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The Contribution of Integrated Watershed Management to Resilience Against Climate Change: the case of floods in Rio Grande do Sul

Edson Luís Piroli
PhD Professor, UNESP, Brazil.
edson.piroli@unesp.br

Adão Robson Elias
PhD Professor, UTFPR, Brazil.
robsonelias@utfpr.edu.br

Wanda Luquine Elias
MSc. Professor, UNIDEP/Afya, Brazil
wanda_le@terra.com.br

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A contribuição do manejo integrado de bacias hidrográficas para a resiliência frente às mudanças climáticas: o caso das inundações no Rio Grande do Sul

RESUMO

Objetivo – Analisar os episódios de inundação ocorridos no Rio Grande do Sul, principalmente nos tributários da Bacia Hidrográfica do Guaíba, nos meses de abril e maio de 2024, sob a ótica do manejo integrado de bacias hidrográficas.

Metodologia – O trabalho, a partir de análises fundamentadas na pesquisa descritiva, busca entender e explicar as causas das inundações, e principalmente, dos seus impactos. Visa, desta forma, indicar recomendações fundamentadas na pesquisa explicativa, para o gerenciamento e a gestão das bacias hidrográficas, baseadas no seu manejo integrado.

Originalidade/relevância - Os episódios de chuvas intensas têm se tornado mais frequentes no Brasil, especialmente no Rio Grande do Sul, causando graves impactos sociais, econômicos e ambientais. As chuvas intensas resultam em destruição de casas, perda de vidas e danos a infraestruturas essenciais, como saúde, educação e transporte. O setor produtivo também sofre com perdas significativas na agricultura, pecuária e comércio, afetando a economia regional e nacional. Ambientalmente, as chuvas causam inundações, erosões, deslizamentos e assoreamentos, prejudicando solo, água, flora e fauna. A intensificação desses eventos está ligada a mudanças climáticas e à falta de planejamento na ocupação do território e na gestão dos recursos hídricos. A ocupação de áreas de risco, como planícies de rios e encostas declivosas de morros, exacerba os desastres naturais. Para mitigar esses impactos, é necessário adotar o Manejo Integrado de Bacias Hidrográficas (MIBH), que considera as características naturais e os limites de uso das áreas. O MIBH envolve políticas e legislações robustas, como a Política Nacional de Recursos Hídricos, e técnicas de manejo que promovem a infiltração e retenção de água no solo, reduzindo o escoamento superficial e os riscos.

Resultados – Os resultados obtidos demonstram as características da área analisada, das causas das inundações e a importância da adoção das técnicas de manejo integrado das bacias hidrográficas.

Contribuições teóricas/metodológicas – Os métodos utilizados, fundamentados na pesquisa descritiva e explicativa, contribuíram para a compreensão das inundações, suas causas, consequências e possibilidades de ações para a minimização de seus impactos.

Contribuições sociais e ambientais – As análises e observações demonstradas no artigo, evidenciam a importância de políticas públicas voltadas à ocupação adequada do solo urbano e rural, sobretudo em áreas de risco. Evidenciam ainda a importância do desenvolvimento de estratégias para a mitigação de riscos hidrológicos em áreas vulneráveis, a partir das técnicas de manejo integrado de bacias hidrográficas, protegendo assim pessoas, animais, patrimônios e estruturas.

PALAVRAS–CHAVE: Eventos extremos. Chuvas intensas. Rio Grande do Sul. Impactos ambientais. Inundações.

The Contribution of Integrated Watershed Management to Resilience Against Climate Change: the case of floods in Rio Grande do Sul

ABSTRACT

Objective – To analyze the flooding episodes that occurred in Rio Grande do Sul, mainly in the tributaries of the Guaíba River Basin, in the months of April and May 2024, from the perspective of integrated river basin management.

Methodology – The work, based on descriptive research analyses, seeks to understand and explain the causes of flooding, and mainly, their impacts. It aims to indicate recommendations for the management of the river basins.

