculture and disaster relief. The research sheds light on Maharashtra's vulnerability landscape, assisting stakeholders and policymakers in comprehending the distribution and possible effects on other sectors, including agriculture.

Table 3: Districts and Climate Extent patterns

Sr. No.	**District**	**Extent**	**No. of Districts**
1	Nadurbar	Most Vulnerable	1
2	Buldhana, Beed, Jalna, Aurangabad, Hingoli, Parbhani, Nanded, Akola, Amaravati, Washim	Highly Vulnerable	10
3	Dhule, Jalgaon, Ratnagiri, Sindhudurg, Sangli, Solapur, Osmanabad, Latur, Yavatmal, Wardha, Chandrapur, Bhandara, Gondia and Gadchiroli	Moderately Vulnerable	14
4	Ahmadnagar, Kolhapur, Nashik Nagpur, Palghar, Pune, Raigad, Satara, Thane	Least Vulnerable	9

(Source: Compiled by Researcher based on Secondary Data Source IANS 2021, Chatterjee B. 2020)

The statistics of table no.3 reflects that, Nardurbar is the district with the highest level of vulnerability, followed by districts with extremely high level of vulnerability such as Beed, Jalna, Aurangabad, Hingoli, Parbhani, Nanded, Akola, Amaravati, and Washim. Districts like Dhule, Jalgaon, Ratnagiri, Sindhudurg, Sangli, Solapur, Osmanabad, Latur, Yavatmal, Wardha,

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Chandrapur, Bhandara, Gondia, and Gadchiroli are considered to be somewhat vulnerable. Ahmadnagar, Kolhapur, Nashik, Nagpur, Palghar, Pune, Raigad, Satara, and Thane are the districts that are least vulnerable. By implementing strategies specific to each category, policymakers and stakeholders may increase resilience to climate-related concerns with the use of this knowledge.

4.1.1 **Vulnerability to Floods:**

Due to its low-lying coastal setting, fast urbanization, inadequate rubbish management, overburdened infrastructure, and probable interruptions to key services, Mumbai is prone to floods (Figure No.3).

