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Heavy Rainfall Risk Management Policy: Effectiveness and Challenges from a Systematic Review

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Abstract The article addresses risk management in the face of heavy rains, highlighting the importance of developing comprehensive public policies that minimize the impacts on infrastructure, economy, and security. This study addresses the urgent need to implement preventive and resilient measures through a qualitative phenomenological approach. A systematic literature review was conducted, using recognized databases and applying rigorous inclusion criteria, which allowed us to analyze studies published between 2019 and 2024. In addition, structured search equations were adopted, and specific cases evidencing the effectiveness and challenges of these policies were evaluated. The results show that strategies such as early warning systems, resilient infrastructure, and community participation have been implemented; however, limitations related to inter-institutional coordination, resource allocation, and integration with urban and environmental development plans persist. The discussion also highlights the need to strengthen evaluation and monitoring mechanisms to adjust response protocols to extreme events. Finally, it is concluded that an effective risk management policy requires a preventive and collaborative approach that integrates innovative technologies and promotes the participation of all stakeholders.

Keywords Risk Management, Heavy Rains, Resilience, Public Policies, Coordination

1. Introduction

Heavy rains are natural phenomena that have an impact on infrastructure, the economy, and the safety of the population, and their recurrence has generated floods, landslides, and human losses [1]. These events have significant social and economic consequences, such as limited access to basic services, forced displacement, and health crises [2].

Increasing climate variability has exacerbated these effects, highlighting the urgency of developing comprehensive mitigation and response strategies [3]. In this context, risk management is consolidated as a fundamental pillar of public policy, as its proper implementation reduces damage, optimizes resources, and ensures an effective response to adverse events [4]. However, the formulation and application of these policies vary significantly according to the regulatory frameworks, availability of resources, and institutional articulation, which raises questions about their effectiveness and scope in different territories.

Despite the existence of regulations and action plans aimed at reducing the impact of heavy rain, disasters associated with these phenomena continue to generate adverse consequences in various regions [5]. The absence of adequate territorial planning, insufficient investment in resilient infrastructure, and limited inter-institutional coordination have weakened the response capacity of governments and communities [6].

In addition, risk management is not always integrated in a cross-cutting manner into urban development and environmental policies, which hinders the implementation of long-term prevention and adaptation strategies [7]. Inefficient resource allocation and the lack of monitoring and evaluation mechanisms have also hindered the consolidation of a preventive approach, thereby increasing the vulnerability of the population to extreme events [8]. In view of this problem, the purpose of this study is to identify the strengths and weaknesses of existing policies and propose improvements to increase their effectiveness.

The scientific literature has addressed various dimensions of risk management in the face of heavy rains; likewise, multiple studies have shown that collaborative governance and citizen participation are key factors for improving the effectiveness of responses [9]. Recent research has highlighted the importance of sustainable urban planning, the construction of resilient infrastructure, and the use of monitoring and early warning technologies to reduce risk exposure [10] [11].

It has also been shown that education and public awareness play a key role in disaster preparedness and response [12]. However, significant gaps persist in the evaluation of the long-term impact of these policies, as well as in their capacity to adapt to changing social, economic, and climatic contexts [13]. Likewise, the lack of integration between different levels of government and the limited cooperation between the public and private sectors have been identified as obstacles to the effective implementation of risk management strategies.

Given the impact of the problem and the need to strengthen risk management strategies, this research seeks to generate knowledge that will contribute to the design of more effective and sustainable policies. Reviewing the effectiveness of the measures implemented will make it possible to identify successes and areas for improvement, facilitating informed decision-making and the optimization of available resources.

In addition, understanding the challenges faced by these policies will enable the development of more comprehensive and adaptive approaches aimed at reducing the vulnerability of communities exposed to heavy rains. Coordination between the different actors involved, the use of innovative technological tools, and the incorporation of an inclusive and participatory approach will be key aspects in ensuring the success of these strategies.

Therefore, the objective of this research is to analyze the design of risk management policies in the face of heavy rainfall and to examine their effectiveness and the challenges they face during implementation. To this end, specific cases will be studied in areas that are particularly vulnerable to rainfall, as in the case of the Koshi River Basin in Nepal. However, other cases of vulnerable areas, mainly in the global South, are also addressed. The aim is to contribute to the development of more efficient, equitable, and adaptive management models to reduce the impact of these natural events and strengthen the resilience of affected communities.

2. Materials and Methods

2.1. Research Approach and Design

The study adopts a qualitative approach based on a systematic review of the literature, as it allows understanding of the experiences and perceptions about risk management policies in the face of heavy rainfall from the perspective of the actors involved. This approach is relevant for exploring complex phenomena in their natural context, identifying trends, gaps, and common approaches in previous research, and conducting an in-depth analysis based on academic and regulatory sources. According to Hamilton & Finley [12], qualitative research is appropriate when seeking to explore complex phenomena in their natural context and to capture the diversity of meanings attributed by participants. In this case, the interpretive analysis of relevant studies provides a critical understanding of the implementation and effectiveness of these policies.

