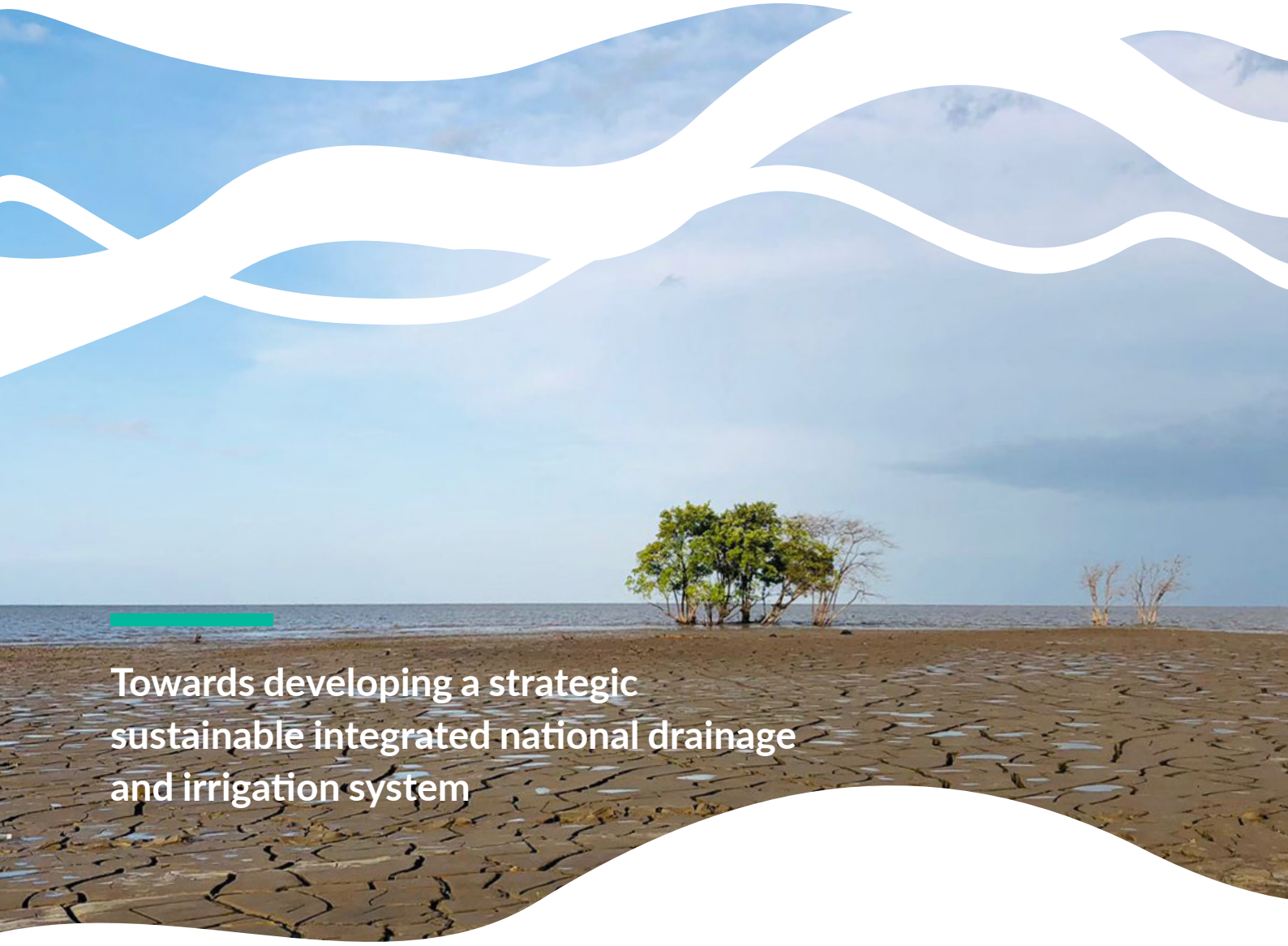
Making the case for resilient drainage and irrigation systems in Guyana



Towards developing a strategic sustainable integrated national drainage and irrigation system

National Drainage & Irrigation Authority
MINISTRY OF AGRICULTURE

GGGI

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Coalition for Disaster Resilient Infrastructure
IRAF
Infrastructure Resilience Accelerator Fund
IRIS

This Technical Study on ***Making the Case for Resilient Drainage and Irrigation Systems in Guyana*** was developed by the Global Green Growth Institute (GGGI) and the National Drainage and Irrigation Authority (NDIA).

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1. Summary

Floods are not new; they have been occurring over the years and yet they continue to challenge government interventions in responding to every possible outcome. Reports on urbanisation spread, aging infrastructure, maintenance and operations of equipment are the underlying themes, but do they really account for why flooding occurs on the coastal regions in Guyana. Looking back at the functions of NDIA, urban floods are not priority as the agency remains committed to monitoring riverine flooding that affects farmland in rural settings. To give a clearer picture, urban flooding is under the purview of the Ministry of Local Government and Regional Development with NDIA providing technical maintenance support in addition to managing and operating their own drainage and irrigation infrastructure. However, the 2005 national flood – which was caused by an enormous breakaway of sea defence and resulted in a devastated damages where the government machinery was unprepared to tackle a disaster of that magnitude – was a driving force for NDIA to rethink its approach in urban flooding in addition to riverine flooding.

Moreso, there is increased pressure on the agriculture sector in Guyana to innovate, create jobs, increase export revenue and offer local consumers with quality food, thereby building on the government initiative of '25 by 2025'. The sector is also being directly affected by climate change scenarios where processes of droughts and rainfall are becoming erratic and unpredictable, increase salinity and fluctuating temperatures[1], all of which affects productivity and loss of national revenue. Safeguarding agricultural infrastructure, particularly drainage and irrigation assets from these unfavourable consequences of climate change is necessary as the agriculture sector is highly dependent on rainfed irrigation. Given that a significant number of productive lands are located in the low-lying coastal plains, drainage and irrigation (D&I) infrastructure are critical to maintaining agricultural productivity in changing climate conditions.

To make matters worse, the drainage and irrigation infrastructure around Georgetown and other regions are considered dire need of rehabilitation or lack the efficiency to manage storm water and flooding. For instance, the lack of operation and maintenance of D&I assets has led to failure of koker structures at Canal No 1[2]; Providence[3], and Grove[4], which led to flooding and threatened the livelihoods of communities and ecosystems. As such, there is urgent need to investigate government strategies relating to D&I and flood management to avoid projected and future flood-like events. Recognising the state of D&I assets, the National Drainage and Irrigation Authority (NDIA) has prioritised an integrated and sustainable drainage and irrigation strategy to solve water challenges and mitigate flooding and entrusted the task of interrogating this through baseline studies of existing conditions to the Global Green Growth Institute (GGGI).

The GGGI Guyana country team went about this process in a very systematic manner, starting with creating a baseline analysis of the existing D&I conditions. A comprehensive assessment of Guyana's existing drainage and irrigation infrastructure, particularly its capacity to manage excess water, is contingent upon the availability of accurate and reliable data. This includes detailed information on the structural integrity, hydraulic capacity, and operational efficiency of drainage networks, canals, and associated flood management systems. It is important to also recognised that an effective disaster risk reduction and flood mitigation strategies rely on a robust understanding of these existing systems,

1 Karri, V., & Nalluri, N. (2024). Enhancing resilience to climate change through prospective strategies for climate-resilient agriculture to improve crop yield and food security. Plant Science Today, 11(1), 21-33.

2 Staff Reporter. (October 3, 2024). President Ali mobilises quick response to koker failure at Canal. Guyana Chronicle, https://guyanachronicle.com/2024/10/03/president-ali-mobilises-quick-response-to-koker-failure-at-canal/

3 Staff Editor. (September 8, 2022). Koker door collapses at Providence, 200 households affected. Stabroek News, https://www.stabroeknews.com/2022/09/08/news/guyana/koker-door-collapses-at-providence-200-households-affected/

4 'Major flooding in Grove after koker breaks away'. (August 19, 2020). iNews Guyana, https://www.inewsguyana.com/major-flooding-in-grove-after-koker-breaks-away/

ensuring that interventions are both data-driven and context-specific. While designing new D&I systems from a project perspective may seem straightforward, overlooking the interconnectivity and functionality of existing drainage networks can lead to inefficiencies, redundancies, and potential system failures. Recognizing this, GGGI has taken a strategic approach that prioritizes a thorough evaluation of current D&I infrastructure and institutional frameworks before proposing new interventions. An integrated and sustainable D&I strategy can only be realized if the existing systems are accurately mapped, analyzed, and aligned with future developments.

The development of an effective drainage and irrigation strategic plan must be informed by extensive research into global best practices that demonstrate applicability in Guyana's hydrological and climatic context. This involves assessing adaptive engineering solutions, nature-based interventions, and digital monitoring technologies that enhance resilience to extreme weather events. Such an approach ensures that Guyana's D&I framework is not only technically sound but also sustainable, adaptive, and responsive to evolving environmental and socio-economic challenges.



A section of the seawall eroded due to structural failure, causing flooding of over 1,000 hectares of rice farmland. As a result, the affected area remains uncultivable due to the high salt content left by the seawater intrusion.

2. Introduction

2.1 Setting the context and rationale

The unique geography and socio-economic conditions of Guyana have given rise to flood, droughts and environmental hazards that are overburdening the country's infrastructure. These risks are compounding everyday with the rise in greenhouse gas emissions and poses a significant threat to the country's booming oil and gas sector and its transition towards a low-carbon economy. In this context, building resilience for effective functioning of critical infrastructure networks such as water, energy, transport along with physical infrastructure such as housing, educational and health institutions become necessary[5]. The intensity of water related shock and stresses faced by the different regions in Guyana are evident with unexpected coastal floods. Such untimely events disrupt socio-economic activities and cause damages to critical infrastructure in addition to impacting lives and livelihoods of citizens[6]. For example, in May 2021, more than 48,720 households were impacted by flooding across all ten regions in Guyana. The flood caused damages to homes, livestock, farms and buildings which were primary sources of safety and income for many people[7]. Such events that cause flooding in coastal cities are increasing due to climate change where the IPCC Sixth Assessment report modelled past storm surge and highlighted high variations of risk along the coastlines, due to exposure, topography and bathymetry[8]. However, proper urban infrastructure planning and management can influence vulnerability by reducing exposure to flooding.