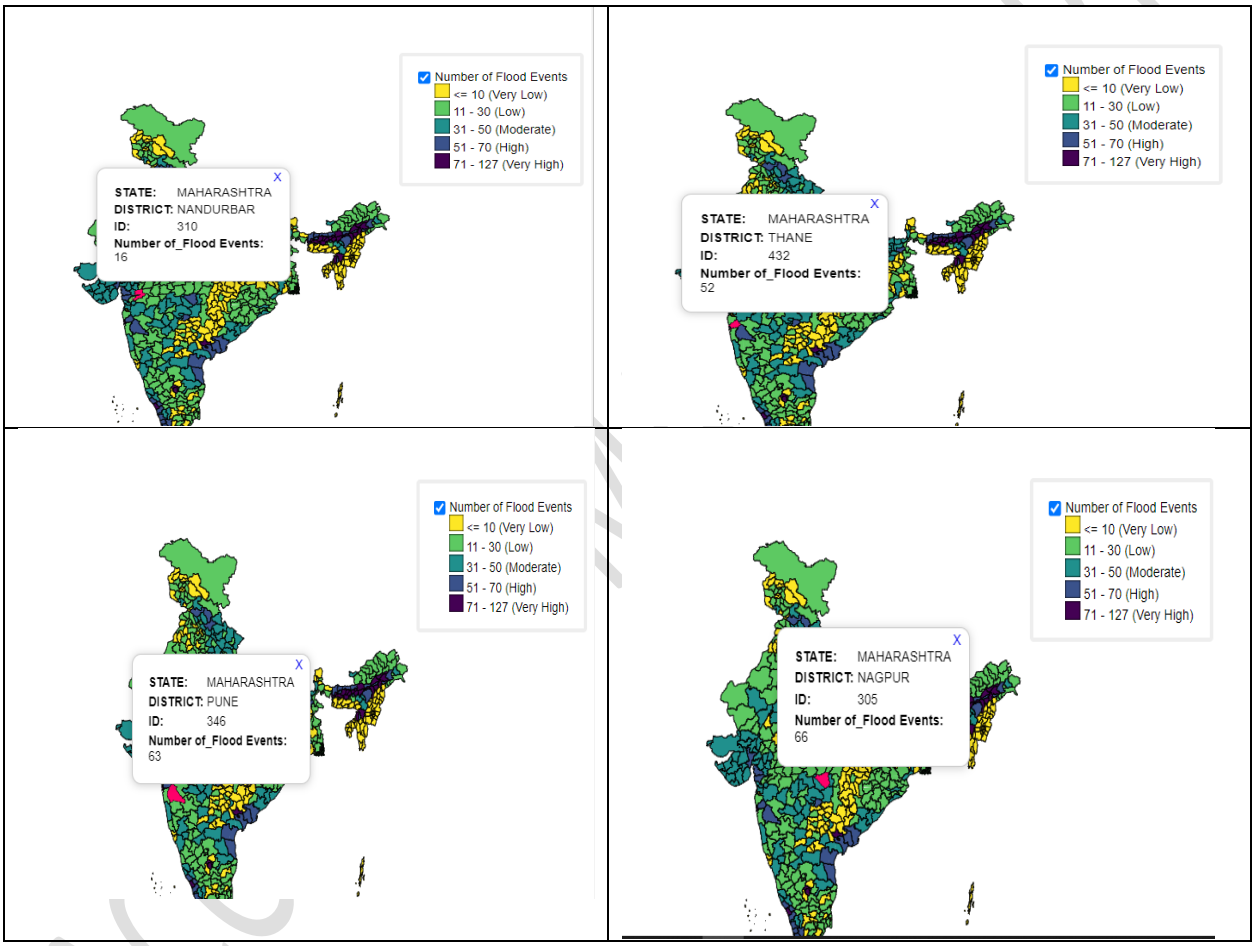

Figure 3: Flood Events Maharashtra (source imdpune)

Floodwaters have the potential to ruin electrical substations, create power outages, and impede public transportation. Overcrowded roadways and railroads can also halt public transportation, limiting mobility and access to critical services. Floods contaminated with bacteria can spread and damage human health. Addressing these concerns is critical to guaranteeing Mumbai's coastal environment's resiliency.

4.1.2 Vulnerability to Droughts:

Mumbai is prone to water supply outages, poor distribution, and excessive groundwater exploitation due to its reliance on faraway water suppliers. Droughts can reduce water supply, affecting everyday living as well as economic productivity. They are also dangerous to one's health since inadequate sanitation and hygiene can lead to waterborne infections. Furthermore, access to safe drinking water may become increasingly challenging for poor communities, exacerbating existing imbalances. Addressing these concerns is critical to ensuring long-term water supply and lowering the danger of waterborne infections and public health hazards.

Regional differences in Mumbai, Thane, and Palghar's susceptibility to drought occurrences are shown in the figure no. 4 by the Drought Vulnerability Index (DVI). Mumbai's DVI of moderate indicates a moderate risk of the effects of the drought, such as water scarcity. Thane's DVI is greater, which suggests that it is more vulnerable to environmental issues like water supply and climatic trends. Palghar has a higher DVI as well, suggesting comparable difficulties. The disparities in DVIs draw attention to the necessity of effective water management plans, steps to increase climate resilience, and adaptation plans. It is essential to include the community in order to recognize and mitigate vulnerabilities. Local communities and politicians may create focused policies for resilience and adaptation to changing climatic circumstances by using the DVI values as a guide.

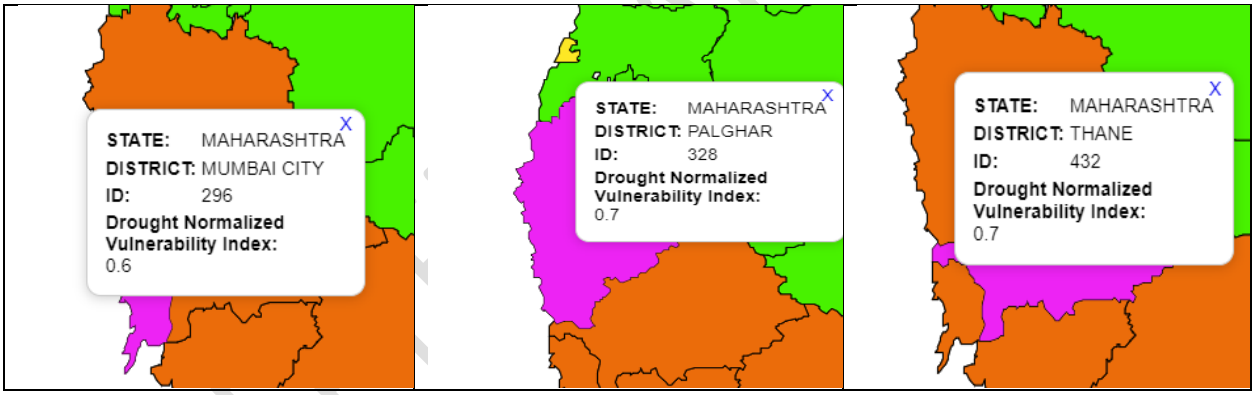

Figure 4: Droughts in Mumbai Region (Source: impdpune)

4.1.3 Vulnerability to Water Scarcity:

Mumbai's population is rapidly increasing, placing strain on infrastructure and water supplies. Water scarcity, disruption of production and growth, and social stress can result from ineffective water management, climatic unpredictability, and economic implications. Competition for finite water sources may lead to conflicts between residents, businesses, and industries. Water resource and ecosystem depletion can affect biodiversity and ecosystem services, threatening long-term sustainability.