Originality/relevance - Episodes of heavy rainfall have become more frequent in Brazil, especially in Rio Grande do Sul, causing serious social, economic and environmental impacts. Heavy rainfall results in the destruction of homes, loss of life and damage to essential infrastructures, such as health, education and transportation. The productive sector also suffers significant losses in agriculture, livestock and commerce, affecting the regional and national economy. Environmentally, rainfall causes flooding, erosion, landslides and silting, damaging soil, water, flora and fauna. The intensification of these events is linked to climate change and the lack of planning in the occupation of the territory and in the management of water resources. The occupation of risk areas, such as river plains and steep hillsides, exacerbates natural disasters. To mitigate these impacts, it is necessary to adopt Integrated Watershed Management (IWM), which considers the natural characteristics and limits of use of the areas. IWM involves robust

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policies and legislation, such as the National Water Resources Policy, and management techniques that promote infiltration and retention of water in the soil, reducing surface runoff and risks.
Results – The results obtained demonstrate the characteristics of the area analyzed, the causes of flooding and the importance of adopting integrated watershed management techniques.
Theoretical/methodological contributions – The methods used, based on descriptive and explanatory research, contributed to the understanding of flooding, its causes, consequences and possible actions to minimize its impacts.
Social and environmental contributions – The analyses and observations demonstrated in the article highlight the importance of public policies aimed at the adequate occupation of urban and rural land, especially in risk areas. They also highlight the importance of developing strategies to mitigate hydrological risks in vulnerable areas, based on integrated watershed management techniques, thus protecting people, animals, assets and structures.

Keywords: Extreme events. Intense rainfall. Rio Grande do Sul. Environmental impacts. Floods.

La contribución de la gestión integrada de cuencas hidrográficas a la resiliencia frente al cambio climático: el caso de las inundaciones en Rio Grande do Sul

RESUMEN
Objetivo: Analizar las inundaciones ocurridas en Rio Grande do Sul, principalmente en los afluentes de la cuenca del río Guaíba, durante los meses de abril y mayo de 2024, desde la perspectiva de la gestión integrada de cuencas hidrográficas.
Metodología: El trabajo, basado en análisis descriptivos, busca comprender y explicar las causas de las inundaciones y, principalmente, sus impactos. Su objetivo es formular recomendaciones para la gestión de las cuencas hidrográficas.
Originalidad/relevancia: Las lluvias torrenciales se han vuelto más frecuentes en Brasil, especialmente en Rio Grande do Sul, causando graves impactos sociales, económicos y ambientales. Estas lluvias provocan la destrucción de viviendas, la pérdida de vidas y daños a infraestructuras esenciales, como la salud, la educación y el transporte. El sector productivo también sufre pérdidas significativas en la agricultura, la ganadería y el comercio, lo que afecta la economía regional y nacional. Ambientalmente, las lluvias provocan inundaciones, erosión, deslizamientos de tierra y sedimentos, dañando el suelo, el agua, la flora y la fauna. La intensificación de estos eventos está vinculada al cambio climático y a la falta de planificación en la ocupación del territorio y en la gestión de los recursos hídricos. La ocupación de zonas de riesgo, como llanuras fluviales y laderas escarpadas, agrava los desastres naturales. Para mitigar estos impactos, es necesario adoptar la Gestión Integrada de Cuencas (GIC), que considera las características naturales y los límites de uso de las áreas. La GIC implica políticas y legislación sólidas, como la Política Nacional de Recursos Hídricos, y técnicas de gestión que promueven la infiltración y retención de agua en el suelo, reduciendo la escorrentía superficial y los riesgos.
Resultados: Los resultados obtenidos demuestran las características del área analizada, las causas de las inundaciones y la importancia de adoptar técnicas de gestión integrada de cuencas.
Contribuciones teóricas/metodológicas: Los métodos utilizados, basados en investigación descriptiva y explicativa, contribuyeron a la comprensión de las inundaciones, sus causas, consecuencias y las posibles acciones para minimizar sus impactos. Contribuciones sociales y ambientales: Los análisis y observaciones presentados en el artículo resaltan la importancia de las políticas públicas orientadas a la adecuada ocupación del suelo urbano y rural, especialmente en zonas de riesgo. También destacan la importancia de desarrollar estrategias para mitigar los riesgos hidrológicos en zonas vulnerables, basadas en técnicas de gestión integrada de cuencas hidrográficas, protegiendo así a las personas, los animales, los bienes y las estructuras.