The research answers the following question: What are risk management policies in the face of heavy rains, and what is their effectiveness, their limitations, and the challenges they face in their implementation? For this purpose, relevant academic and normative sources are examined, allowing a detailed analysis of the strategies implemented and their impact on risk mitigation. Thus, the study does not use primary data, but is based on a critical analysis of existing research documenting experiences, results, and challenges related to heavy rainfall risk management.

2.2. Research Technique

A systematic literature review is employed, a method widely recognized in qualitative research for its ability to synthesize existing knowledge and provide a sound framework for decision making. The systematic review allows a structured and transparent evaluation of the available evidence, which guarantees the rigor of the analysis and minimizes biases. In addition, this technique enables the identification of gaps in the literature and the formulation of informed recommendations [14].

The selection of studies was carried out following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which allowed for transparent documentation of the process of searching, screening, and excluding sources, based on previously defined inclusion and exclusion criteria.

Although the main focus was on studies published since 2019, key works from 2010 to 2012 were included due to their foundational relevance in the development of public policies, which allowed for the contextualization of regulatory and technical developments in this field.

2.2.1. Search Equations

The information gathering process is based on the formulation of structured search equations by the database and Boolean operators. The databases consulted include Scopus, Web of Science, ScienceDirect, and Google Scholar. The search equations combine key terms and synonyms related to the subject matter, using operators such as AND, OR, and NOT to delimit the results. The equations used are detailed in Table 1.

2.2.2. Inclusion and Exclusion Criteria

Studies included in the review should meet the following criteria:

1. Publications from 2019 onward ensure that the analysis and relevance of the policies reviewed are up to date.
2. Studies that address the effectiveness of strategies implemented in risk management in the face of intense rainfall.
3. Evidence-based research includes case studies, comparative analysis, or impact assessments.
4. Peer-reviewed articles and papers from recognized international organizations.
5. Studies that consider the relationship between risk management and climate adaptation in urban or rural contexts.
6. Studies published between 2010 and 2012, which, although before the main range, provide key elements for understanding the regulatory and conceptual evolution of the risk management approach.

On the other hand, the following papers are excluded:

1. Do not analyze specific public policies or their application in real contexts.
2. Focus exclusively on technical aspects without evaluating the implementation of policies.
3. Present duplicated or non-original information.
4. A clearly described methodology allows for replicability.
5. Focus on natural phenomena unrelated to heavy rains or floods.

2.3. Information Analysis Procedure

The analysis of the information is carried out through coding and classification into predefined dimensions and categories (Figure 1). Two main dimensions are considered: effectiveness and challenges. Within the former, the impact of policies on risk mitigation, adaptability to different scenarios, and the sustainability of the strategies applied are evaluated. On the other hand, the challenges dimension examines the regulatory, technical, and operational barriers that hinder their implementation. In addition, the extracted data are organized and compared according to their relevance and coherence with the research question.

Table 1. Search equations

Database	Search equation
Scopus	("gestión del riesgo" OR "reducción del riesgo de desastres") AND ("lluvias intensas" OR "inundaciones" OR "precipitaciones extremas")
Web of Science	("políticas públicas" OR "marco normativo") AND ("gestión del riesgo" AND "eficacia" AND "desafíos")
ScienceDirect	("desastres naturales" AND "adaptación climática") AND NOT ("terremotos" OR "volcanes")
Google Scholar	("planificación de emergencias" AND "cambio climático") AND ("gestión del riesgo" OR "resiliencia urbana")

Figure 1. Information analysis matrix

An exercise in reflexivity is also incorporated, in which the researcher acknowledges how his experience in public policy management and risk analysis may have influenced the interpretation of the findings, thereby lending greater transparency to the analytical process.

3. Results and Discussion

3.1. Quantitative Results

The present systematic review was developed following the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart, which ensured a rigorous and transparent process in the selection of studies (Figure 2). In the identification phase, 1,243 records were retrieved: 1,075 through databases and 168 through additional records or literature, although this division is not shown visually in the figure. Subsequently, 312 duplicate records were eliminated, leaving 931 unique studies for evaluation.

These records underwent a screening process, in which titles and abstracts were reviewed. During this phase, 765 records were excluded for not meeting the inclusion criteria. Then, in the eligibility phase, 166 full texts were evaluated, of which 120 were excluded for reasons such as lack of specific information, inadequate methodological approaches, or thematic irrelevance. Finally, in the inclusion phase, 46 studies that met all the established criteria were selected.

This process resulted in a high exclusion rate, approximately 88% of the initial records, reflecting a highly rigorous selection process focused on thematic relevance and methodological quality. In addition, the use of the PRISMA flowchart ensured systematic and transparent screening of the evidence, ensuring the inclusion of relevant and scientifically sound studies.