The table no.4 represents the large deficient rainfall in Maharashtra State following top two Madhya Pradesh and Uttar Pradesh states.

Table 4: Large Deficient Rainfall Trends Top 5 Rank

Rank No.	States	Large Deficient Rainfall
1	Madhya Pradesh	39
2	Uttar Pradesh	31
3	Maharashtra	27
4	Tamil Nadu	19
5	Rajasthan	18

(Source: Compiled by Researcher based on Secondary Data Source IMD)

The trendline graph in the figure no.5 shows the distribution of Large Deficient Rainfall across India's top 5 states, providing insights into water shortages. The graph highlights the importance of addressing water shortage issues in these states. This information can be used by policymakers, environmentalists, and local governments to create targeted plans for agricultural planning, water conservation, and sustainable development. Implementing preemptive measures can provide a more resilient and water-secure future for these regions by understanding the patterns in Large Deficient Rainfall.

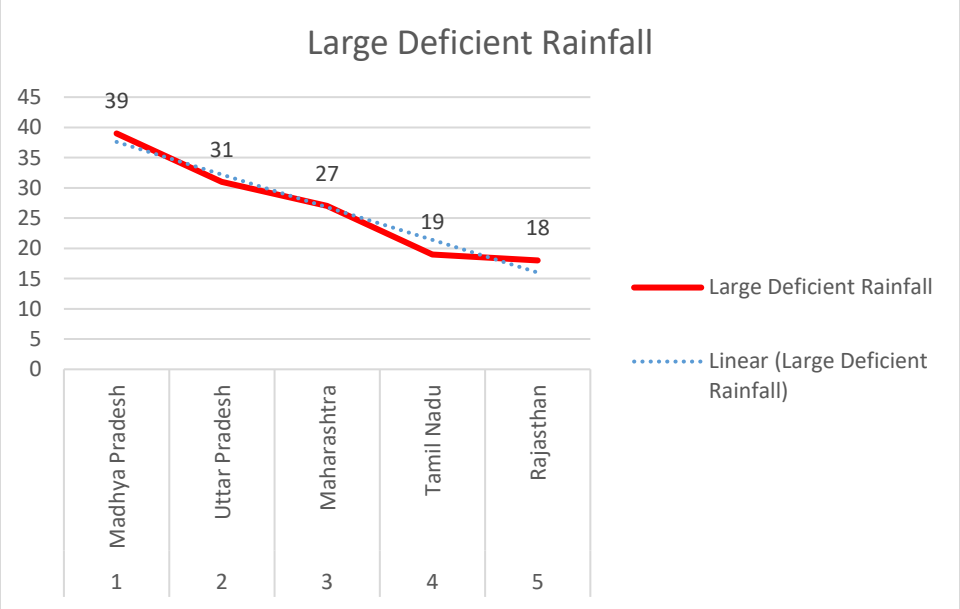

Figure 5: Large Deficient Rainfall Trends Top 5 State's Rank

Mumbai's susceptibility to floods, droughts, and water scarcity is influenced by geographical, urbanizational, and infrastructural variables. The potential consequences for key services, transportation, and public health underline the importance of rigorous planning and adaptable solutions. A holistic strategy involving urban design, sustainable water management, climate-resilient infrastructure, and community engagement is required to address these vulnerabilities and ensure the city's resilience in the face of hydrological difficulties.

4.2. **Integrated Urban Planning:** Working with urban planners, engineers, and decision-makers, create integrated urban planning strategies for managing the dangers of floods and drought

in Mumbai. These strategies include flood-resistant infrastructure, water-sensitive urban design, green infrastructure, and watershed-based management. Watershed-based management comprises recognizing natural drainage pathways, wetlands, and floodplains with the purpose of directing development while protecting flood-absorbing zones. Surface runoff is decreased during periods of high rainfall, and water infiltration is increased through green infrastructure and nature-based solutions. Rainfall collecting devices, artificial recharge structures, and decentralized wastewater treatment systems are all part of water-sensitive urban design (WSUD).