2.1.1 The IRIS-Funded Coastal Resilience Project

The Infrastructure for Resilient Island States (IRIS) project is a multi-year initiative funded by the Infrastructure Resilience Accelerator Fund (IRAF) through its IRIS. The project is designed to support the Ministry of Agriculture (MoA) in developing an Integrated Strategy for Draining and Irrigation (ISDI) for the period 2025-2030, aligning with Guyana Low Carbon Development Strategy 2030 (LCDS 2030) and enabling inter-ministerial collaboration on Drainage and Irrigation (D&I) and flood management efforts. The updated ISDI will guide the National Drainage and Irrigation Authority (NDIA)'s decision-making regarding operations, investment prioritization, and resource allocation. The project's specific objectives are to reduce Guyana's vulnerability to floods through integrated planning while supporting institutional strengthening and improved capacity in addition to enhancing data collection and management to measure impact while emphasizing collaboration. With a completed ISDI, the project aims to support the government in taking D&I planning one step further by offering technical support and training to enable the ISDI through enhanced data collection and the development of prioritization systems that can enable a greener and more inclusive D&I system. As the fastest growing economy in world, the government of Guyana faces a massive challenge in channelling financing into effective development over the coming years. This project therefore proposes to specifically address the following key challenges:

- Reducing Guyana's vulnerability to floods through integrated planning
- Supporting institutional strengthening and improving capacity
- Enhancing data collection and management to measure impacts

Discussions during the project inception phase highlighted various ongoing efforts regarding strategic planning and capital works development, including the implementation of the $46M GRIF-funded World Bank

5 Rajasekar, U. et al. (2022). Catalogue of Best Practices for Building Flood Resilience. Climate Centre for Cities, National Institute of Urban Affairs (NIUA) in association with The World Bank.

6 Lionel Wordworth. (September 2024). Welcome address at the NDIA Strategic Planning Workshop. Global Green Growth Institute, Guyana.

7 IFRC. (2022). DREF Final Report-Guyana Floods. International Federation of Red Cross and Red Crescent Societies (IFRC).

8 Mycoo, M. et al. (2022). Small Islands. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Sixth Assessment Report to the Intergovernmental Panel on Climate Change.

interventions.

2.1.2 Addressing climate implications for drainage and irrigation in Guyana

Guyana's drainage and irrigation (D&I) infrastructure can be considered the lifeline of the country as it sustains more than 90% of the population and nearly all of the productive agricultural lands[9], in addition to mitigating climate-induced flood risks. However, much of the system is outdated, with poor river gradient flow, inadequate drainage capacity, and ineffective maintenance. Climate change has also intensified these challenges, increasing the frequency of extreme rainfall, prolonged droughts, and rising sea levels, which threaten both food security and infrastructure stability. For instance, under the IPCC's SP2 scenario using the 83rd percentile projection, sea level rise in Guyana is estimated at approximately 0.18 metres by 2030, increasing to 0.37 metres by 2050 and reaching 0.71 metres by 2080[10]. These projections underscore the increasing risk to Guyana's low-lying coastal areas, where even moderate sea level rise can significantly compromise the reliability and performance of drainage and irrigation systems, exacerbate saline intrusion into agricultural lands and increase the frequency of coastal flooding events[11].

To address these vulnerabilities, there is need for a long-term climate-resilient D&I strategy that must firstly, recognise the local and regional challenges and secondly, integrate data-driven management, nature-based solutions (NbS), and global best practices to enhance system efficiency and sustainability. Currently, the D&I sector faces critical challenges, including insufficient hydrological data, fragmented institutional governance, and inadequate private investment in infrastructure rehabilitation[12]. Failures in flood control structures, such as kokers and sluice gates, have led to severe flooding[13], highlighting the urgent need for predictive modelling and improved coordination.

There is also the need to explore global practices to provide valuable insights into building resilience. Cities in Singapore and India emphasize real-time monitoring and digital hydrological models to optimize water management, while the Netherlands demonstrates how NbS, such as wetlands restoration, can enhance flood mitigation[14]. Nepal's irrigation strategy highlights the importance of decentralized governance and farmer-led water management[15], an approach that could be adapted to strengthen community-driven D&I initiatives in Guyana.

Against the background, this study and the project to a larger extent, attempts to integrate flood resilience in Guyana's D&I systems through a strategic approach that involves multiple interventions. Specific outputs of the study will address why data-driven water flow management should be prioritized through GIS mapping, remote sensing, and IoT-based flood forecasting to enhance decision-making. Incorporating NbS, such as mangrove restoration, floodplain zoning, and green infrastructure, can improve drainage efficiency while supporting biodiversity and groundwater recharge. Decentralized governance mechanisms, including strengthened Water User Associations (WUAs) and improved interministerial collaboration, will ensure more efficient and locally responsive D&I management. Additionally, targeted investments leveraging climate finance and public-private partnerships will be essential for modernizing infrastructure and expanding adaptive capacity. Implementing these measures will ensure that Guyana's D&I system remains sustainable, adaptive, and capable of addressing future environmental and economic challenges.

9 Ministry of Agriculture. (2014). A National Strategy for Agriculture in Guyana 2013-2020. Ministry of Agriculture, Government of Guyana.

10 World Bank, Climate Change Knowledge Portal. (2025). URL: https://climateknowledgeportal.worldbank.org. Date Accessed: 21st May 2025

11 Cazenave, A., & Cozannet, G. L. (2013). Sea level rise and its coastal impacts. Earth S Future, 2(2), 15–34. https://doi.org/10.1002/2013ef000188

12 National Drainage and Irrigation Authority. (2017). Data collection survey on drainage capacity in Georgetown in the Co-operative Republic of Guyana. Ministry of Agriculture, Government of Guyana and Japan International Cooperation Agency.

13 Newsroom. (January 19,2023). Faulty work by contractor at Princes Street koker results in flooding.

14 Climate Centre for Cities, National Institute of Urban Affairs (NIUA) in association with The World Bank (2022). Catalogue for best practices for building flood resilience.

15 Department of Water Resources and Irrigation. (2019). Irrigation Master Plan 2019. Ministry of Energy, Water Resources, and Irrigation, Government of Nepal.

2.2 Objectives of the study

The study is aimed at understanding the challenges with the current scenario of drainage and irrigation management and thereby suggesting approaches which focus on lowering the hydrological impact of riverine flooding in the coastal regions of Guyana. The study also highlights the impact of storm water management in Guyana, in the context of climate change and changing land use land cover as Guyana rapidly develops and urbanises.

The objectives of the study are:

- Assess the existing drainage and irrigation infrastructure in Guyana, and identify deficiencies in policy, planning and designing of infrastructure for flood management and irrigation.
- Identify various structural and non-structural issues in flood management and irrigation planning in coastal regions.
- Present global best practices for drainage and irrigation management, and infer key learnings and applicability for local context.
- Recommend principles and strategies for drainage and irrigation management for Guyana regions based on best practices.



A minor section of mangrove remains, and a mitigation measure has been put in place to provide internal drainage just behind the existing earthen seawall, which is reinforced to temporarily mitigate erosion while adaptation measures are implemented. A green-grey infrastructure solution is currently being developed to address this issue.

2.3 Scope and limitations of the study

This study is geographically focused on Guyana's coastal regions, particularly Regions 2, 3, 4, 5, and 6, which collectively represent the most densely populated zones and contain the highest concentration of agricultural activity. These regions also have the most extensive drainage and irrigation infrastructure and are consequently the most vulnerable to coastal flooding and sea-level rise. The study prioritizes these areas due to the critical importance of safeguarding farmland, settlements, and livelihoods against increasingly frequent and intense climate-related hazards.

Data collection and analysis are therefore concentrated within these coastal regions, with a strong emphasis on collaboration with the National Drainage and Irrigation Authority (NDIA), as well as other relevant government agencies involved in D&I planning and resilience-building. A key limitation of the study is its restricted geographic scope, which may not capture the full extent of inland vulnerabilities, or the unique challenges faced by hinterland regions. Additionally, the study is dependent on the availability and accessibility of spatial, hydrological, and infrastructure data, which may vary in completeness across agencies.

3. Towards a Resilience Planning Framework

3.1 Definition of resilience in the context of drainage and irrigation in Guyana

The report on UN Common Guidance on Helping Build Resilient Societies, defines **resilience** as:

The ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all[16].

- Systems thinking approach that recognises the interconnectedness of the social, ecological, economic and governance structures across scales, and how changes in one component can have multiplying effects on others
- Inclusive and gender-responsive stakeholders' engagement to ensure community needs and knowledge are integrated in risk management
- Multiple capacities in anticipation, adaptation, accommodation and transformation, to ensure institutions and societies recover and evolve in more robust ways.

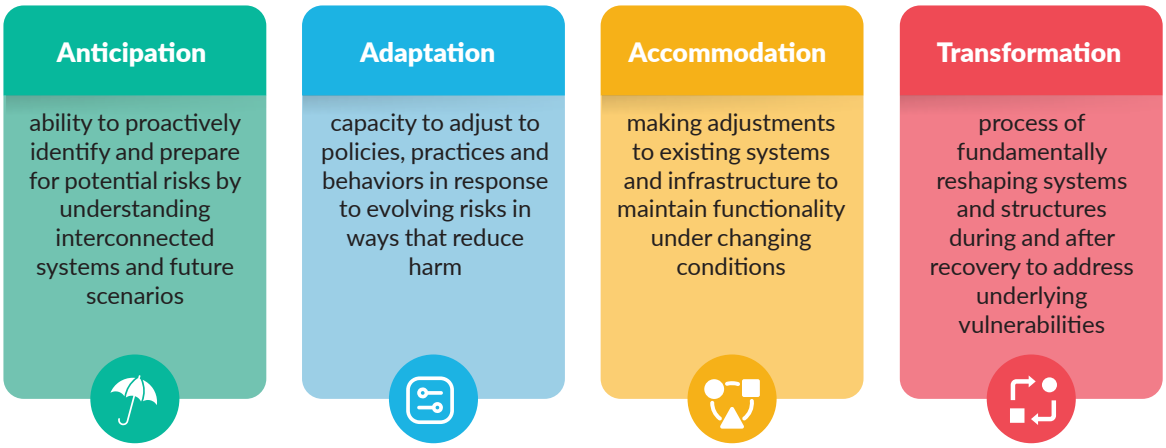


Figure 1. Elements of resilience. Adapted from the UN Common Guidance on Helping Build Resilient Societies

This definition entails four key elements (Figure 1) of anticipation, adaptation, accommodation, recovery and transformation from the effects of a hazard.