PALABRAS CLAVE: Eventos extremos. Lluvias intensas. Rio Grande do Sul. Impactos ambientales. Inundaciones.

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1 INTRODUCTION

Episodes of heavy rainfall, leading to flash floods, widespread flooding and landslides on slopes have become increasingly frequent across Brazil, with greater recurrence in some regions. Among the set of extreme episodes observed in recent years, those that occurred in Rio Grande do Sul stand out due to their intensity and the extensive impacts on communities, the productive sector, the economy, and natural ecosystems.

These events cause profound human suffering, including the destruction of homes, loss of lives, and disruption of essential infrastructure such as healthcare, education, transportation, food supply, security, clothing, communication, electricity, commerce, and even water distribution. Heavy rainfall, the primary trigger, inundate surface areas and damages treated water distribution systems, compromising access to clean water and aggravate living conditions for displaced and homeless populations. These events also affect residents in unaffected municipalities, amplifying the crisis (Marengo *et al*, 2023; Lima; Silva, 2024).

The productive sector in general is heavily impacted by the destruction of crops, loss of livestock and significant soil erosion and siltation of water bodies. Here it is important to consider that when a farmer loses the soil on his property, he loses the main part of his means of production and subsistence. Given that agriculture is a cornerstone of Rio Grande do Sul's and Brazil's economy, these losses reverberate across the state and nation. Additionally, damage to industries, businesses, services, roads, bridges, and airports further harms the economy of affected regions and the state as a whole (Simionatto *et al*, 2024).

Environmental damage is equally severe, encompassing soil degradation through erosion, landslides, and siltation; contamination and disruption of streams, rivers, and their ecosystems; destruction of native flora, including riparian forests and hillside vegetation; and loss of wildlife due to habitat destruction and deaths during floods and landslides. These consequences highlight the urgent need to understand the causes of intensified extreme rainfall and to develop strategies to mitigate its impacts (Azadi *et al*, 2022).

In this context, this study aims to investigate the origins of these extreme weather events and propose strategies for managing geographic space through integrated watershed management techniques. The goal is to reduce social, economic, and environmental damage, with a focus on the Jacuí and Taquari river basins, tributaries of the Guaíba Watershed, where the impacts of extreme rainfall have been most pronounced in Rio Grande do Sul.

These consequences reflect inadequate territorial planning, poor water resource management, and a lack of integrated natural resource management in these basins. Combined with the ongoing challenges of climate change, this situation risks escalating into crises of increasing severity, underscoring the need for proactive and sustainable solutions (Winkler *et al*, 2021; Silva *et al*, 2023).

2 CLIMATE CHANGE

The global climate is undergoing significant changes, marked by an increase in the frequency, intensity, and extent of extreme weather events. Heatwaves have become more common in the western United States since the 1980s, while drought risk has risen over the past

century. Conversely, eastern regions of the U.S., particularly east of the Rocky Mountains, have seen more extreme rainfall in recent decades (Marvel, 2023). These shifts highlight the growing variability in global weather patterns driven by climate change.

As a continental country with diverse physiographic characteristics in terms of natural elements such as relief, climate and vegetation (Salgado et. al., 2019), Brazil exhibits significant variations in terms of rainfall distribution. These factors define the main precipitation actions in Brazilian territory and make the southern region, characterized by relatively uniform rainfall distribution throughout the year, the second-rainiest in Brazil, surpassed only by the Amazon rainforest (Luiz-Silva *et al*, 2021).

The characteristics of precipitation in the southern region, in turn, profoundly influences socioeconomic factors such as water resources, energy production, and agriculture. Understanding rainfall characteristics is essential for ensuring water security, managing drinking water supplies, and predicting extreme weather events that can cause significant damage. To this end, accurate, high-resolution weather and climate monitoring is essential for effective forecasting and disaster preparedness (Delgado *et al*, 2020).