Flood resistance is integrated into critical infrastructure such as hospitals, emergency rooms, and power substations. This means elevating critical infrastructure above flood levels and installing backup systems to assure ongoing operation during flood catastrophes. Sustainable storm-water management techniques include detention basins, retention ponds, and swales to manage excess precipitation and reduce flash floods and erosion.

Smart land use planning, which fosters mixed land use planning, results in shorter travel times and the development of compact, walkable communities. Community participation and education are critical components of the planning process because they educate residents about the hazards of floods and droughts and encourage water-wise behavior. Integrated infrastructure networks reduce resource consumption and boost resilience by utilizing dual-use infrastructure that serves many functions. Real-time data and communication networks are employed in flood and drought early warning systems and disaster preparedness.

Policy integration and capacity building involve working with policymakers to include flood and drought resilience considerations into urban planning laws and construction standards. This technique promotes sustainability, raises living standards, and reduces the risks associated with hydrological extremes. By using these integrated urban planning strategies, Mumbai can create a resilient and adaptable metropolitan environment that successfully addresses the difficulties caused by floods, droughts, and water scarcity.

4.3. **Community Engagement:** Attend seminars and focus groups with community leaders, local companies, and individuals. Inquire about their perceptions of the dangers of drought and flooding, as well as potential coping techniques. To successfully schedule workshops and focus group talks with neighborhood residents, businesses, and community leaders to learn about their perspectives on flood and drought threats and appropriate adaptation solutions, an organized technique is required. The technique is explained in the models in figure 6.

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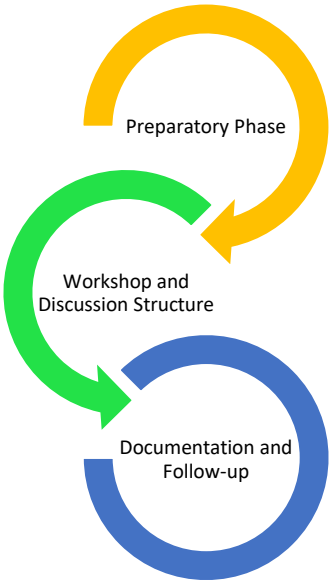

Figure 6: Organized technique Models for Community Engagement

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Model 1: Preparatory Phase

Stakeholder mapping: Identify important parties, such as members of the local community, companies in the area, NGOs, and authorities. Sort them into groups depending on the roles they play and the conversation contributions they might make.

To tell stakeholders about the workshops and focus group discussions, create welcoming communication tools (such as emails, posters, and social media posts). Stress the significance of their involvement in creating a resilient community.

Model 2: Workshop and Discussion Structure

- **Introductory Session:**

Introduce yourself and the workshop's context while highlighting the value of local knowledge in the management of flood and drought risk.

Engage participants in icebreaker activities to create a welcoming and honest atmosphere for sharing.

- **Perception Mapping:**

Perception mapping helps identify hazards in drought and flooding, using maps and visual tools to identify danger zones. Encourage participants to share their experiences, worries, and observations during brainstorming sessions.

- **Adaptation Strategies:**

Expert Advice: Request presentations from pertinent experts on potential adaption tactics and best practices. Give participants background information and illustrations of effective strategies from other areas.

Discussions in small groups: Participants should be divided into smaller groups, with each group given a particular priority area (such as infrastructure, community involvement, or green solutions). Encourage conversations about possible repositioning tactics in these areas.

- **Interactive Activities**

Engage participants in interactive activities to create future scenarios considering flood and drought severity, and encourage suggestions for adaptive measures. Arrange role-playing activities for community members, decision-makers, or first responders to simulate real-life situations.

Model 3: Documentation and Follow-up

- Recording and taking notes for workshops and focus groups should be delegated, and whiteboards and flip charts can be used to record ideas, criticism, and adaption tactics.
- Feedback and Validation: • Review sessions validate and clarify recorded insights, assuring correctness and enhancing participants' feelings of being heard and valued.
- Synthesis and Reporting: • Gather and summarize findings, emphasizing recurring themes, creative concepts, and potential obstacles. Make thorough reports outlining debates, viewpoints, and adaption techniques and distribute them to participants and stakeholders.
- Action Planning: • Encourage stakeholder cooperation to rank and hone adaption plans in accordance with their viability, significance, and community requirements. To include these ideas into frameworks for urban planning, development, and disaster management, collaborate with local authorities and politicians.

The workshops and focus group discussions may successfully include stakeholders, obtain insightful information, and promote community ownership in managing flood and drought risks while generating contextually pertinent adaptation solutions by adhering to these models.