Investing in resilience is not only about reducing the adverse effects of a hazard but also to keep transforming and strengthening the institutions and structures to be more resilient in the threat of emerging challenges. Therefore, when thinking of what resilience means for the drainage and irrigation system in Guyana, it needs to be grounded on four thinking:

- Understanding the risk – its drivers and dimensions – within a specific political, socio-economic and environmental context

Recognising the intentions of this section is to derive an understanding of resilience in D&I, and incorporating guidance from above, resilience should capture the D&I infrastructures and address the dominant risks of sea-level rise and flooding – riverine and urban. To this end, defining resilience for D&I can be:

The capacity of D&I infrastructures, institutions and communities to anticipate, adapt and transform from climate-induced risks relating to urban and riverine flooding, sea level rise, and rainfall variability without affecting agricultural productivity, livelihoods or development trends.

16 United Nations. (2020). UN Common Guidance on Helping Build Resilient Societies. United Nations Sustainable Development Group.

This definition reflects not just the reliance of canals, pumps, and sluices, but also the ability of NDIA systems and stakeholders to adapt in real-time, accommodate hydrological changes, and transform when existing approaches becomes inadequate to recover from complex climate shocks. Ultimately, resilience in D&I systems should be about ensuring continuity of livelihoods, agriculture systems and national development while being able to respond to emerging climate challenges.

3.2 Principles of resilience infrastructure design and planning

In order to overcome climate challenges, there are several development measures that cities can adopt to build flood and water resilience. According to a report by the Climate Centre for Cities, National Institute of Urban Affairs (NIUA) in association with The World Bank, four key interventions and best practices (Figure 2) have been developed by learning from global cities for mitigating floods and building resilience[17]:

• Nature-Based Solutions (NbS)

A widely recognized intervention, these approaches emphasize restoring and utilizing natural ecosystems to manage flood risks, improve drainage, and enhance resilience. Case studies such as mangrove restoration in Mumbai, wetland conservation in Kolkata, and river restoration in Chennai highlight the role of ecological restoration in mitigating flood risks. These interventions reduce surface runoff, enhance water retention, and improve biodiversity while supporting community livelihoods and groundwater recharge. In Guyana, integrating NbS into the D&I framework could involve mangrove restoration along the coast (already established cases in Guyana), wetland conservation for natural water storage, and the promotion of agroforestry practices to manage excess water in agricultural landscapes.

• Planning Interventions

At the macro level, regional planning plays a crucial role in minimizing flood risks and ensuring long-term D&I resilience. The Room for the River program in the Netherlands showcases how spatial planning can create buffer zones and expand floodplain capacity. Similarly, Cape Town's water resilience strategy and Kanpur's river-centric master plan illustrate how urban flood risk management can be incorporated into city development frameworks. In Guyana, this underscores the need for Integrated Water Resource Management (IWRM), floodplain zoning, and river basin management strategies that align with national climate adaptation policies such as the Low Carbon Development Strategy (LCDS) 2030.

• Technological Interventions

The use of advanced digital tools and real-time monitoring enhances proactive flood preparedness and response. Early warning systems in Guwahati and Kolkata, hydrodynamic modeling in Jakarta, and cloudburst management in Copenhagen exemplify how data-driven decision-making can improve D&I operations. For the case in Guyana, deploying GIS-based flood risk mapping, real-time water level sensors, and AI-driven predictive models can optimize D&I infrastructure management, ensuring proactive rather than reactive responses to extreme weather events.

• Infrastructural Interventions

Hard-engineered solutions remain a critical component of flood resilience, particularly in densely populated areas. Examples such as Tokyo's underground flood defense system, Singapore's water management strategy, and Delhi's stormwater drainage network demonstrate the importance of reservoirs, embankments, flood tunnels, and retention basins. In Guyana, modernizing D&I infrastructure should include technology-enhanced sluice gates and kokers, expanding retention and detention basins, and improving pump station capacity to manage storm surges and high-intensity rainfall events.

17 Climate Centre for Cities, National Institute of Urban Affairs (NIUA) in association with The World Bank. (2022). A catalogue of best practices for building flood resilience.

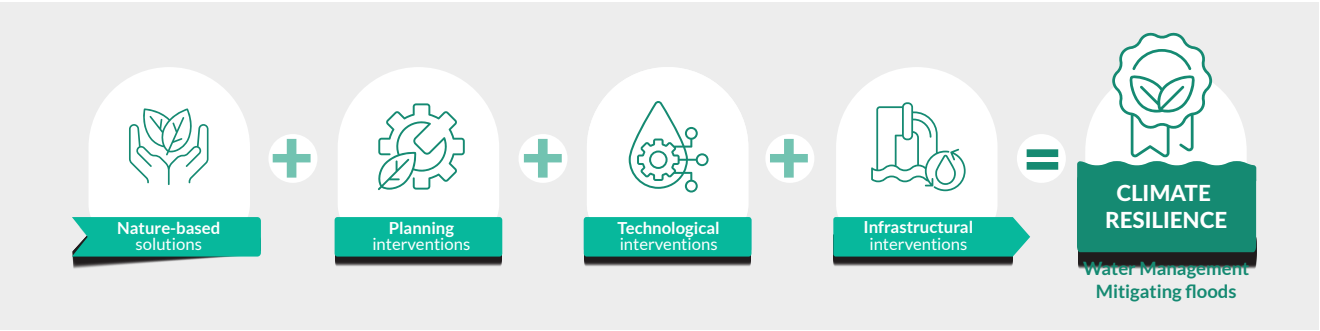


Figure 2. Best practices for integrating resilience in flood management

Before applying these global best practices to Guyana's D&I sector, a critical understanding is needed as to how to combine NbS with advanced planning, digital technologies, and resilient infrastructure. Towards this end, government will need to prioritize integrated, multi-sectoral coordination, investment in climate-smart infrastructure, and community engagement to enhance long-term D&I and flood resilience.

3.3 Global best practices of resilience drainage and irrigation planning

3.3.1 The Case of Nepal

The Irrigation Master Plan 2019 for Nepal provides valuable insights and approaches for developing countries to create and effective and sustainable master plans for drainage and irrigation. The plan highlights the need for a comprehensive and integrated approach, prioritizing food security, embracing innovation and sustainable solutions, and building strong institutional capacity. A key takeaway from the plan is the importance of a demand-driven approach to irrigation development, which aligns projects with the evolving values of the community. Such transformations should focus on governance, participation and social development instead of physical infrastructure, thereby enabling drainage and irrigation systems to be both technically efficient and socially just. The learning lessons and approaches of the Nepal Plan are discussed below[18]:

Prioritize comprehensive and integrated D&I planning

Detailed mapping of water resources is critical, including identification of different ecological zones, soil types and irrigation potential. Recognizing the interconnectedness of D&I systems with other sectors needs to be emphasized for integrating these systems within agriculture, watershed management and flood control.

Strategic Transformative Approach

The plan prioritizes the development of D&I systems that address food security demands and highlights the need to increase irrigation access through inter-basin transfers and groundwater development, thereby providing support for seasonal water scarcity. The modernization of existing D&I systems to improve efficiency needs to integrate water management to user groups, private sectors, or sub-national bodies to manage transfer and ensure effective utilization.

Empowering Water Users Association

There is an urgent need to promote capacity development and training of WUA in areas such as irrigation management, operation, maintenance and financial management. This would entail equipping WUA's to enforce, collect service fees, and address conflict effectively.

Groundwater Development

Groundwater development is recognized as potential for a more efficient and cost-effective option for irrigation in areas where surface water development is constrained by environmental factors or long implementation timelines. As such, there is a need for comprehensive assessment of groundwater resources, including recharge rates and demand.

18 Department of Water Resources and Irrigation. (2019). Irrigation Master Plan 2019. Ministry of Energy, Water Resources, and Irrigation, Government of Nepal.

Financing and Prioritizing Irrigation Projects

Economic and feasibility studies prioritize projects based on their cost-benefit ratio in terms of different irrigation approaches, like surface water versus groundwater development and others. D&I plan should also develop appropriate frameworks to attract private investment and ensure long-term project sustainability.

The key principles and approaches in Nepal's D&I plan will need to consider the unique characteristics and socio-economic conditions of developing countries and can contribute to the creation of effective and sustainable D&I systems.

3.3.2 The Case of Delhi NCT

The Drainage Master Plan for the NCT of Delhi is a comprehensive study to address the chronic flooding issues in the city. It starts with a thorough analysis of the existing natural and engineered drainage systems, including an inventory of storm drains, water bodies, and pumping system. The plan demonstrates a dynamic model to simulate flood conditions under various scenarios, evaluating the effectiveness of existing infrastructure and exploring potential interventions and low-impact development (LID) options to mitigate flooding. The highlights and best practices of the plan are discussed below[19]:

Data Accuracy and Validity

There is a paramount need for accurate and validated data on existing drainage systems as incomplete or erroneous data can lead to inaccurate simulations and ineffective planning.

Interministerial Coordination

Successful drainage and irrigation planning depends heavily on effective coordination among relevant departments and agencies. The lack of coordination in Delhi has led to duplicated efforts, data silos and inconsistent management practices, thereby compromising the effectiveness of drainage networks.

Detailed Drainage Network Assessment

An inventory of all drainage structures, including natural drains, engineered drains, pumps, and water bodies is critical to evaluate the overall drainage network performance and adequacy in terms of conveyance capacity, flooding hotspots, and impact of existing infrastructure on flood runoff. Deploying hydraulic modeling to stimulate storm water flow under various conditions can help identify flooding hotspots and assess the adequacy of conveyance capacity.

Simulation Scenarios and Validation

Multiple simulation scenarios should be used to evaluate different intervention strategies. A baseline scenario of the current drainage system provides for a comparison and helps to identify areas most vulnerable to flooding. Intervention scenarios, such as changes to drainage cross-section, constructed wetlands, and the implementation of low impact development options, allow for evaluating the effectiveness of these interventions. Comparing the model simulations with actual flooding data helps to ensure the model's accuracy and reliability.