The results obtained from these studies were organized around two main axes: the effectiveness of risk management policies in the face of heavy rains and the challenges faced by these policies in their formulation, implementation, and evaluation. The number of articles reviewed varies over the years, reflecting fluctuations in research production on the topic (Figure 3). In 2019, 5 relevant articles were identified. This number increased to 8 in 2020, then slightly decreased to 7 in 2021. In 2022, it returned to 8 articles. In 2023, the number dropped again to 5. A peak was observed in 2024, with 12 articles reviewed. For 2025, 3 articles meeting the inclusion criteria have been identified so far.

This pattern could reflect the evolution of interest in flood and heavy rainfall risk management research, and how it has been influenced by factors such as extreme weather events, changes in regulations or policies, and advances in the scientific understanding of these phenomena. The variability in results could also reflect how research priorities change over time, or even limitations in the availability of resources to research these topics on an ongoing basis.

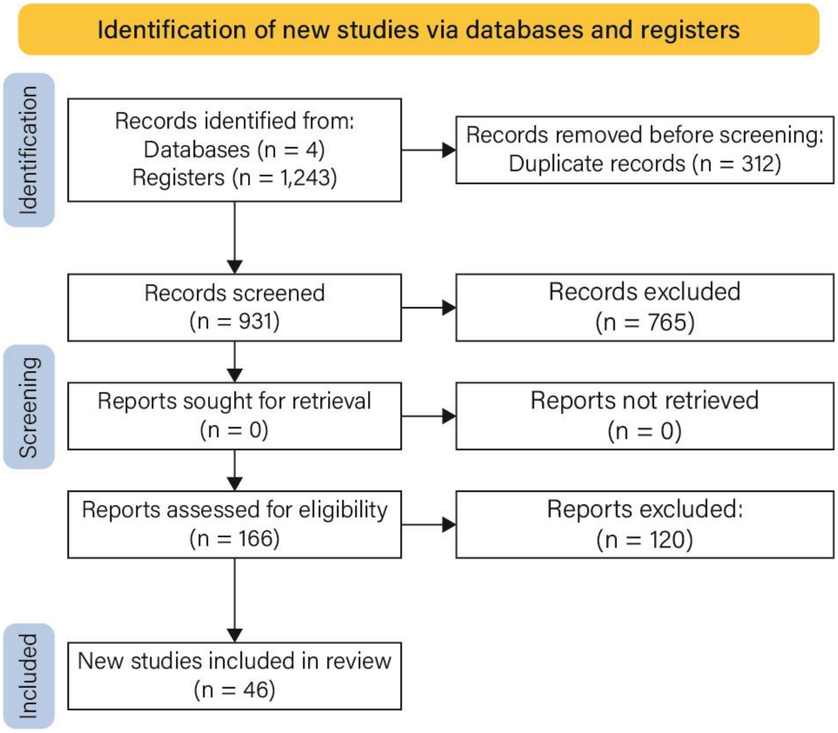

Figure 2. PRISMA Flowchart

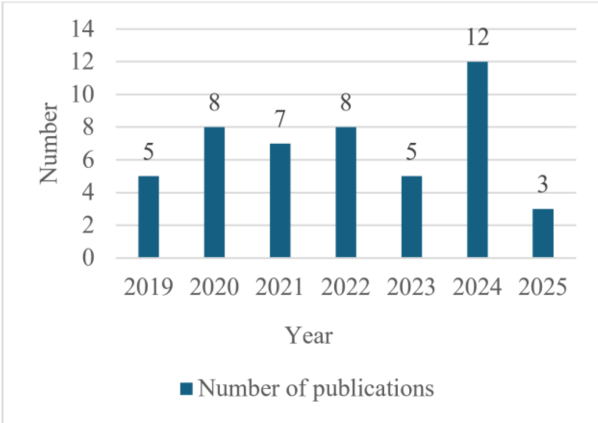

Figure 3. Distribution of publication of articles

3.2. Effectiveness of Risk Management Policies in the Face of Heavy Rain

3.2.1. Reduction of Material and Human Damage

The reduction of material and human damage in the face of heavy rains requires risk management policies that integrate technical, regulatory, and territorial criteria, and that prioritize anticipation over reaction [15]. These policies should be based on detailed studies of regional hydrometeorological behavior and should include both the analysis of the historical recurrence of extreme precipitation and the projection of future scenarios. Land-use plans, therefore, should prohibit the occupation of areas susceptible to flooding and incorporate measures that regulate land use according to the identified hazard level [16].

An example of this approach can be found in the Koshi River basin in Nepal, where land-use zoning policies and bans on settlements in flood-prone areas have been reinforced following recurring disasters, such as the 2008 floods, which displaced more than 50,000 people. These events prompted the integration of hydrological behavior studies into local land-use plans, with positive results in reducing material and human losses.