4.4. Flood Early Warning System:

A localized flood early warning system is crucial for flood preparation and reducing damage in Mumbai's flood-prone regions. It combines real-time data, weather forecasts, and river level monitoring to provide timely notifications and increase preparedness. The development and testing process involves locating flood-prone areas, deploying sensors, and creating a centralized data integration platform. Data analysis, modeling, setting triggers and thresholds, and designing an automated alert system are essential steps. The system can be distributed through various communication techniques, such as SMS, mobile apps, social media, and sirens. Testing and validation involve simulated testing, real-time testing, feedback, and capacity building. Simulated testing uses historical data and planned flood scenarios, while real-time testing in flood-prone areas

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allows for feedback and iterative adjustments to the system's parameters and alert message efficacy.

Public awareness and capacity building are coordinated through workshops, training sessions, and emergency response planning. It is also critical to collaborate with local emergency management groups to develop and test flood response techniques. To ensure the system's operation, it must be regularly monitored and maintained. The system's performance must be maintained on a regular basis through sensor calibration, weather forecasts, and early warning algorithms. Accuracy and efficacy must be continually enhanced by utilizing new technology and data analysis approaches. A localized flood early warning system may be efficiently created, tested, and deployed in Mumbai's flood-prone areas, enhancing community preparation, minimizing flood-related losses, and saving lives during extreme weather events.

4.5. **Rainwater harvesting and Reuse:** To encourage rainwater collecting and greywater reuse efforts in metropolitan areas, determine the viability of establishing decentralized water management systems to reduce water shortages during droughts as shown in figure no.7.

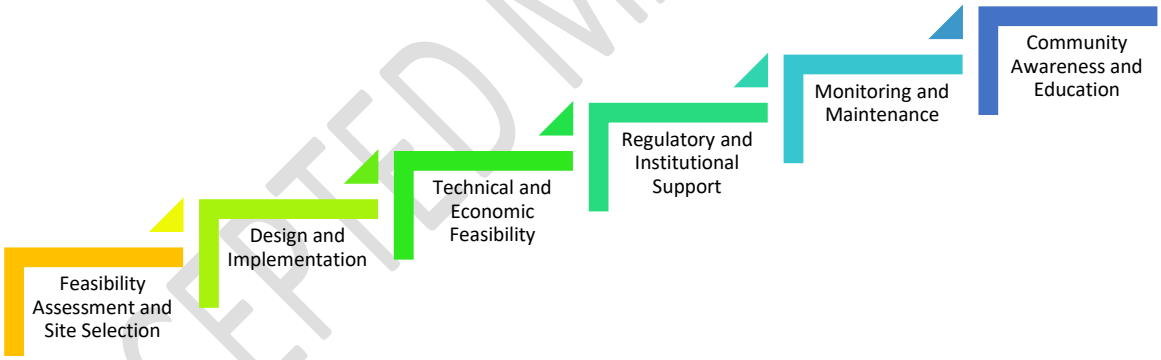

Figure 7: **Rainwater harvesting and Reuse Management**

Step 1: Feasibility Assessment and Site Selection

Collaborate with local government authorities and community leaders to identify viable locations in urban communities for rainfall harvesting (RWH) and greywater reuse systems.

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Site Evaluation: Make a thorough examination of the site to identify elements such as roof area, drainage patterns, soil composition, and water use. Consider the advantages and disadvantages of gathering rainfall and recycling greywater.

Step 2: Design and Implementation

Rainwater collecting systems, which include gutters, downspouts, and storage tanks, should take into account limited roof area and yearly precipitation. Calculate the storage capacity and household density, as well as the frequency of rainfall and water usage. Install filtration and disinfection devices to guarantee that rainwater is not drinkable. Greywater reuse include source separation, treatment techniques such as sedimentation, filtration, and disinfection for non-potable purposes such as irrigation. Organize seminars and awareness campaigns to educate residents about the benefits of decentralized water management and to encourage community participation. Finally, hold seminars and public awareness campaigns to educate communities about the advantages of decentralized water management and its contribution to water conservation.

Step 3: Technical and Economic Feasibility

Calculate water savings, reduced demand on centralized water supplies, and possible wastewater treatment cost reductions. An examination of the cost-benefit relationship: The following costs should be calculated: Calculate the costs of installing RWH and greywater reuse systems, including equipment, installation, and maintenance.

Step 4: Regulatory and Institutional Support

Government approvals for rainwater collecting and greywater reuse systems involve local collaboration and subsidies. Supporter incentives, such as subsidies or tax breaks, encourage the installation of these systems in households.