When talking about weather and climate monitoring, observations should be made about the increase in the severity, extent, and/or frequency of various types of extreme events related to floods and droughts in different regions of the country (Rocha *et al*, 2019). Disasters resulting from extreme events, such as severe precipitation, lead to significant risks to human life, environmental degradation, infrastructure damage, and economic losses (Debortoli et. al., 2017). Therefore, it is necessary to analyze and study the causes associated with the frequency and intensity of such extreme precipitation events (Luiz-Silva *et al*, 2021) in order to develop effective forecasting, early warning systems, and response strategies when these phenomena occur.

Rainfall, especially in the southern region of Brazil, is influenced by mesoscale convective systems, with a combination of seasonal factors, such as the El Niño Southern Oscillation (ENSO), decadal oscillations and climate change (Teixeira; Satyamurthy, 2007). Clarke et. al. (2024) attribute to El Niño events an atmospheric wave pattern from the South American Pacific (SAP) that generates a persistent high-pressure system over South America's east coast. As a result, they frequently cause flooding in southern Brazil, Uruguay and northern Argentina during El Niño years. Although the SAP pattern is strongest during spring and summer, heavy rainfall and flooding can also occur in autumn and winter, when frontal systems begin to come from higher latitudes and become trapped in the region, blocked by the persistent high-pressure system over central Brazil. Thus, the most impactful floods in southern Brazil associated with El Niño typically occur in autumn and early winter.

For Clarke et. al. (2024), ENSO, a natural climate phenomenon, can explain the rainfall variability observed in Rio Grande do Sul (Valente, 2018). However, the same authors note that human factors exacerbate flood risks. Weak enforcement of environmental laws protecting waterways and regulating land use has led to construction in flood-prone areas, increasing exposure to flooding.

It is important to consider that the three parameters that affect this set of processes are the intensity, duration and frequency of rainfall. Knowledge of these parameters is essential for land use planning and hydraulic infrastructure to mitigate flooding. Maximum rainfall is an

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extreme occurrence, with a critical duration and spatial and temporal distribution for an area or river basin. It can cause soil erosion and flooding in urban and rural areas, damage hydraulic infrastruture and cause several other losses (Bertoni; Tucci, 2007).

3 FLOODING IN THE JACUÍ AND TAQUARI RIVER BASINS

Rivers present a set of natural processes that occur cyclically anywhere on the planet. The most notable are floods, periods in which the river is filling up, usually due to intense and/or prolonged rainfall; high waters, which are related to the overflow of water from the main riverbed, reaching the plains that generally border larger bodies of water; and low water, a period in which the waters that had overflowed from the riverbed return to their normal bed (Piroli, 2022). The larger the river, the larger its flood plain, also called the main seasonal riverbed (Scartazzini *et al*, 2008). The fact that these places are flat and generally have fertile soil, means that they have been historically used for agriculture and settlement due to their proximity to water. However, population growth and increasing demand for food and housing have driven the expansion of human settlements into these flood-prone areas worldwide.

This situation places human beings and their infrastructure within the larger seasonal riverbed. Thus, when heavy rainfall occurs in larger volumes than normal over considerable areas or over the entire area of large river basins, surface runoff increases. The water that runs off the surface reaches the rivers and when their beds are full, it overflows across their plains. This process of water overflowing the riverbed and reaching people and structures is called flooding.

Flooding has increased in recent years due to factors such as more intense and concentrated rainfall in some periods; increased impermeability and soil compaction in increasingly larger areas of river basins; and occupation of river flood plains. Changes in land use, lack of planning in the occupation of land, both rural and urban, and the absence of integrated management of river basins also contribute to the increase in flood occurrences. These factors should also include the lack of knowledge or disregard for natural cycles, especially the water cycle, when making decisions (Cui *et al* 2022; Duan *et al* 2023; Teck *et al* 2023).

Thus, the he root cause of flood-related disasters is often the occupation of high-risk areas. In other words, without human presence in vulnerable floodplains or slopes, the impacts of floods and landslides would be minimal. However, as the population has increased and in the process occupied more areas, some of which are at risk, natural disasters have increased. Furthermore, climate change and changes in the way land is used increase the likelihood of extreme events (Clarke, 2024), such as the rainfall that occurred in the Jacuí and Taquari river basins and the flooding in the plains of these rivers in the second half of 2023 and the first half of 2024.