In addition, infrastructure should be designed based on specific hydraulic engineering standards for high-intensity events and should include adequate safety margins. Urban drainage systems, for example, should be sized considering the intensity and duration of extraordinary rainfall, in addition to being complemented with control devices such as detention ponds, lined channels, and pumping stations [17]. At the same time, the restoration of natural watercourses and the preservation of wetlands allow the absorption of excess water and offer an additional solution to the collapse of artificial works.

On the other hand, hydrometeorological monitoring should be articulated with warning systems that use sensors, forecast models, and highly available communication platforms [18]. The early activation of emergency protocols requires accurate and timely information and depends on the correct synchronization between technical agencies and civil protection bodies [19]. This coordination should be supported by standardized procedures, but should also consider the operational flexibility needed to adapt to unforeseen situations.

Likewise, community participation strengthens the effectiveness of institutional measures and allows for a faster response at critical moments. Information campaigns should be specific and should target the most exposed social groups. The identification of meeting points, the assignment of neighborhood responsibilities, and the regular practice of drills increase the collective response capacity and reduce evacuation times. Thus, it is not enough to have technical resources available; the population must be aware of the risks and act based on clear protocols.

In summary, reducing material and human damage from heavy rains benefits from integrated policies that combine technical, territorial, and social criteria, as well as preventive infrastructure design and community participation. However, their effectiveness is limited by a lack of inter-institutional coordination and low investment in monitoring and warning systems. To improve, urban planning measures need to be coordinated with citizen education and institutional strengthening actions.

3.2.2. Implementation of Early Warning Systems

The implementation of early warning systems in risk management policies for intense rainfall is a priority technical measure, which requires an operational structure that combines meteorological monitoring, predictive analysis, and immediate communication [20][21]. These systems should integrate highly sensitive sensors that record variables such as precipitation intensity, wind speed, and stream level, and should be connected to control centers that interpret the data based on hydrological models adjusted to each region [22].

Furthermore, the functionality of the system depends not only on the instruments used but also on the institutional organization that coordinates the response. National and local authorities must define joint protocols, as well as establish activation thresholds that consider climate variability and the absorption capacity of the soil [23]. In turn, technical teams should work in close collaboration with civil protection bodies and ensure a rapid and effective distribution of warnings to potentially affected communities.

In the Koshi River region, a community early warning system has been implemented that combines hydrometeorological sensors, community radios, and local training, significantly increasing reaction times before floods. This model has been recognized for its effectiveness in contexts with limited resources.

Likewise, warnings must be transmitted through redundant mechanisms and reach both urban and rural areas [24]. Audible alarms, mobile network messages, and radio announcements should work in a complementary manner~~,~~ and should be activated simultaneously to avoid delays in evacuation [25]. The clarity of the message is essential, and the information must specify the threat level, the estimated time of impact, and the precise instructions that the population must follow [2].

On the other hand, the effectiveness of the system depends largely on the prior knowledge that the public has about its operation [26]. People must identify the meaning of each signal and know what actions to take at each level of alert. Therefore, public policies should include permanent training campaigns, as well as involve schools, community centers, and local organizations in practical exercises that simulate real emergencies.

Finally, system maintenance should be constant and should include both the technical review of equipment and the updating of operating procedures [27]. Weather conditions evolve, and precipitation patterns may change over time; therefore, it is necessary to periodically adjust activation parameters and validate the efficiency of communication channels [28]. Only through a sustained articulation between technology, institutional planning, and citizen education is it possible to reduce the devastating effects of heavy rain and preserve both the physical integrity of people and the stability of urban and rural environments.

In summary, early warning systems offer concrete benefits by anticipating extreme events and activating emergency protocols, especially when monitoring technologies are integrated with community communication. However, their implementation faces limitations associated with coverage, maintenance, and social understanding of the messages. To overcome these challenges, it is necessary to consolidate robust institutional structures, invest in local training, and ensure the continuous updating of activation parameters.

3.2.3. Community Training and Preparation

Training and community preparedness are fundamental pillars of risk management policies in the face of heavy rains and make it possible to consolidate an organized social response to extreme events [29]. Exposed populations must receive specific knowledge about the effects of torrential rainfall and must accurately identify the factors that increase their level of risk. For this reason, training programs should be structured according to the profile of the territory, as well as considering the social, economic, and environmental particularities of each locality.

In Nepal, communities in the Koshi River basin have been trained through programs led by international NGOs, where participatory risk maps and frequent drills have been developed. This community preparedness has enabled faster and more effective evacuation in recent events of heavy rainfall.

In addition, educational content should address specific procedures and be clearly explained to facilitate their application in emergency contexts. On the other hand, communities should be aware of evacuation routes, safe meeting points, and recommended actions in the face of different scenarios [30]. Practical exercises, such as evacuation drills and first aid practices, make it possible to evaluate the collective reaction and strengthen the operational capabilities of community groups. In this way, preparedness not only improves immediate response but also decreases dependence on relief agencies alone.