Step 5: Monitoring and Maintenance

Establish home training sessions for proper RWH and greywater system operation, maintenance, and cleaning. Perform routine inspections and create a maintenance plan to verify system effectiveness and functionality.

Step 6: Community Awareness and Education

Hold public workshops, seminars, and awareness campaigns to educate the public about the benefits of rainwater collection and greywater reuse.

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4.6. Demonstration projects

Make model installations: Demonstration projects should be built in a few metropolitan areas to demonstrate the efficiency and advantages of rainwater collection and greywater reuse systems.

By taking these actions, cities may help promote rainwater collecting and greywater recycling programs, therefore contributing in the sustainable management of water resources and reducing water shortages during dry spells. These initiatives not only increase water availability, but also encourage water conservation and environmental responsibility across the community.

4.7. Public Awareness Campaigns: To inform the public about the dangers of floods and droughts, water conservation practices, and emergency response procedures. To reach an urban population that is varied, use a variety of communication platforms as depicted in figure no.8.

Making Public Awareness Campaigns for Flood and Drought Resilience

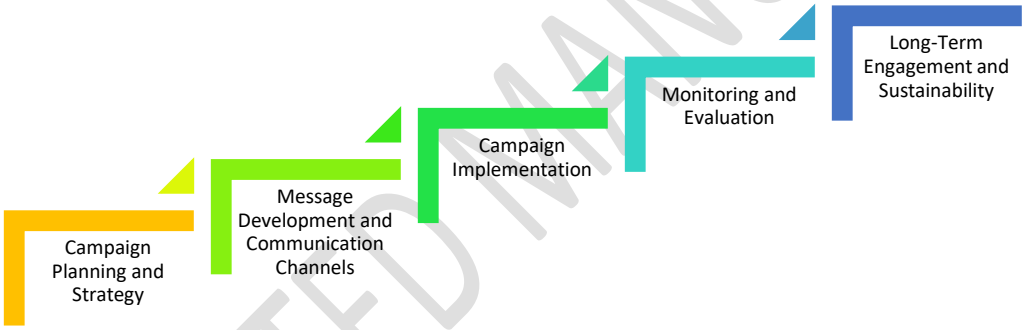

Figure 8: Public Awareness Campaigns for Flood and Drought Resilience

Step 1: Planning and strategy for the campaign

Stakeholder Engagement: Form a campaign committee by working with local government officials, community leaders, NGOs, and professionals. To meet the requirements of various population segments, make sure varied representation is present.

Needs Assessment: Assess the present knowledge, attitudes, and views of the populace on flood, drought, water conservation, and disaster response by conducting surveys and focus groups.

Step 2: Communication Channels and Message Development

Message Development

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Clear Communication: Create succinct, culturally sensitive messages that stress the significance of being prepared for floods and droughts, conserving water, and responding to emergencies.

Present realistic and constructive steps that locals can take to promote sustainability and resilience.

A Traditional Multi-strategy

Use conventional media such as television, radio, and newspapers to reach a large audience and transmit vital messages at the appropriate time. To promote awareness among tech-savvy city inhabitants, create interesting social media posts, videos, and infographics.

Community Events

To give interactive learning opportunities, plan seminars, town hall meetings, and community fairs.

Step 3: Campaign Implementation

To successfully propagate ideas, select well-known community ambassadors and local leaders. Educate ambassadors on campaign goals, themes, and communication strategies. Create powerful public service messages (PSAs) highlighting flood and drought threats, water-saving advice, and disaster response strategies. Distribute PSAs across a variety of media outlets, emphasizing on peak hours for maximum impact.

Participatory Workshops:

Holding educational seminars Develop programs that focus on drought and flood preparedness, water sustainability, and disaster response. Include individuals in practical activities and simulations to engage them.

Create user-friendly mobile applications and websites with interactive quizzes, instructional articles, and flood, drought, and water information.

Make sure the material is accessible and available in a range of languages and devices to appeal to a broad audience.

Step 4: Evaluation and Monitoring

To evaluate the effectiveness of the campaign, provide surveys and feedback forms to guests. Analyze social media interaction data and user interactions on the campaign website or app.

Step 5: Engagement throughout the long term and sustainability

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Continuous communication and a consistent campaign are required for behavior modification and knowledge promotion. Working with schools and educators to integrate flood, drought, and water conservation education ensures that the next generation is aware of and engaged in these issues.

Local Participation:

Community contests encourage participation and creativity in water-saving solutions, flood-resistant structures, and disaster response strategies. Flood dangers, water conservation methods, and emergency protocols are all taught to city dwellers through public awareness programs. By offering knowledge and skills, these projects strive to improve resilience and contribute to a more sustainable society.