Low-Impact Development Options

Incorporating LID options into the drainage master plan such as bio-retention ponds, infiltration trenches, and rain gardens can effectively manage excess runoff, reduce flooding and promote ground water recharge. These options should also consider on-site specific conditions such as soil type, land use and available space. Simulating the drainage system with incorporated LID options can help to quantify the impact of these interventions and demonstrate their effectiveness in reducing floods.

Infrastructure and Maintenance

Consistent and proactive maintenance of drainage infrastructure is required including desilting drains, removing encroachments, and preventing the dumping of solid waste and sewage. Designing appropriate regulations for enforcement may be necessary to ensure compliance with the drainage plan.

Public Engagement

Educating the public about the importance of drainage infrastructure and responsible waste management can promote responsible practices such as avoiding disposal of waste into storm drains and utilizing alternative methods of storm water management.

19 Indian Institute of Technology Delhi. (2018). Drainage Master Plan for NCT of Delhi. Final report prepared for Department of Irrigation & Flood Control, Government of Delhi.

By implementing these learnings, it is possible for developing countries to develop a roadmap for sustainable drainage management and improve flood control.

3.3.3 The case of the African Union's Framework for Irrigation Development and Agricultural Water Management (IDAWM)

The IDAWM framework outlines strategies and approaches for sustainable irrigation development across the African continent and highlights several key lessons learned from past irrigation projects in Africa, including[20]:

- Irrigation contributes to poverty reduction and economic growth: Investments in irrigation and agricultural water management (AWM) generally produce positive returns. Irrigation systems create jobs during construction and stimulate economic activities in the agricultural value chain.
- AWM leads to increased land and water productivity: Irrigation can significantly increase cropping intensity, allowing for more food production on less land. This benefits both farmers and the environment by reducing land pressure and mitigating the need for expansion into more sensitive ecosystems.
- Small-scale irrigation offers high returns compared to large-scale projects: Small-scale irrigation schemes typically generate higher returns on investment for individual farmers than larger, centrally managed schemes. The document emphasizes that while large-scale schemes can play a role, particularly for infrastructure development, the majority of future irrigation expansion should focus on supporting small-scale irrigation development.
- Water harvesting and conservation add resilience to rain-fed agriculture: The IDAWM document stresses the importance of rainwater harvesting and soil water management practices for enhancing resilience in rain-fed agriculture. These practices can significantly increase crop yields and help to mitigate the impact of droughts and climate change.
- Integrated agricultural water management projects are more successful: The framework emphasizes the importance of taking an integrated approach to AWM, incorporating both social and environmental factors into project design and implementation. Success is more likely when projects integrate water management with land use, crop production, and community development.

The IDAWM document proposes four pathways for irrigation development, each with its own set of interventions:

- Improved water control and watershed management in rain-fed farming: This pathway focuses on utilizing water-harvesting techniques, conserving soil moisture, and adopting climate-smart agriculture practices to increase production in rain-fed systems.
- Farmer-led irrigation development: This pathway focuses on supporting small-scale irrigation schemes led by farmers, providing access to technology, finance, and secure land tenure. The aim is to promote entrepreneurial activities and market-oriented production.
- Irrigation scheme development and modernization: This pathway emphasizes the need to rehabilitate and modernize existing irrigation schemes, particularly those that are publicly managed. The document stresses the need for a shift towards commercially viable irrigation farming and the establishment of strong water user organizations.
- Unconventional water use for irrigation: This pathway acknowledges the potential for re-using wastewater, desalination, and other unconventional water sources for irrigation. The framework emphasizes the importance of ensuring safety and mitigating environmental risks associated with unconventional water use.

Beyond the four pathways, the IDAWM framework also identifies several cross-cutting issues that need to be addressed for successful irrigation development. These include:

- Inclusiveness: The importance of including women, youth, and other marginalized groups in irrigation development is highlighted. The document advocates for greater participation by these groups in decision-making processes and access to resources and training.
- Private sector involvement: The document encourages private sector investment in irrigation,

20 African Union. (2020). Framework for Irrigation Development and Agricultural Water Management in Africa.

recognizing its potential for co-financing, innovation, and competitiveness. This necessitates creating an enabling environment for private sector participation through appropriate policies and regulations.

- Climate change adaptation and resilience: The document emphasizes the need to integrate climate change adaptation and resilience into all aspects of irrigation development. This includes promoting practices that build resilience, such as diversification of farming systems, water-efficient irrigation technologies, and soil and water conservation measures.
- Micro-credit and agricultural financing mechanisms: The IDAWM document acknowledges the importance of access to affordable financing for small-scale irrigation projects. It recommends developing appropriate financing mechanisms and strengthening institutional support for microfinance institutions.
- Policies, institutions, and governance arrangements: The document underscores the need for enabling policies and strong institutions to facilitate the effective implementation of irrigation schemes. These include clear regulations regarding land tenure, water rights, and the operation and management of irrigation schemes.
- Improving water and soil quality and other environmental problems: The document emphasizes the importance of addressing environmental problems such as soil degradation, water pollution, and salinization. These problems can negatively impact irrigation schemes and reduce their long-term productivity.
- Research, monitoring, evaluation, and knowledge transfer: The IDAWM document recognizes the need for ongoing research, monitoring, evaluation, and knowledge sharing to improve irrigation development practices. This involves collecting data on existing irrigation schemes, evaluating the effectiveness of different interventions, and disseminating best practices.

Overall, the IDAWM framework offers a comprehensive and valuable contribution to the discourse on sustainable irrigation development in Africa. Its emphasis on a multi-pronged approach, inclusive development, and a focus on both social and environmental aspects of irrigation is commendable. The framework provides a roadmap for policymakers, researchers, and practitioners working towards the goal of achieving food security and sustainable agricultural development in Africa through effective and responsible use of water resources. In the context of Guyana, the framework provides learning lessons on integrated approaches such as combining farmer-led irrigation, water harvesting and adaptive governance which aligns with the need to address sea-level rise, infrastructure gaps and saline intrusion. By prioritizing smallholder participation, Guyana can foster decentralized resilience through empowering communities to manage water resources more efficiently and adapt cropping patterns to climate variability.



A rice farmer doing land preparation to plan the next crop. Land preparation for large-scale rice cultivation in Berbice. This aspect of land preparation requires significant freshwater because rice is cultivated in flooded fields.

4. Methodology

For capturing and identifying the needs of the study, it becomes necessary to outline the proper directions of carrying out the methods and deploying tools. This helps to justify and provide weightage to the results. The data collection design is considered the most important step in providing a direction to the project objectives and deals with aspects such as the type of tool required and approaches for the data analysis . Obviously, having a well-planned structure for the data needs and methods does not simply guarantee that the objectives will be achieved as what is required is the articulation and cohesion to stitch together the different sections set out in the study. Thus, by following the guidelines in Figure 3, the study ensures that the purpose behind the data collection strategy is fulfilled and also the study is conducted within all corners of the stated objectives.

4.1 Data collection

The study is based predominantly on empirical data as well as secondary and existing documents due to the nature of the objectives.

4.1.1 Literature review

A comprehensive desk analysis of secondary literature including annual reports of NDIA, previous project reports and published literature was carried out, utilizing the literature survey questionnaire identified in Annexure 1, and aimed to uncover the major causes of flood and the challenges to the existing D&I system. These steps are important in the data collection process as it supports future planning of D&I improvements.

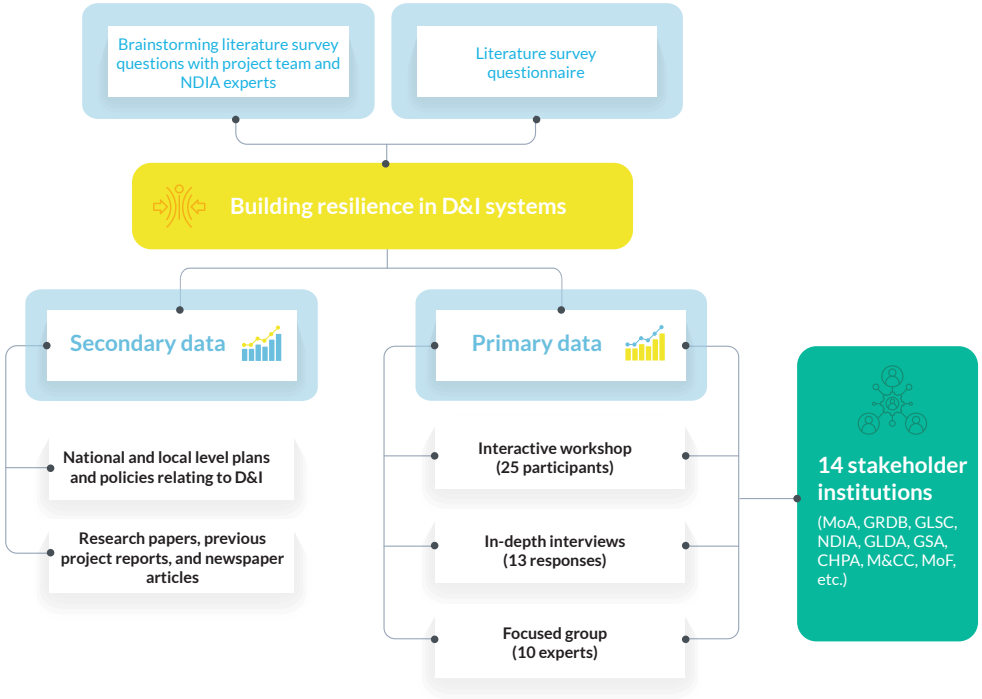


Figure 3. Methods of data collection

21 Joshi, P. (2019). Research Design: CRC Press.

4.1.2 Interactive workshop[22]

A two-day workshop was held at Regency Suites, Georgetown to bring together stakeholders for a focused learning and planning workshop on national drainage and irrigation needs (Image 1). The aim was to orient the stakeholders involved to global best practices for integrating nature-based solutions (NbS) and Gender, Equality and Social Inclusion (GESI) into D&I planning. The workshop focused on the flood-related challenges affecting Guyana and how NDIA's strategic plan be positioned to solve the identified challenges and support inter-ministry and agency collaboration.