Likewise, training actions should be linked to institutional structures, as well as developed in coordination with technical entities, local authorities, and educational centers [31]. The articulation between these actors guarantees broad coverage and allows information to reach different social sectors simultaneously. At the same time, the contents must be kept up to date and transmitted through accessible media that respect the cultural and linguistic codes of each community [32]. In this way, the understanding of risk is reinforced and a proactive attitude towards natural hazards is promoted.

On the other hand, neighborhood organization improves the efficiency of responses to heavy rains and facilitates the distribution of tasks at critical moments [33]. The designation of neighborhood leaders, the formation of emergency committees, and the joint planning of preventive measures strengthen the social fabric and expedite decisions [34]. When the population acts in a coordinated manner, reaction times are reduced and adverse consequences are mitigated in both urban and rural areas.

Ultimately, risk management policies should allocate adequate resources to implement continuous training programs, while establishing evaluation mechanisms to measure their effectiveness. Training activities should be reviewed periodically and adapted to changes in weather patterns and environmental conditions. In this way, society acquires concrete tools to face the effects of heavy rain and consolidates a culture of prevention that protects lives, property, and essential structures.

In conclusion, community training and preparedness strengthen collective response capacity and reduce dependence on relief agencies, offering sustainable benefits in high-exposure contexts. However, uneven coverage and a lack of coordination with official structures limit their impact. To improve, these programs need to be institutionalized, continuous funding secured, and content adapted to the cultural and territorial realities of each community.

3.2.4. Efficiency in Institutional Response

Efficient institutional response plays a fundamental role in risk management policies in the event of heavy rains, since timely and coordinated action can significantly reduce the impacts of these phenomena [35]. To ensure an adequate response, institutions must establish clear protocols that define the actions to be taken before, during, and after the event. It is essential that each level of government, from local to national, has specific attributions, which facilitate the organization and execution of the necessary tasks during an emergency.

In addition, the availability of human and material resources is essential to ensure effective intervention. The entities in charge of risk management must have specialized and well-trained teams, as well as sufficient infrastructure to attend to the affected population [36]. In this sense, policies should provide not only for the acquisition of rescue teams but also for the logistics necessary to distribute supplies, medicines, and food in the first hours after the disaster.

Coordination between different institutions is also crucial for an efficient response. Local authorities must work closely with technical agencies, such as meteorological and hydraulic agencies, to correctly interpret information on rainfall and associated risks [37]. This collaboration should also include the armed forces, non-governmental organizations, and other actors that can provide additional resources or specialized assistance. In this way, the response is optimized, as all actors involved can act in a complementary manner and with a unified vision.

Likewise, communication with the population must be clear and effective to avoid misinformation and panic. Warnings should be issued promptly, and messages should be accurate, detailed, and easily understandable so that people can make informed decisions [38]. In addition, it is important for authorities to use multiple communication channels and to ensure that the most vulnerable or hard-to-reach areas receive warnings efficiently. Constant updating of information also helps the population to stay oriented and to follow instructions appropriately.

Finally, post-emergency assessment is essential to improve response capabilities in future risk situations. It is necessary to review each phase of the intervention to identify the aspects that worked well and those that require adjustments. Lessons learned should be used to refine response protocols, resource allocation, and personnel training. This will strengthen the institutional system and increase the effectiveness of risk management, contributing to greater protection of the population and material assets in future events.

In summary, an efficient institutional response can significantly reduce the damage caused by heavy rains through timely and coordinated action by multiple actors. Its benefits include greater operational organization and better distribution of resources; however, it faces obstacles such as resource scarcity, overlapping functions, and communication deficiencies. To move forward, it is key to establish clear protocols, strengthen local capacities, and promote systematic post-event evaluation.

3.2.5. Adaptation of Urban and Rural Infrastructure

The adaptation of urban and rural infrastructure is a fundamental aspect of risk management policies in the face of heavy rains, since the capacity of cities and rural areas to withstand these phenomena depends largely on the planning and design of their structures [39]. First, drainage systems must be designed to handle the volumes of water produced by extreme rainfall [40]. Hydraulic infrastructures, such as canals and sewers, must be sized based on hydrological studies that anticipate the most severe events, while buildings and housing must have adequate materials that withstand the action of intense rainfall without compromising the safety of the inhabitants.

In the urban context, adaptation requires the implementation of innovative solutions that promote soil permeability and water absorption capacity. The restoration of green areas, the reforestation of watersheds, and the construction of permeable pavements make it possible to reduce surface runoff and mitigate the effects of flooding [41]. These strategies not only contribute to risk management but also improve the quality of the urban environment by increasing biodiversity and regulating temperatures. The integration of these solutions into urbanization plans is essential to strengthening the resilience of cities to extreme climate events.