1. **Policy Recommendations:** Policy recommendations for local and state governments to improve the resilience of urban water systems based on the findings are shown in figure no.9. Strongly support the inclusion of flood and drought factors in building and urban planning standards to be proactive.

Figure 9: policy recommendations for local and state governments

1. Integrated Water Management Framework:

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Create an integrated paradigm for urban water management that expressly takes drought and flood factors into account. This framework will direct decision-making and encourage comprehensive planning that takes into account both normal water needs and exceptional situations.

2. Comprehensive Risk Assessment:

Recommendation: Make thorough evaluations of the danger of flooding and drought a requirement for urban planning procedures. By identifying sensitive locations, informing development guidelines, and encouraging proactive efforts to reduce potential effects, these assessments will help.

3. Mandatory Green Infrastructure: It is advised to pass laws requiring green infrastructure, such as rain gardens, permeable pavements, and green roofs, to be incorporated into new construction. The use of green infrastructure improves storm-water management, lowers the risk of flooding, and helps recharge groundwater during dry spells.

4. Water-Sensitive Design Incentives: Provide rewards, exemptions from taxes, or accelerated permitting for construction projects that adhere to water-sensitive urban design principles. Financial incentives motivate builders to include elements like rainwater collection, greywater recycling, and flood-resistant construction.

5. Flood-Resilient Building Codes: It is advised that building regulations be changed to make it mandatory to build in a flood-resistant manner and to elevate vital infrastructure above projected flood levels. Making sure that structures are flood-resistant protects lives, limits property loss, and lowers post-flood recovery expenses.

6. Water Conservation Standards: Create laws requiring water conservation for industrial processes, building fixtures, and urban landscaping. Lowering water consumption helps ensure sustainability over the long run and eases shortages during droughts. Encourage dual water supply systems that divide potable and non-potable water for different needs.

7. Dual Water Supply Systems.

During droughts, using treated rainwater or graywater for non-potable purposes relieves pressure on the centralized water supply.

8. Public Awareness Programs: It is advised to allocate funds for ongoing public education initiatives on the dangers of floods and droughts, water conservation, and emergency preparedness. Citizens who are well-informed are more likely to support policy initiatives and adopt resilient practices.

9. Adaptive Land-Use Planning: Develop zoning ordinances that give low-risk areas priority for key infrastructure and facilities, avoiding flood-prone areas. Strategic land use planning increases long-term urban resilience and lowers vulnerability to flood and drought risks.

10. Climate-Responsive Policies: It is advised that policies take future changes in rainfall patterns and extreme weather occurrences into account by incorporating climate projections into urban planning. Adaptive strategies to the changing climate are essential for preserving resilience.

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11. Collaboration across Sectors:

Create departmental and public-private partnerships to ensure that efforts to implement water-resilient policies are coordinated. The articulation of varied interests and expertise is made easier by collaborative techniques.

Through the incorporation of flood and drought factors into building codes and urban planning rules, these policy ideas seek to increase urban water resilience. Local and state governments may build a more resilient and sustainable urban environment that is better prepared to handle issues related to water by implementing these measures.

These case study methodologies seek to offer useful insights into the particular difficulties and solutions associated with floods, droughts, and water scarcity in Maharashtra. The state may seek to create a more resilient and sustainable water future for its residents and ecosystems by tackling these interconnected concerns.

12. AI Solutions:

AI solutions for managing the Flood-Drought-Water Scarcity Nexus in Maharashtra's River Basin include integrating data sources, predicting floods and droughts, providing early warnings, assessing risks, optimizing water resources, supporting decision-making, engaging communities, improving policies, promoting collaboration, and learning and adapting continuously. Collaboration among specialists, data scientists, and communities is essential for effective deployment, as is regular validation and updating of AI models.

5. Results Analysis and Discussion:

The study examines Mumbai's vulnerability to floods, droughts, and water scarcity, focusing on its impact on public health, transportation, and key services. The study reveals a significant increase in drought and high flood occurrences in Maharashtra over the past 50 years, highlighting the need for adaptation plans and sustainable water management techniques. Mumbai faces water supply outages and poor distribution during droughts, with data from the Municipal Corporation of Greater Mumbai indicating such issues. Maharashtra has seen an increase in severe weather events since 2005, with large deficient rainfall trends highlighting water scarcity issues. Stakeholder interviews reveal challenges in current water management strategies, and district-wise vulnerability classifications show variations in susceptibility. The Drought Vulnerability Index (DVI) for Mumbai indicates a moderate risk, and integrated urban planning strategies are informed by statistical evidence. Thematic analysis of qualitative data reveals community perspectives on water resilience. District-wise vulnerability classifications reveal distinct patterns, with Nardurbar showing the highest vulnerability. Mumbai ranks third in Large Deficient Rainfall among India's top five states, highlighting the need for strategic water resource management. The study proposes integrated urban planning strategies, including flood-resistant infrastructure, water-sensitive urban design, green infrastructure, and watershed-based management. This holistic approach can enhance resilience and address challenges posed by floods, droughts, and water scarcity, fostering a sustainable and adaptive urban environment.