Knowing the natural, social and economic characteristics, as well as the history of the river basins, is essential to avoid or minimize losses. In the case of the Jacuí and Taquari river basins, there are records of floods with characteristics similar to those that occurred in early September 2023 and May 2024, in 1941 (Reckziegel, 2018; Valente, 2018). Since then, these episodes have been repeated in several other years, such as the flood that occurred in the city of Marques de Souza on January 4, 2010, when the waters of the Forqueta River rose rapidly

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and residents did not have time to collect their belongings or move their animals from rural properties. Many agricultural properties located near riverside areas were completely destroyed. In addition, 60% of the urban perimeter was flooded. In other words, looking at the history of the last century, it is clear that this type of event is nothing new in the region. The main difference between the first recorded floods and those occurring today is that today there are many more people and economic, social, cultural, tourist and other activities taking place in the floodplains of the rivers in the affected area. This increases the disasters, losses and deaths. And the records go back just over a century. If we carefully observe the geomorphological characteristics of the basins, with their rugged terrain and the large plains bordering the lower reaches of their rivers, we can see that these plains did not appear overnight. They are the result of processes that have been developing for thousands, possibly millions of years.

4 THE GUAÍBA RIVER BASIN

The Guaíba river basin is one of the three large basins of Rio Grande do Sul (Figure 1), formed by the sub-basins of the Jacuí, Taquari (which suffered the main flooding processes in 2023 and 2024), Caí, Sinos and Gravataí rivers. The total area of the Guaíba basin, including the lateral contribution to Lake Guaíba, is 84,763.54 km2 (Silveira, 2020).

Figure 1. Hydrographic basins and sub-basins of Rio Grande do Sul.

Source: SEMA, 2002.

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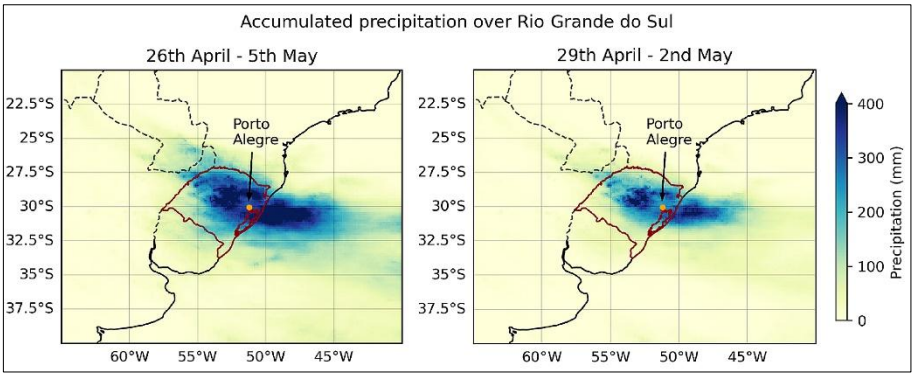
The location of the Guaíba Hydrographic Basin and its size show that the volume of water that precipitates over it during periods of intense rainfall can be very large. In the case of the rainfall that occurred between the end of April and the beginning of May 2024, it reached more than hundreds of millimeters, as can be seen in Figure 2.

Figure 2. Accumulated precipitation over the State of Rio Grande do Sul between the end of April and the beginning of May 2024.



Source: Clarke *et al*, 2024.

The extreme rainfall was driven by the persistent "South Atlantic High," a region of high pressure over eastern Brazil and the South Atlantic. This intensified the trade winds, facilitating the easterly flow of moisture from the tropical Atlantic Ocean into central Brazil, followed by enhanced moisture transport from central Brazil towards Rio Grande do Sul via the South American Low-Level Jet (SALLJ). On 26 April, the air masses traveled along a continental route, having originated from central Brazil five days earlier. The persistent high-pressure system that developed over the South Atlantic Ocean acted as a blocking system for the westerly flow. This resulted in high rainfall amounts that led to unprecedented flooding over Rio Grande do Sul (Clarke, 2024).

Rainfall volumes such as these tend to exceed the infiltration and water storage capacity of the soil, causing flash floods and flooding in riverbeds and floodplains, even under natural conditions. In the case of heavily occupied river basins, with largely impermeable and compacted soils, as well as structures for concentrating and directing runoff water, surface runoff will predominate and the volumes of water reaching the lowest points of the relief will be large.