On the other hand, infrastructure adaptation in rural areas presents specific challenges, as many of these areas lack the technical and financial capacity to implement large projects [42]. However, it is possible to adopt context-appropriate solutions, such as the improvement of rural roads to avoid landslide blockages, or the construction of drainage systems that protect agricultural areas and houses from flooding [43]. In addition, the use of accessible technologies, such as the construction of reservoirs for water storage, can help regulate the flow of precipitation and improve water resource management in drought seasons.

The adaptation of infrastructure is not limited only to the construction of new works, but also requires a preventive approach based on the maintenance and improvement of existing structures [44]. Periodic inspections are necessary to verify the condition of drainage systems, electrical networks, and road infrastructures, which makes it possible to identify potential failures and correct them before emergencies arise. This approach reduces repair costs and improves the efficiency of response to heavy rainfall.

In summary, adapting urban and rural infrastructure is a central pillar of risk management policies, as it allows for less structural vulnerability when facing heavy rainfall. Its benefits include reducing surface runoff and improving territorial resilience. However, its implementation is restricted by a lack of funding, technical capacity, and comprehensive planning. As an improvement, it is recommended to prioritize nature-based solutions, update construction standards, and reinforce preventive maintenance.

3.3. Challenges of Risk Management Policies in the Face of Heavy Rain

3.3.1. Climate Change and an Increase in Extreme Events

Climate change has profoundly modified atmospheric regimes and has caused a sustained increase in the frequency and intensity of extreme hydrometeorological events, including torrential rains [45]. This phenomenon has generated alterations in the dynamics of hydrographic basins, has exceeded the drainage capacity of existing infrastructures, and has overwhelmed conventional emergency response protocols [46]. At the same time, it has revealed deficiencies in risk management systems, which remain anchored in fragmented approaches that are poorly articulated with emerging climate scenarios.

Climate variability has disrupted precipitation cycles, increased the recurrence of short-duration, high-intensity rainfall events, and altered local water balances. These changes have made it difficult to accurately identify hazard zones, have weakened real-time monitoring systems, and have limited the anticipatory capacity of the competent authorities [45]. Risk management, however, continues to prioritize post-event reaction schemes and has failed to systemically integrate the components of vulnerability analysis, exposure assessment, and cumulative impact projection.

The experience of the Koshi River has shown how climate change has intensified rainfall variability, exceeding the capacity of infrastructure built under obsolete climate assumptions. Updating hydrological models has been key to adapting policies to this new reality.

Public policies focused on the mitigation of damage caused by heavy rains should be restructured, as well as incorporate technical instruments that allow modeling risk scenarios under non-stationary climatic conditions [47]. The absence of updated geospatial information, poor interoperability between data platforms, and the underutilization of hydrological simulation tools have limited the formulation of effective strategies [48]. In addition, territorial planning still does not consider hazard maps with sufficient rigor, nor does it restrict urbanization in water recharge areas or natural runoff corridors.

Coordination between environmental management agencies, civil protection technical units, and urban planning entities is essential and should be based on inter-institutional protocols that allow for joint action [39]. It is necessary to design resilient infrastructures, sized according to extreme rainfall projections and equipped with hydraulic redundancies that allow them to remain operational during critical events [49]. Likewise, financing mechanisms should be implemented to ensure resources for prospective risk reduction, and not only for post-disaster reconstruction [50].

Thus, climate change has intensified extreme rainfall and has highlighted the technical and structural limitations of risk management policies. Institutional responses require greater technical precision, better operational coordination, and a proactive orientation that considers new climatic conditions as permanent variables in the risk system. Only a profound transformation of regulatory frameworks, assessment methodologies, and planning instruments will make it possible to effectively face the challenges posed by extreme rainfall events.

Thus, recognizing climate change as a factor that intensifies extreme rainfall events allows risk management policies to be adapted to non-stationary scenarios. Among its benefits are the updating of hydrological models and the incorporation of forward-looking approaches. However, limitations persist, such as institutional disarticulation, the use of outdated information, and regulatory resistance to change. To improve, it is necessary to redesign regulatory frameworks, promote data interoperability, and prioritize investments in resilient infrastructure.

3.3.2. Integration of Sustainable and Resilient Approaches

The integration of sustainable and resilient approaches in risk management policies constitutes a significant challenge in the face of the increase in the intensity and frequency of extreme rainfall, a phenomenon directly associated with climate change [51]. In this sense, conventional policies, which have historically focused on reactive disaster management, are insufficient to address the complexity of the impacts generated by these events. There is an urgent need to rethink the management approach, incorporating measures to mitigate long-term effects, reduce structural vulnerabilities, and promote effective adaptation of affected communities.

From a technical perspective, sustainability in risk management requires a thorough and continuous evaluation of natural resources, prioritizing those ecosystems that fulfill vital functions in water regulation, such as riparian forests, wetlands, and watersheds [52]. These natural areas act as regulators of the water cycle, attenuating the effects of heavy rains by absorbing and redistributing excess water. The degradation of these ecosystems, caused by uncontrolled human activities, has generated increasing vulnerability in urban and rural areas, which lack adequate mechanisms to mitigate risk [53]. Consequently, policies must shift from approaches focused solely on artificial infrastructure to nature-based solutions, such as the restoration of natural ecosystems and the implementation of sustainable drainage solutions, which are more efficient and less costly in the long term.