Image 1. Participants at the NDIA Strategic Planning workshop on the IRIS project

4.1.3 Semi-structured interviews

The interview method was adopted to feed objectives 1 and 2 of the study and to gather preliminary insights appropriate strategies for D&I management. To collect primary information on the technical and institutional challenges related to D&I in Guyana, a holistic and inclusive semi-structured interview schedule was developed (Annexure 2). It was deployed to make sense and provide justification of the data received during the interactive workshop and literature review. The approach was taken to administer the interview schedule with NDIA regional engineers, agricultural engineers, mechanical engineers across regions 2, 3, 4, 5, 6, 7 and 10, as well as Regional Democratic Council (RDC) and the Mahaica, Mahaicony and Abary Authority (MMA) in Region 5. The schedule was designed and comprised of 22 questions which captured information about how to build and sustain resilience in D&I, integrating or augmenting possible nature-based solutions to minimize floods and improve irrigation; and what are the capacities and training required to have a more gender inclusive D&I strategy.

Of the total 13 experts, a majority of them were affiliated with NDIA including Head Office and regional departments. This included five regional engineers, two civil engineers, one agricultural engineer, and one field auditor. Senior-level representation came from the RDC and MMA.

4.1.4 Focused group discussion

The primary aim of the focused group discussion was to engage key agencies under the Ministry of Agriculture (MoA) to discuss data access needs and identify opportunities for collaboration to support the development of a national flood risk assessment model (Image 2). Such a model could serve as a critical foundation for evidence-based planning, enhancing climate resilience, and implementing nature-based solutions (NbS) across Guyana's coastal regions.

The discussion featured a cross-functional group comprising planners, GIS engineers, monitoring and evaluation officers, cartographers, IT and systems analysts. Institutions represented included the National Drainage and Irrigation Authority (NDIA), Guyana Rice Development Board (GRDB), National Agricultural Research and Extension Institute (NAREI), Guyana Livestock Development Authority (GLDA), Guyana Lands and Surveys Commission (GLSC), and the Ministry of Agriculture. This diverse mix ensured a multidisciplinary dialogue on data coordination, allowing technical, institutional, and strategic perspectives to inform the development of the flood risk model. In addition, the discussion sought to present the preliminary findings of the in-depth interviews and gather feedback from agencies on existing gaps, alignment opportunities, and their institutional roles and mandates.

22 See workshop report on "Strategic Meeting on IRIS Project" held at the Regency Suites on 17-18 September 2024.

4.2 Data handling and analysis

Transcribing interview data was done with the help of software that involves converting audio text for subsequent analysis and inference. Charts and graphs were primarily based on the responses generated from the data collection tools. A separate analysis on flood risk assessment was conducted to understand hazard and vulnerability risk on the coastal regions in Guyana.



Image 2. Focused group discussion held at the Ministry of Agriculture in Georgetown



Image of an eroded seawall and ongoing work to serve as a breakwater, trap sediment, and move mudbanks to enable the natural regeneration of mangroves in Dantzig Mahaicony Berbice.

5. Exploring Coastal Flood Risk Hazards and Vulnerabilities

The publicly available probabilistic risk model, Global Infrastructure Risk Model and Resilience Index (GIRI) recognized the Latin America and Caribbean (LAC) region as one of the most climate-vulnerable globally, having both high exposure to climate-related hazards and the highest regional Average Annual Loss (AAL), estimated at 0.22 percent. The key climatic hazards include cyclonic winds, storm surges, flooding, and rainfall-induced landslides. In Guyana, flooding emerges as the most significant hazard to infrastructure asset, accounting for approximately 98% of the country's AAL, or nearly USD 89.7 million. This reflects the high exposure of low-lying coastal lands, aging drainage infrastructure, and increasing intensity of rainfall events.

Cyclones and earthquakes contribute marginally to the overall risk profile, with AALs of USD 1.25 million and USD 0.31 million, respectively, indicating localized or infrequent impacts (Figure 4). This figure incorporates key underlying risk drivers such as weak governance, socio-economic inequality, poverty, and environmental degradation, highlighting the systemic nature of climate vulnerability. Thus, these findings emphasize the need for a comprehensive risk management approach that integrates climate adaptation and mitigation with structural reforms to address the root causes of risk.

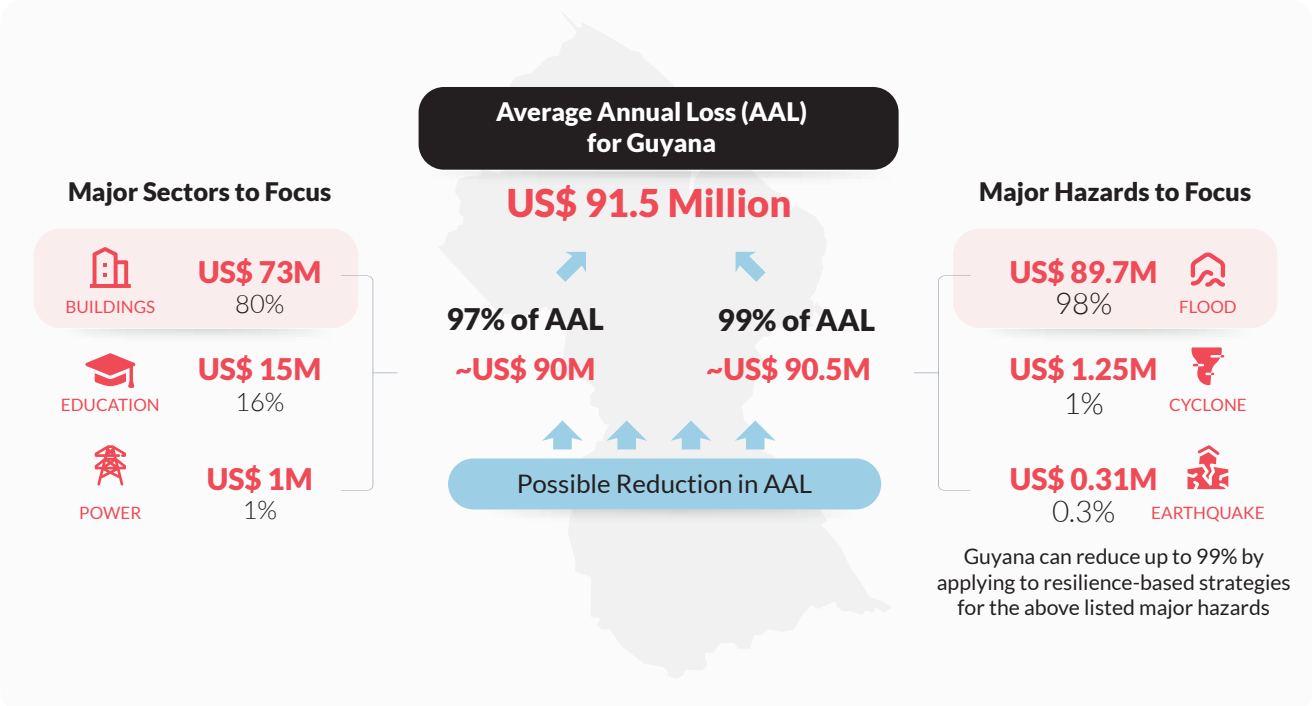


Figure 4 . Hazards risk to infrastructure in Guyana. Adapted from CDRI-GIRI[24] .

23 Supported by CDRI and developed by 4-member global consortium, GIRI estimates the probable risk to infrastructure and covers 7 major climate and geo-hazards on 9 critical and social infrastructure sectors. Homepage | GIRI

24 CDRI (2023). Global Infrastructure Resilience: Capturing the resilience dividend - A Biennial Report from the Coalition for Disaster Resilient Infrastructure, New Delhi.

When accounting for sea-level rise and hazard exposure, in terms of population and farmlands affected, the cumulative risk could become even more pronounced. This warrants a deep dive on the key exposures and vulnerabilities of the regions. The IPCC Sixth Assessment Report (2022) highlights the small island countries, particularly those in the Caribbean, are becoming increasingly exposed to a convergence of risks such rising temperatures, sea-level rise, droughts, and extreme weather conditions[25]. These physical changes could significantly disrupt both natural and human systems leading to adverse impacts on water and food security, infrastructure, coastal erosion, and exacerbate existing vulnerabilities. These impacts are not specific to just Guyana, many systems and infrastructure are now being affected by climate change and in order to adapt, many vulnerable countries have put in place adaptation and resilience measures to deal with climate change. These adaptation measures may soften the adverse impact of climate change but cannot be seen in isolation and needs to be planned and integrated with other measures. Therefore, addressing these risks would require an integrated adaptation approach combining hard infrastructure, nature-based solutions, and community-driven responses, all tailored towards the current and future risks.

Despite recognition of growing threats, adaptation measures are being constrained by structural barriers. The report further identified lack of financial instruments and gaps in education and research hinder effective strategic actions. However, cultural and political dimensions also play in the success of interventions, especially in areas of mangroves restoration and land relocation. Strategically filling these research and institutional gaps will be essential to support climate-resilient development pathways that are adaptive, inclusive, and grounded in both scientific evidence and local realities. To deal with climate change adaptation, Guyana's Low Carbon Development Strategy 2030 talks about strengthening community resilience, particularly in vulnerable rural areas, investment in the protection of coastal zones and the upgradation of drainage and irrigation to manage flood risk[26]. Therefore, augmenting appropriate drainage and irrigation would be able to increase the resilience of agricultural production, critical infrastructure, and livelihoods, among others.



Area along the Essequibo Coast in Region 2 where, owing to sea-level rise, the old seawall is no longer able to keep the water out, and the land is being washed away owing to erosion.

25 Mycoo, M., M. Wairiu, D. Campbell, V. Duvat, Y. Golbuu, S. Maharaj, J. Nalau, P. Nunn, J. Pinnegar, and O. Warrick, 2022: Small Islands. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2043–2121.

26 Government of Guyana. (2022). Guyana's Low Carbon Development Strategy 2030. www.lcds.gov.gy

5.1 Localized trends under climate change scenarios

Projections of sea-level rise and associated flood risk indicate that coastal floods exceeding one meter above the current high tide line are likely to become increasingly frequent by the end of the century (Figure 5). This trend raises the possibility of permanent inundation in low-lying areas where rising sea levels surpass the existing land elevation[27]. As a result, the scale and frequency of coastal flood events are expected to intensify, posing more severe threats to infrastructure, livelihoods, and ecosystem stability in vulnerable coastal zones.