The analysis of the area of the management units of the Guaíba River Basin (Figure 3), represented by the letter G, shows that the majority is composed of a large number of municipalities. Each of them has an urban area, normally quite impermeable. In addition, they are connected to neighboring municipalities, as a rule, by highways, which also make the soil impermeable and concentrate and direct rainwater. In addition, there are rural areas being used for the production of food and raw materials for all the people who live in the cities and for trade with other regions. In production areas, it is common the lack of soil and water conservation techniques necessary to maintain the balance of the soil-water relationship, even under normal precipitation conditions. In extreme cases, this relationship becomes even more unbalanced.

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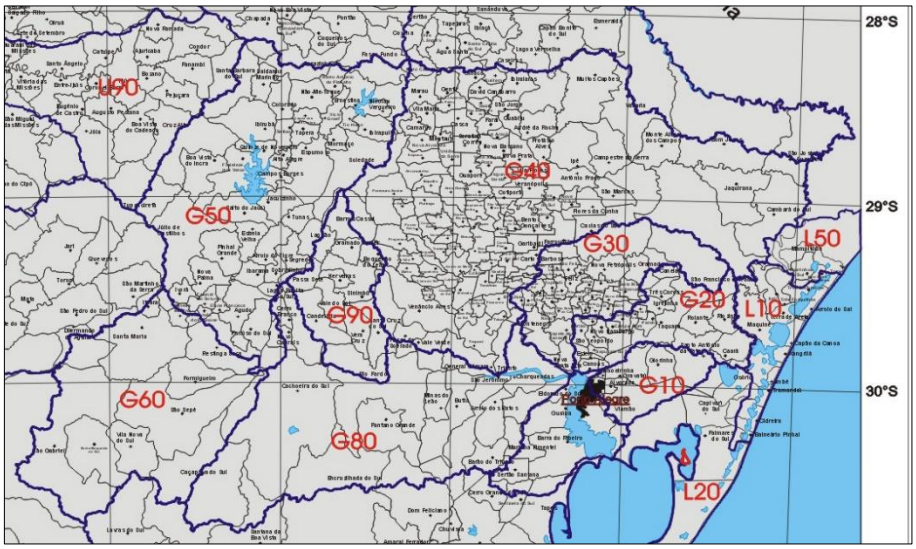
Figure 3. Large number of municipal divisions in the Guaíba Hydrographic Basin (G10 - Gravataí, G20 - Sinos, G30 - Caí, G40 - Taquari-Antas, G-50 - Alto Jacuí, G60 - Vacacaí-Vacacaí-Mirim, G70 - Baixo Jacuí, G80 - Guaíba Lake and G90 - Pardo).



Source: SEMA, 2003.

Thus, in a context of extreme rainfall, which concentrates water over the area of a large river basin, with significant areas of impermeable or compacted soil and people living in high-risk areas, the natural disasters that we saw in Rio Grande do Sul and that have been repeated throughout Brazil and the world have arisen. From there, the pressing question arises: how can we live with climate change, maintaining and improving the socioeconomic conditions of the population, the productive capacity of the soil, water, food and energy security, and also maintaining or recovering natural ecosystems, which are the basis of all existing relationships between humanity and its habitat?

5 INTEGRATED WATERSHED MANAGEMENT

One possible answer is Integrated Watershed Management (IWM). In this system, watersheds are occupied and used for human activities, taking into account the natural characteristics of the area and its limits of use. The National Water Resources Policy (NRHP) defined by Law 9,433/1997 established IWM as a framework for integrated, participatory, and decentralized water resource management, with watersheds as the primary planning unit. Water is recognized as a public good with economic value. Since 1997, Brazil has made significant institutional progress by involving municipal, state, and federal entities, private sectors, and civil society in multilevel governance. However, practical challenges persist in implementing IWM principles effectively. IWM aligns with modern concepts like nature-based solutions, as both prioritize environmental sustainability while addressing the social and economic needs of communities. By integrating ecological, social, and economic considerations, IWM offers a robust strategy to combat climate change, mitigate risks, and protect people and ecosystems.