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6. Key Findings:

i. Trends in Climate Vulnerability: Over the past 50 years, Maharashtra and Mumbai have seen a marked rise in the frequency of both major floods and droughts. The data emphasize the necessity of taking preventative action as well as the changing environment and increased vulnerability to catastrophic weather occurrences.

ii. District-wise Vulnerability Variations: Different patterns are shown by the district-wise vulnerability classifications, highlighting the need for customized and nuanced approaches. Finding areas that are particularly vulnerable—like Nardurbar—provides important information for targeted interventions and flexible planning.

iii. Challenges Associated with Large Deficient Rainfall: Out of the top five states, Maharashtra has the third-highest Large Deficient Rainfall, which calls for focused measures for sustainable development, water conservation, and agricultural resilience. For local governments and politicians to create efficient strategies for managing water resources, these insights are essential.

iv. Integrated Urban Planning Strategies: Based on statistical data, integrated urban planning strategies are suggested, such as water-sensitive urban design and infrastructure that is resistant to flooding. With these tactics, Mumbai hopes to become more resilient and adaptable to water scarcity, droughts, and floods.

7. Future Scope of Research

Effective approaches and guidelines can address situation and vulnerability specific problems to handle climate issues related to flood, droughts and water scarcity.

i. Data-driven Policy Formulation: Stress the use of statistical insights in policy formulation to guarantee that data-driven methods will guide the creation of future municipal policies and development plans.

ii. Enhanced Climate Resilience: Create and carry out infrastructure improvements that are climate resilient while taking statistical susceptibility tendencies into account for each district. This entails making investments in environmentally friendly water management techniques, structures resistant to flooding, and natural remedies.

iii. Community Involvement: Promote community involvement and educational programs by using vulnerability data. This guarantees that locals are aware of the dangers associated with droughts, floods, and water scarcity, encouraging water-conscious behavior and resilience at the local level.

iv. Research and Monitoring to Come: Put in place a strong mechanism for keeping an eye on how vulnerability patterns and climate trends are changing. Sustained study endeavors will be important in order to modify tactics in reaction to changing weather patterns.

8. Conclusion:

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This study highlights the necessity of effective urban water management plans to deal with drought and flood situations. To improve urban water resilience, it suggests including drought and flood issues into building standards and urban planning rules. Water-sensitive urban design, rainwater collection projects, greywater reuse schemes, and decentralized water management systems are examples of workable alternatives. These tactics are essential for development and expansion that is sustainable because they protect regular water needs and build a strong foundation for withstanding major weather occurrences. The study offers as a guide for action, advising communities, urban planners, and legislators to work together to strengthen cities against unforeseen events.

So, the study starts with case approach which investigates Mumbai's metropolitan infrastructure and inhabitants' susceptibility to floods, droughts, and water scarcity. The study uses statistical data, maps, and graphs to highlight the significant impact of climate variability, floods, droughts, and water scarcity in Maharashtra. The hazards connected with these hydrological extremes are heightened by the city's distinctive geographical characteristics, fast development, and socioeconomic dynamics. Flood susceptibility is influenced by elements such as low-lying coastal areas and urbanization-induced drainage concerns, which have an impact on critical services, transportation, and public health. Drought vulnerability originates from reliance on water supplies, unequal distribution, and climate variability, all of which have an impact on everyday living, socioeconomic inequality, and environmental health.

The report makes policy suggestions to municipal and state governments in order to improve urban water resilience. Flood and drought concerns can be included into planning rules and construction codes to reduce hazards, stimulate sustainable practices, and assure inhabitants' well-being. Public awareness programs are critical for teaching populations about flood and drought concerns, as well as measures for water conservation and emergency reaction. Adopting integrated urban planning techniques that include green infrastructure, water-sensitive urban design, and flood-resilient infrastructure will help Mumbai build a more resilient future. In this process, engaging stakeholders, utilizing specialists, and empowering local communities are critical. A concerted effort to improve water resilience is critical for constructing a sustainable and flourishing city for future generations.

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