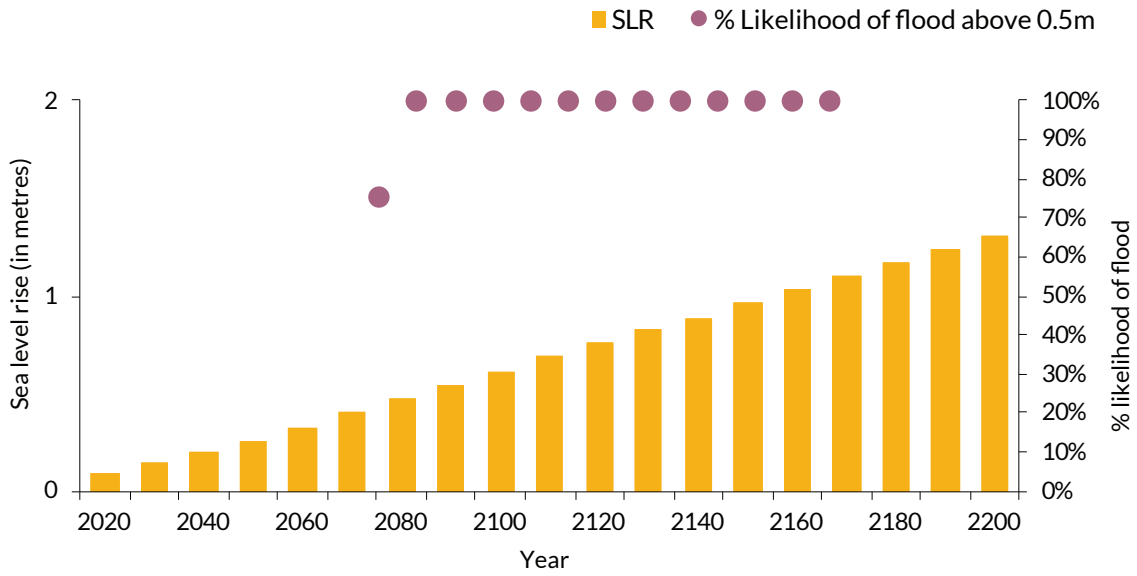


Figure 5. Local projections for sea-level rise and likelihood of floods in Guyana*. Adapted from [28]

* At Pointe water level station, 1255.1 miles from Guyana.
Sea level projections assume moderate cuts in heat-trapping pollution (RCP 4.5) and median systemic sensitivity (Kopp et al. 2014, Earth's Future). Sea level rise is relative to a 1992 baseline.

The question now arises how sea-level rise will directly affected agriculture systems? Recalling the "National Strategy for Agriculture in Guyana: 2013 – 2020" that Guyana coastal areas is home to majority of agricultural lands with crops being the largest share of agricultural production, as represented by 24.5% of agriculture GDP and 4.8% of total GDP. The rise in sea-level exacerbate agricultural risk in two interconnected ways. First, projections from Figure 5, indicate a 74% probability of flood events exceeding 0.5 meters above the current high tide line by 2070, with a near certainty (100% likelihood) from 2090 onwards. This increased flood probability, coupled with a projected sea-level rise nearing 1 meter by 2100 and potentially reaching 1.5 meters by 2200, poses a systemic threat to farmlands, irrigation infrastructure, and drainage capacity. Second, the encroachment of saline water into freshwater systems and agricultural lands compromises soil fertility and crop yields, especially for salt-sensitive crops like rice.

Another major dimension of climate vulnerability lies in the spatial concentration of human settlements along the low-lying coastal zone. As shown in Figure 6, regions such as East Berbice-Corentyne, Mahaica-Berbice, and Demerara-Mahaica are among the most densely populated, collectively accounting for over 332,339 people (4632 sq.km) residing on lands situated below 1

27 IDB. (2018). Sea-level rise threats in the Caribbean: Data, tools, and analysis for a more resilient future.

28 Climate Central Risk Finder. (2025). http://riskfinder.org/

metre relative to the local high tide line. These areas, marked in darker shades, represent zones of heightened exposure where even modest sea-level rise or tidal surges could disrupt livelihoods. The ongoing development of coastal urban expansion further compounds this risk, increasing the exposure of residential buildings, roads, schools, and hospitals to recurrent flooding, saline intrusion, and erosion.

Technically, these vulnerabilities reflect both geographic and systemic factors—where natural low-lying topography overlaps with limited drainage capacity, and inadequate spatial planning. There is urgent need to address this challenge through a strategic and integrated approach at the conservancy and watershed level[29] . The identification of 4,632 sq. km of land under threat reinforces the urgency for strategic land-use planning, adaptive infrastructure investment, and improved early warning systems to reduce exposure and enhance resilience in these critical coastal zones.

Changes to local cropping systems could also be impacted during prolonged seasons of drought, shorter wet days and prolonged rainfalls, leading to crop damages from either shortage of water or too excessive water. Figure 7 shows the number of wet and dry days from 2004 to 2024 for the primary wet season and main dry season. Reduce wet days is observed in region 5 with increased rainfall days in regions 1, 2, 3, and 6. This may indicate an increased risk of floods and is particularly useful considering most of the rice lands are rainfed, however irrigation will be crucial for region 5 (refer to Annexures 3 and 4). Similarly, trends over the last 10 years indicate increase dry days along the coastal stretch, particularly in areas of crop cultivation. The suggestion for these regions is that more intense rainfall has been recorded over the last 10 years with a greater number of dry days annually. Future D&I planning will need to reconsider the Hinterlands as these areas will suffer extended drought and reduced wet days.

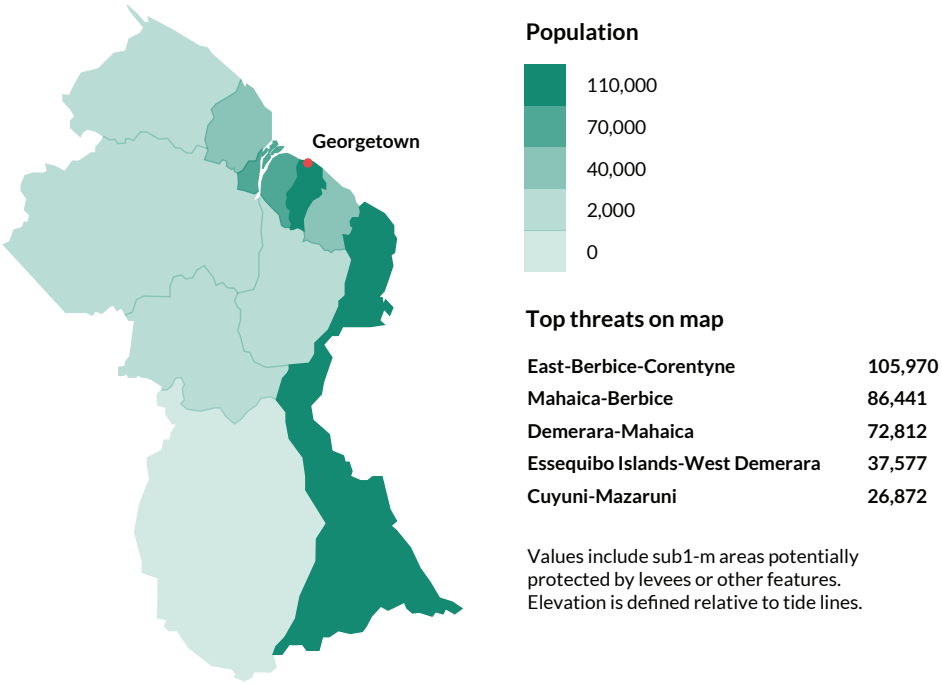


Figure 6. Total population below 1m in Guyana by region.