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Key techniques for implementing IWM include:

Knowledge, improvement and application of national and state policies and legislation

Brazil has a comprehensive legal framework for land use, water management, and environmental protection. The main examples include the National Policy on Water Resources (Law 9,433/1997), the Statute of Cities (Law 10,257/2001), the National Policy on Climate Change (Law 12,187/2009), the National Policy on Solid Waste (Law 12,305/2010), the new Forest Code (Law 12,651/2012), and the Environmental Crimes Law (Law 9,605/1998).

Despite this robust legal framework, enforcement remains inconsistent, limiting the conservation of natural resources and improvements in socio-economic conditions. Effective implementation of these laws is critical to achieving their intended outcomes.

Proper territorial planning of river basins

Territorial planning is provided for in Brazilian legislation and other complementary documents, however, it often lacks clear conceptual and methodological guidance, resulting in vague applications. In the Federal Constitution of 1988, article 30, items II and VIII, are attributed to municipalities:

Art. 30. It is the responsibility of the Municipalities:

II - to supplement federal and state legislation where applicable;

VIII - to promote, where applicable, adequate territorial planning, through planning and control of the use, subdivision and occupation of urban land (Brazil, 1988).

According to Câmara and Medeiros (1998, p. 5), "Land planning works aim to regulate the occupation of space, seeking to rationalize the management of the territory, with a view to a process of sustainable development." The authors show that every action of planning, ordering or monitoring of space must include the analysis of the different components of the environment, which include the physical-biotic environment, human occupation and their interrelationship. Santos (2004) indicates that to order the territory it is necessary to consider alternatives of possible and acceptable uses.

Orea and Villarino (2014) state that territorial systems are a social construction that represents the development style of a society, through the activities that the population practices on the physical environment and the interaction between these components, through the regulatory channels that aim to provide the functionality of this system (legal and institutional framework). They recommend working with three complementary and interactive dimensions: territorial diagnosis (interpretation of the territorial system considering the historical evolution and evolutionary trends without intervention); territorial planning (or definition of a future territorial system and regulatory, intervention and management measures with a view to defining imaginable future scenarios and situations in the long term); and territorial management (understood as the set of steps to implement measures capable of directing the territorial system towards the desired scenario) (Santos, 2020). According to Ross (1994), the basic principle of territorial planning must be based on the assumption that it must prioritize development alongside conservation.

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Characterization and diagnosis of the territory of river basins

Piroli (2022) indicates that for the correct management of water in a river basin, it is necessary to identify data related to the natural water drainage system, the interferences that occurred in the basin and in the drainage, the way in which buildings and paving were built, and whether there was concern about surface runoff throughout the evolution of urban centers. He also indicates the need to seek out the management or environmental management plans of the municipalities located in the river basins, starting this search with the master plan and macro-drainage plans, if available.

Based on this, the same author recommends that diagnoses be made regarding the physical, biological, social, and economic conditions of the area, as well as the environmental guidelines established by the Public Authorities, the environmental impacts, and the systems of community participation in decision-making regarding the occupation of the basin. He also recommends surveying the legal and administrative devices of the systems for full use of water and for water security, and the monitoring, maintenance, alert, and evacuation systems (Piroli, 2022).

Implementation of IWM techniques

In the context of climate change and the intensification of extreme events, it is crucial to protect communities by protecting soil and water. Ideally, water that falls on river basins should infiltrate and remain in the system for as long as possible, reducing the risk of flash floods, erosion, silting and flooding. To achieve this, it is crucial to adopt management techniques that are appropriate to the conditions of each region and municipality in the basin, as well as each land use (Piroli, 2023).