In this regard, the restoration of wetlands in the Koshi River basin has proven to be an effective and sustainable alternative. These areas have absorbed excess water during extreme events, reducing pressure on artificial defenses and integrating traditional water management practices with modern solutions.

On the other hand, resilience to intense rainfall must contemplate an update of infrastructure designs and standards, considering long-term climate projections [54]. Water infrastructure, such as drainage systems and dams, must be designed to withstand extreme events without compromising their functionality or causing collateral damage to nearby populations. In this framework, the implementation of advanced technical solutions, such as watershed modeling with extreme event simulations, the planning of stormwater storage systems, and the construction of green infrastructure, is presented as a key measure to reduce the pressure on conventional infrastructure [55]. The redundancy of systems and the incorporation of technological alternatives, such as modular and flexible infrastructures, will allow a greater capacity to adapt to climate uncertainty scenarios.

In addition, community resilience must be understood from a participatory approach that involves local stakeholders in the planning and decision-making process. Community capacity building is essential, as it allows inhabitants not only to understand the risks associated with heavy rains but also to actively participate in prevention and response actions [34], [56]. The integration of early warning systems, based on continuous monitoring of meteorological conditions, together with the training of community leaders in evacuation techniques and civil protection, significantly increases the effectiveness of disaster response.

Regarding the regulatory and administrative sphere, the implementation of sustainable and resilient policies should involve a thorough review of legislative frameworks, which often present gaps in the articulation between different governmental entities and productive sectors [57]. Interinstitutional cooperation is crucial to ensure comprehensive planning that considers not only the technical aspects but also the socioeconomic and cultural aspects of the affected communities [2]. In turn, the absence of a coherent and unified vision among the different levels of government, from local to national, can hinder the implementation of effective policies and perpetuate fragmentation of efforts.

Finally, risk management policies should incorporate social justice criteria to ensure that the most vulnerable communities, which are often the most affected by extreme rainfall events, have the necessary resources and capacities to cope with the impacts of these phenomena [58]. This approach requires the adequate allocation of financial resources, the promotion of an inclusive policy framework, and the creation of innovative financing mechanisms to ensure the long-term sustainability of interventions. Thus, the integration of sustainable and resilient approaches to risk management seeks not only to adapt infrastructures and planning processes to new climate scenarios but also to promote equitable and effective climate governance that favors the safety and well-being of all populations.

In this way, integrating sustainable and resilient approaches into risk management for heavy rainfall brings benefits such as ecosystem restoration, strengthening green infrastructure, and social inclusion in decision-making. However, limitations include fragmented legal frameworks, poor inter-institutional cooperation, and low investment in nature-based solutions. As a necessary improvement, multisectoral policies must be implemented, adequate financial resources must be guaranteed, and climate justice with a territorial focus must be promoted.

3.3.3. Improved Data Collection and Use

Improved data collection and use has been established as a primary technical and strategic challenge for risk management policies in the face of heavy rainfall, because the quality and accuracy of information play a crucial role in the planning and implementation of preventive measures [32]. Currently, meteorological monitoring and data collection systems operate discontinuously and without full integration with other risk management systems, which substantially limits the ability to model and forecast extreme events with the necessary accuracy [59]. Poor interconnection between climate, geospatial, and socioeconomic databases prevents comprehensive risk assessment, resulting in fragmented and often ineffective responses to intense rainfall events, which can generate devastating impacts on infrastructure and population.

One of the main deficiencies lies in the fragmentation of data systems at the institutional level. Agencies in charge of meteorological monitoring, watershed management authorities, and entities responsible for urban planning produce valuable information, but it is often not correlated due to the lack of a common platform for its integration [60]. Rainfall data, for example, are not properly aligned with structural vulnerability studies or urban growth projections, which prevents proper identification of risk areas [61]. This disconnection between different data sources hinders the development of predictive models based on a holistic view of the environment and limits the ability to anticipate extreme events in an efficient and timely manner.

In addition, the lack of constant updating of data and the lack of advanced technologies in many regions contribute to an inaccurate understanding of risk scenarios. Despite technological advances in weather forecasting and remote observation, many areas lack the resources to implement and maintain these technologies, resulting in a reliance on historical data that do not adequately reflect current climate conditions or long-term projections [21]. The use of advanced climate modeling tools, such as numerical forecasting systems and runoff simulation models, can improve the accuracy of extreme event predictions, but their implementation requires not only substantial investments in technological infrastructure but also an effort in technical training of the professionals involved [60].