Source: Climate Central Risk Finder (2025). http://www.riskfinder.org

29 Aqueduct 4.0 Water Risk Atlas-WRI

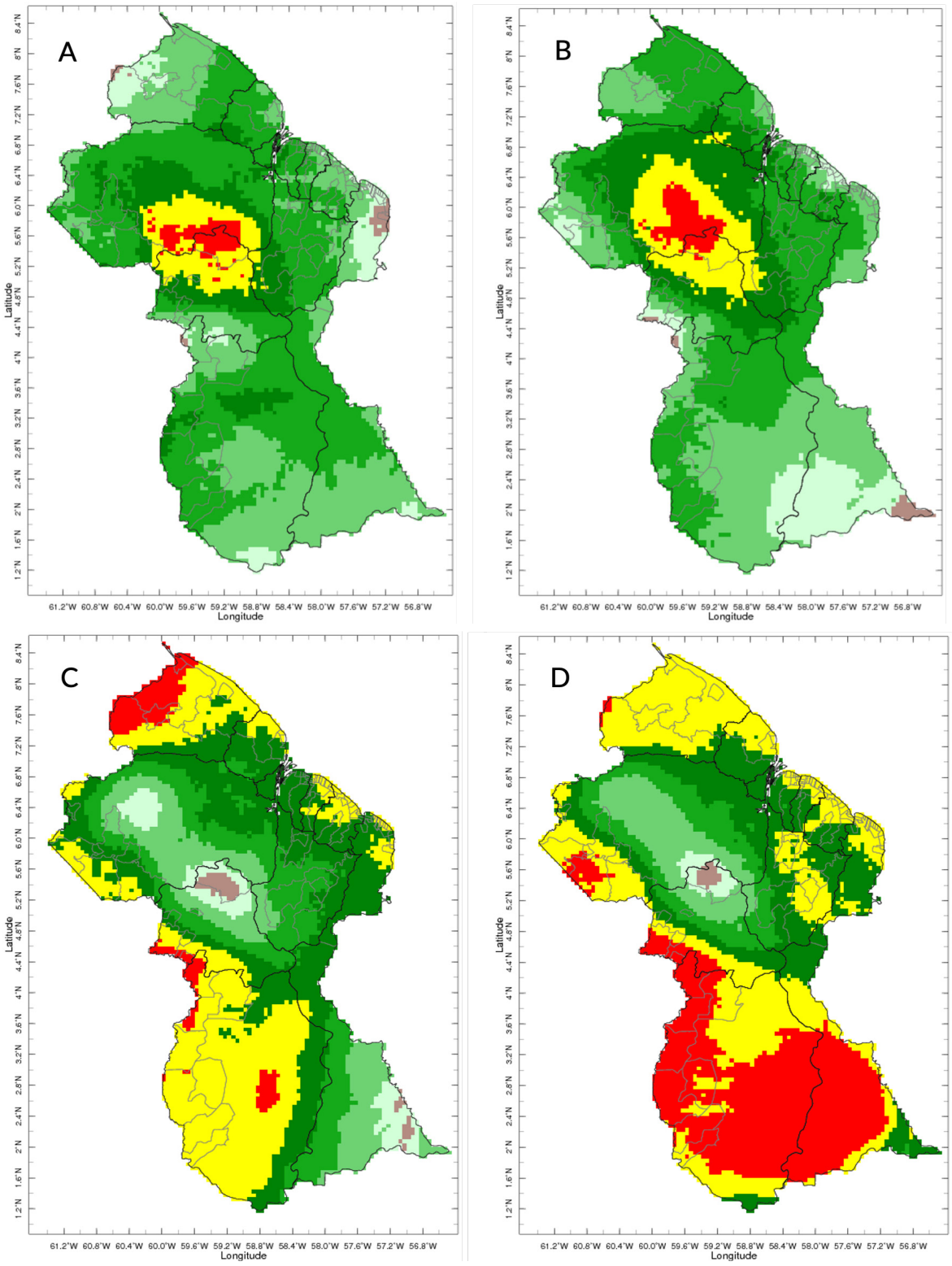


Figure 7. Number of wet (dry) days during the rainy (dry) season with rainfall above (below) 10mm/day from May to July (February to April) with A, (C) showing period from 2004-2014 and B, (D) from 2015-2024[30].

Source: Map Room, Guyana Hydrometeorological Service, Ministry of Agriculture.

30 Map Room, Guyana Hydrometeorological Service, Ministry of Agriculture. Hydrometeorological Service, Guyana

6. Situational Analysis of the Drainage and Irrigation System in Guyana

6.1 Overview of the current drainage and irrigation system infrastructure

Much of Guyana's canals and drainage and irrigation system can be reference during the colonial period, designed to support plantation agriculture, mainly sugar cane and rice[31] – a practice still dominating the agricultural sector at present. The cultivation lands that were prone to flooding were engineered through a network of gravity-fed canals, drainage channels, sluices and later pumps were added. This engineering practice has been continuing in today's land use and settlement patterns, but not without modifications and changes. Pivotal to the D&I systems are conservancies such as the East Demerara Water Conservancy (EDWC) and Boerasirie, which store fresh water from inland catchments (Image 3). The water from these conservancies is released through canals for irrigation of agricultural lands and into the Atlantic Ocean for drainage purposes. The EDWC also acts as storage facility for urban areas as it serves as the primary source for the Guyana Water Incorporated Shelter Belt Water Treatment Plant[32].



Image 3. Field trip visit to the East Demerara Water Conservancy located in Region 4, 15 miles south of the most densely populated section of Guyana Coast.

31 Hickey, C., & Weis, T. (2012). The challenge of climate change adaptation in Guyana. Climate and Development, 4(1), 66–74. https://doi.org/10.1080/17565529.2012.661036

32 National Drainage and Irrigation Authority. East Demerara Water Conservancy. Booklet. Ministry of Agriculture.

When it comes to sluices and pumps, these are based on the topography and position of coastal zones just below the mean se level which creates a dependency on tidal cycles to discharge stormwater. This means that drainage can only occur during low tide, creating a narrow window for effective runoff. Given that rainfall intensity usually exceeds this window, significant investments have been made on large pumping stations to quickly discharge water[33]. Throughout Regions 2, 3, 4, 5, and 6, the D&I infrastructure remains vital for flood protection and irrigation (Image 4). For these Regions, the composition of D&I includes smaller conservancies, primary and secondary canal, and regulators (intake and outflow structures). These infrastructures are managed, maintained and improved through NDIA region offices and water users' associations. However, while NDIA have oversight of major D&I assets including fixed and mobile pumps and primary sluices, other government agencies including the Regional Democratic Councils (RDCs), and Neighbourhood Democratic Councils (NDCs) are responsible for secondary drainage and operational support.

Additionally, Guyana Sugar Corporation (GuySuCo) also operates and manages their own drainage and irrigation system with technical oversight from NDIA. This fragmented maintenance and operation often results in overlapping mandates and delayed interventions,



Image 4. Field visit at the EDWC with experts from NDIA, CDRI and GGGI

particularly when emergency repairs or infrastructure upgrades are required. An evaluation report conducted in 2017[34], shows systems in Georgetown and surrounding areas suffer from sediment buildup, vegetation overgrowth, and damages to hydraulic structures, and unregulated urban expansion that encroaches on drainage reserves, thereby increasing the potential of flooding during heavy rainfall. Furthermore, the report highlighted the need for integrated planning between urban development and D&I interface to build resilience to climate challenges. Thus, Guyana is at risk of experiencing severe water logging, flooding and drought if an integrated and sustainable drainage and irrigation strategy is not implemented at the earliest.

6.2 Adaptation challenges in D&I systems

With much of Guyana's canals and drainage and irrigation system been designed with gravity flow of water as a priority, the country illustrates both the challenges and learning models associated with climate change adaptation. It is extremely vulnerable and increasingly affected by rise in temperature, more intense tropical storms and changing precipitation patterns. To fully understand the adaptation challenges facing Guyana, Heckey and Weis, suggested looking at how the coastal landscape, how it functions and how effective it is in today's environmental challenges. The previous section has discussed the current landscape, and this section will attempt to highlight the adaptation challenges as outline in previous D&I studies.

A handful of studies have examined the D&I infrastructure in select regions and map the effectiveness without necessarily considering an integrated approach (Figure 8). Oyedotun & Burningham (2021) suggested lack of real-time hydrological monitoring and weak inter-agency coordination affects NDIA ability to anticipate, model and respond to climate-induced flood risks in low-lying coastal areas that intersects with high population and agricultural productivity[35]. For instance, in 2018, then Minister of

33 Stabroek News. (20 January 2025). $1.4B Liliendaal pump station completed - Stabroek News

34 National Drainage and Irrigation Authority. (2017). Data collection survey on drainage capacity in Georgetown in the Co-operative Republic of Guyana. Ministry of Agriculture, Government of Guyana and Japan International Cooperation Agency.

35 Oyedotun, T. D. T., & Burningham, H. (2021). The need for data integration to address the challenges of climate change on the Guyana coast. Geography and Sustainability, 2(4), 288–297. https://doi.org/10.1016/j.geosus.2021.11.003

Agriculture, Noel Holder, acknowledged the lack of coordination among agencies in the agriculture sector and emphasized the need for greater integration of flood risk management efforts. Hickey & Weis (2012) found that institutional inertia hinders the implementation of comprehensive adaptation strategies necessary for safeguarding agricultural lands and coastal settlements. A report by Delft University of Technology found that the increase in urban spread and encroachment on drainage reserves have diminished natural absorption capacity, thereby exacerbating D&I systems vulnerabilities in periods of intense rainfall[36].

These challenges highlight the need for integrated planning and improved maintenance practices to effectively manage flood risks. The studies have not considered the technical, environmental and social aspects but more towards interministerial planning, implementation and operations of key D&I infrastructure. That being said, the inclusion of nature-based solutions within the hard infrastructure is an emerging concept to complement drainage and irrigation projects, especially in developing countries, promoting inclusivity, accountability and translates local and community knowledge into sustainable infrastructure. Efforts in this regard is promising, with the government establishing the Mangrove Restoration Centre under the National Agricultural Research and Extension Institute (NAREI) to enhance collaboration and incorporate nature-based solutions (NbS) into D&I infrastructure planning. This initiative aims to bridge institutional gaps by aligning mangrove restoration efforts with D&I infrastructure planning, improving coastal resilience, and strengthening multi-agency cooperation.

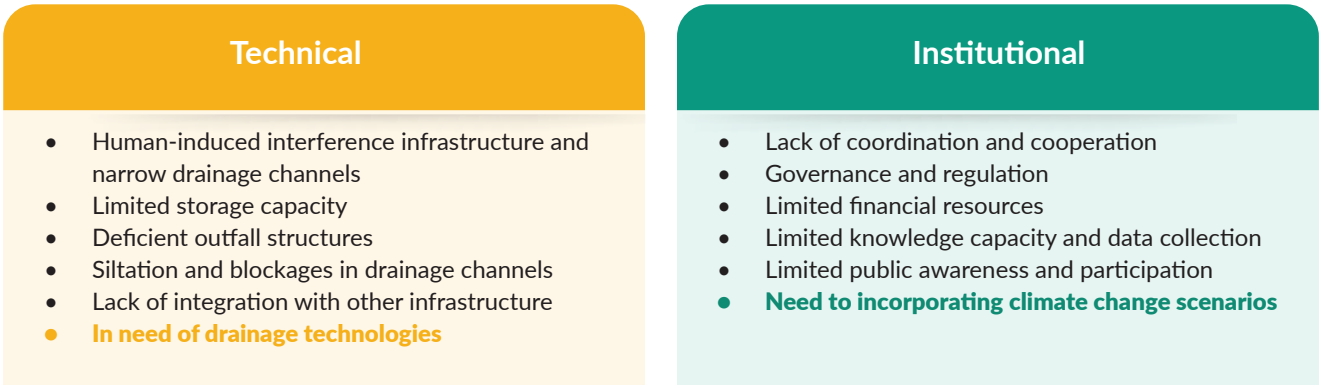


Figure 8. Comprehensive list of technical and institutional challenges identified in previous studies on D&I infrastructure in Guyana

Source: MacDonald, D. (2003). Guyana Drainage and Irrigation Systems Rehabilitation Project. Ministry of Agriculture, Guyana; Delft University of Technology. (2016). Analysis of Drainage System in Georgetown, Guyana; Japan International Cooperation Agency. (2017). Data Collection Survey on Drainage Capacity in Georgetown in the Cooperative Republic of Guyana, National Drainage and Irrigation Authority, Ministry of Agriculture, Guyana.