Among these techniques, the following are mainly recommended:

a – Maintenance and recovery of as much native vegetation as possible, especially that located in areas protected by Brazilian legislation, such as Permanent Preservation Areas (PPA) and legal reserves on rural properties;

b – Soil conservation in agricultural production areas, mainly by adopting practices such as the use of level terraces and direct planting, agroforestry and silvopastoral systems;

c – Adaptation of roads and paths in rural areas, aiming to reduce the concentration of surface water and its potential for erosion and flooding;

d – Maintenance and increase of areas for safe infiltration of rainwater into the soil, such as in recharge areas located in high and flat regions of river basins;

e – Correction of errors related to the planning, management and handling of river basins in rural and urban areas, with the aim of adapting situations identified as generating negative impacts;

f – Reanalysis of the forms of urban land occupation and adaptation aiming at the development of resilient and smart cities. In this case, strategies such as green infrastructure, permeable pavements, infiltration/detention basins, adaptation of trees and, mainly, constant adjustments and maintenance of systems for protecting soil, water and the population against

extreme phenomena can be adopted. Furthermore, it is very important that all urban areas have their drainage plans integrated with the plans of the river basins in which they are located.

g – Implement municipal environmental education strategies applied to the knowledge of the reality of each municipality, its location in the river basin and the ways in which it impacts it aiming to develop awareness of environmental integration and the impacts and risks contained in this relationship;

h – Effective participation of municipalities in river basin committees so that, together, they can get to know the area where they live, plan its use in a way that maximizes gains and reduces losses, both environmental and social and economic.

I – Creation, expansion and maintenance of monitoring and alert systems, as well as real-time dissemination of data to the population. In addition, establish a training schedule for evacuation and provide shelter structures for homeless people and those rescued in extreme cases.

J – Develop municipal, state and national policies, by river basin, to define risk areas and relocate the populations living in these places to new safe and adequately structured spaces.

In addition to this set of techniques, Piroli (2023) also recommends including the theme of rivers and their river basins in the school curricula of the municipalities in the area of each basin; implementation of ecological corridors connecting PPA, legal reserves and conservation units in the basins; establishment of partnerships and support for environmental education activities of the River Basin Committees, schools, universities, NGOs and other institutions operating in the area.

The same author also recommends the creation of structures to support partners in obtaining resources from public and private programs; implementation of projects incentivizing rural producers through payment for ecosystem services; monitoring of results by analyzing the water resources and biodiversity of the region; support for scientific research to collect basic data related to the basins; support for university extension projects to identify the socio-environmental demands of the population and to propose solutions (Ghalehteimouri *et al*, 2024).

Furthermore, Piroli (2023) indicates the importance of supporting the articulation of municipalities with territory in the basins, with the purpose of conserving soil and water and environmental recovery aiming at water production, water, food and energy security for the population; and the establishment of agendas for municipal secretaries and mayors in a bloc with state governments and state and federal deputies in order to secure funding for basin-level projects.

6 CONCLUSION

Brazil is a country with a vast territorial area of over 800 million hectares, which, divided by the number of Brazilians residing in the country in 2024, offers approximately 4 hectares (40 thousand square meters) for each person. Even excluding risk areas, conservation units and those with special purposes from this total, there are still many millions of hectares of flat land suitable for sustainable human settlements. In this context, it is unacceptable that lives continue to be lost every year in episodes of extreme rainfall.

Currently, there is a fairly robust body of knowledge in universities and in science in general, which allows us to understand in detail the conditions of the Brazilian territory. Likewise, it is possible to develop, within scientific precepts, plans and goals for the adaptation of land use in all river basins. However, political will is needed on the part of representatives of the population to make the right decisions to adapt land use, protect ecosystems, increase the resilience of communities and save lives.

In this sense, it is also important for people to increase their awareness of the areas where they live, identifying potential risks and knowing ways and means of escape, if necessary.

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DECLARAÇÕES

CONTRIBUIÇÃO DE CADA AUTOR

Ao descrever a participação de cada autor no manuscrito, utilize os seguintes critérios:

- **Concepção e Design do Estudo**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Curadoria de Dados**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Análise Formal**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Metodologia**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Redação - Rascunho Inicial**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Redação - Revisão Crítica**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias
- **Revisão e Edição Final**: Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias

DECLARAÇÃO DE CONFLITOS DE INTERESSE

Eu/Nós, Edson Luís Piroli; Adão Robson Elias; Wanda Luquine Elias, declaro(amos) que o manuscrito intitulado - A contribuição do manejo integrado de bacias hidrográficas para a resiliência frente às mudanças climáticas : o caso das inundações no Rio Grande do Sul

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