Effective use of the data obtained must go beyond the simple collection of information. Heavy rainfall risk management must be based on an integrated data system that allows predictive analysis, calculation of vulnerability levels, and accurate estimation of the potential impact of meteorological events on infrastructure and exposed populations [61]. The interoperability of information systems is a crucial aspect to ensure that meteorological, hydrological, urban, and social data are used in a coordinated manner. This integration not only makes it possible to assess the capacity of infrastructures to withstand extreme events, but also to identify areas with a high density of vulnerable populations and areas with critical infrastructures that may collapse in the event of flooding.

In the case of the Koshi River, open data platforms have been developed that integrate climatic, hydrological, and social information, allowing authorities and communities to plan more accurately. This approach has been replicated in other regions of the Himalayas, given its effectiveness.

Finally, to improve data collection and use, it is necessary to adopt a holistic approach that considers technological capabilities as well as organizational and human aspects. Public policies should promote continuous training of professionals in charge of data management and risk analysis, ensuring that the tools and methodologies are appropriate for each context. Only through a well-integrated, updated, and easily accessible information system will it be possible to develop more efficient and effective risk management policies, capable of reducing the impacts of heavy rain and improving the resilience of affected communities.

Consequently, it can be argued that improvements in data collection and use enable more accurate risk management by facilitating the anticipation of extreme events and evidence-based planning. Its main benefits include the development of predictive models and the identification of vulnerable populations. However, it faces limitations such as fragmented databases, a lack of advanced technologies, and poor technical training of personnel. To improve, it is necessary to promote interoperable systems, continuously train technical teams, and ensure public access to up-to-date and contextualized information.

4. Conclusions

The systematic review identified recurrent patterns in the formulation, implementation, and evaluation of risk management policies in the institutional context, and also highlighted the need to strengthen the integration between regulatory frameworks and management systems. The studies analyzed agree that an effective policy does not depend only on the existence of formal guidelines, but also on their appropriation by all the actors involved, as well as on the capacity of organizations to adapt to changing contexts without losing institutional coherence.

The findings allow us to conclude that the most effective risk management policies are not limited to technical design, but are articulated with strategic planning, adapt to contextual changes, and are integrated at all hierarchical levels through genuine ownership by institutional actors.

Likewise, the results indicate that the most successful policies share three essential elements: a clear structure of responsibilities, permanent feedback mechanisms, and a solid articulation with strategic planning processes. This coincidence between sources confirms that the technical design of the policy alone is not enough, and that institutional will, sufficient allocation of resources, and committed leadership are required for the measures adopted to produce sustainable effects. In addition, the review showed that those policies that integrate monitoring and evaluation tools have better performance levels and can respond more quickly to emerging risks.

The evidence gathered shows that institutional will, committed leadership, and timely allocation of resources are necessary conditions for ensuring the sustainability of the measures adopted. In addition, policies that incorporate monitoring and continuous evaluation tools show higher levels of performance and responsiveness to emerging risks.

On the other hand, the review also identified common gaps in policy implementation and highlighted the disconnect that persists in some contexts between risk management and mission processes. This gap limits the effectiveness of preventive measures and contributes to risks being addressed in a reactive and fragmented manner. Despite this, significant progress has been made in the recognition of risk as a cross-cutting component of institutional management, and the role of organizational culture as a key factor in the appropriation of the policies reviewed is highlighted.

However, critical gaps remain in the implementation phase, especially in the coordination between risk management and mission-critical processes. This disconnect reduces the effectiveness of preventive actions and generates fragmented and reactive responses. Despite this, substantial progress has been made in incorporating the risk approach as a cross-cutting theme in institutional management, as well as in recognizing organizational culture as a determining factor in the appropriation of policies.

Finally, it is concluded that the documented best practices can be adapted to the local context and can become benchmarks for strengthening institutional policy. However, this adaptation must consider the specific characteristics of the entity and ensure the active participation of all hierarchical levels. Overall, the systematic review made it possible not only to synthesize the available knowledge but also to propose concrete lines of improvement, thus providing a solid basis for informed decision-making and contributing to the consolidation of more effective, transparent, and sustainable risk management.

Within this framework, it is concluded that the good practices identified can serve as benchmarks that can be adapted to different institutional realities, provided that the particularities of the context are respected and the active participation of all organizational levels is promoted.

Most impactful practices identified

- Policy design
- Clear assignment of roles and responsibilities
- Inclusion of the risk approach in strategic planning
- Regulations requiring periodic policy evaluation

Implementation

- Training of leaders with risk management skills
- Specific allocation of resources for preventive actions
- Effective cross-sector coordination and communication protocols

Evaluation

- Monitoring systems with key risk indicators
- Structured institutional feedback mechanisms
- Accountability and public transparency frameworks

As specific guidance, it is recommended to prioritize the integration of risk governance into institutional operations, invest in leadership capacity building, and establish regulatory frameworks that require regular evaluation of adopted policies.

For future research, it is suggested to apply a qualitative methodology with a phenomenological approach, combining semi-structured interviews with decision-makers with a systematic review of recent scientific literature.

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