6.2.1 Corrective strategic actions for adaptation planning

What are the strategic actions/possible thinking that should be reflected in adaptation planning for drainage and irrigation. Reflecting on the discussed challenges, the technical options and strategic actions are mapped in Figure 9.

Many of the mentioned studies advocate for a transition from reactive, experience-based management to a more proactive, data driven approach to drainage and irrigation. A sustainable D&I strategy that's reflects the appropriate flood challenges in Guyana should consider four aspects: engineer, management, operational, and regulatory[37]. These are important starting point for developing sustainable D&I strategic actions. However, such planning will require careful consideration of local contexts, address challenges and implementing robust monitoring and evaluation mechanisms.

36 Delft University of Technology. (2016). Analysis of Drainage System in Georgetown, Guyana.

37 Sirimewan, D. C., Samaraweera, A., Manjula, N. H. C., & Ekanayake, E. M. a. C. (2020). A guideline for sustainable irrigation water management: a case of a developing country. Intelligent Buildings International, 13(2), 129–141.

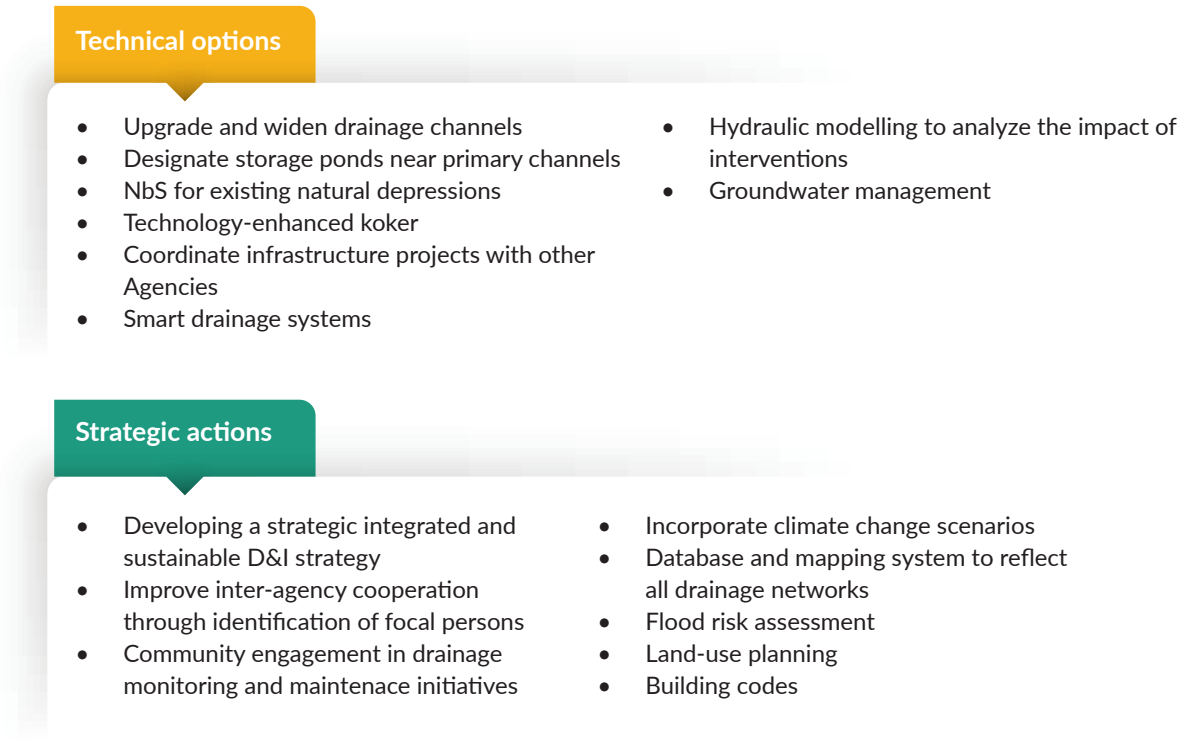


Figure 9. Previous recommended strategies for resilience and adaptation planning in D&I

Sources: Delft University of Technology. (2016). Analysis of Drainage System in Georgetown, Guyana; Japan International Cooperation Agency. (2017). Data Collection Survey on Drainage Capacity in Georgetown in the Cooperative Republic of Guyana, National Drainage and Irrigation Authority, Ministry of Agriculture, Guyana.: Agriculture Information System (AIS).

6.3 Institutional and policy landscape

The overarching framework for drainage and irrigation is the National Strategy for Agriculture in Guyana 2013-2020, particularly Priority 3 and Priority 19. Priority 3 provides for water security and water management through building effective systems for water management and strengthening drainage and irrigation infrastructure, by emphasizing:

- Modernize and expand D&I infrastructure including the Hope-like structures, conservancies, and canals to address sedimentation challenges of poor river gradient flows
- Increasing investment for acquiring fixed and mobile drainage and irrigation pumps
- Strengthening maintenance and operation practices of D&I equipment under the ownership of NDIA, MMA and RDCs
- Supporting the development and inclusion of water users' association and farmers in D&I planning.

Priority 19 supports the development of an Agriculture Risk Reduction and Disaster Management Program through adaptation initiatives such as nature-based solutions to prevent and manage floods and droughts, by emphasizing:

- Incorporating other kinds of disasters such as disease outbreaks
- Building data driven systems for early warning systems
- Building back better-response and rehabilitation.

6.3.1 National Drainage and Irrigation Authority Act

The current D&I legislation that governs NDIA operations is the NDIA Act (2004). The primary mission stated in the Act is: "The National Drainage and Irrigation Authority functions as the Nation's apex organization dealing with all public matters pertaining to management, improvement, extension and provision of drainage, irrigation, and flood control infrastructure and services in declared areas of the country. While providing support and assistance to other public institutions dealing with connected activities, it shall also evolve mechanisms for improved water use with financial sustainability, equity, and efficiency as the guiding principles."

With the rapid unstructured increase in areas brought into farming, consideration must be placed on the improvement and management of both declared and undeclared D&I areas. In many areas, there is also no physical separation of the drainage system of residential and farming areas, which has now inadvertently become the responsibility of the NDIA.

6.3.2 NDIA Strategy 2017-2021

The NDIA Strategy was a strategic framework to guide the development, maintenance and improvement of drainage and irrigation systems in both declared and undeclared lands in Guyana. The specific strategic objectives of the strategy are listed in Table 1:

Table 1. NDIA strategy objectives 2017-2021

Strategic Objectives	Means
GIS Development	Improving data collection of D&I components to facilitate analysis, including the use of geographic information systems, to support informed decision-making and planning.
	Collecting reliable data to conduct thorough risk assessments for farming areas, thereby aiding the identification of vulnerabilities and the prioritization of interventions.
Hydraulic Infrastructure Enhancements	Developing hydraulic models of catchment areas to gain insights into the effects of planned changes and ensure optimal system performance.
	Increasing the discharge capacity of catchment areas to effectively handle a minimum of 3.5 inches of rainfall within 24 hours, resulting in better flood management and a 50% reduction in water-related crop losses.
Community Engagement	Involving local communities in the planning and management of D&I systems, which includes encouraging the creation of WUAs and cultivating a sense of shared responsibility.
	Engaging farmers to understand the importance of cost recovery and ensuring the long-term sustainability of financial sustainability and maintenance of the D&I systems.
Capacity Building and Development	Providing training and capacity building programmes for NDIA Staff to enhance skills and knowledge in D&I planning and execution.
	Identifying and developing 5,000 acres annually for new or renewed cultivation, thus supporting agricultural expansion and contributing to food security.
Inter-agency coordination	Collaborating with various government agencies such as the GRDB, NAREI, GLDA, Hydromet, GMC and MMA/ADA to effectively manage data and implement the D&I strategy.

The D&I Strategy 2017-2021 was an essential step in Guyana's efforts to improve D&I infrastructure. It set the foundation for future initiatives focused on reliable data modelling to sustainable manage drainage and irrigation, reduce the vulnerabilities of climate change, and promote agriculture development.

6.3.3 NDIA Capital Works Strategy 2017-2021

This strategy emphasizes the importance of making capital investments to enhance the country's drainage and irrigations systems and build resilience to climate-related challenges. The key elements of the Strategy are listed in Table 2:

Table 2. Key elements of NDIA capital works strategy

Key Elements	Means
Infrastructure Enhancement	Increase the discharge capacity of catchment areas to effectively handle a 15-year return period, which translates to an average of 3.5 inches of rainfall within a 24-hour period, thereby strengthening resilience against severe weather events.
	Fast-track the deployment of pumped drainage systems to enhance water management in low-lying areas and complement the existing gravity-based discharge.
	Prioritize the regular maintenance of sluice outfalls to ensure optimal functioning.
Technology Integration and Mapping	Adopt new technologies to enhance management of D&I infrastructure.
	Conduct detailed mapping of catchment areas and determine drainage coefficients.
Community Engagement and Capacity Building	Foster community involvement through the formation of WUAs in DDIAs and UDIAs.
	Implement comprehensive capacity building programmes for NDIA staff to enhance their expertise in managing D&I systems.
Risk Assessment	Collect data to perform risk assessments of farming areas to identify vulnerabilities and prioritize mitigating measures.
	Support agricultural expansion through the identification and development of 5,000 acres of land for new or renewed agricultural cultivation.
Climate Adaptation	Improve road access to both existing and newly developed farmlands.
	Implement strategies to reduce weather-related crop losses by 50%.

With a strong emphasis on improving infrastructure, integrating technology, engaging communities and supporting agriculture, the strategy aims to a reliable and sustainable D&I system while enhancing resilience to the effects of climate change.

6.3.4 Stakeholder roles in supporting resilient drainage and irrigation planning

The relevant stakeholders for drainage and irrigation in Guyana are listed in Table 3.

Table 3. Important stakeholders in the drainage and irrigation interface in Guyana

Shareholders	Category	Roles
Ministry of Agriculture (MoA)	Government of Guyana	The main government agency responsible for the development and management of drainage and irrigation systems. They play a crucial role in setting policies, allocating resources, and overseeing the implementation of projects.
National Drainage and Irrigation Authority (NDIA)	Ministry of Agriculture	An established government agency that will be responsible for the overall management of drainage and irrigation in Guyana. The NDIA will play a key role in developing and implementing policies, coordinating with other stakeholders, and ensuring the efficient operation and maintenance of drainage and irrigation systems.
Regional Democratic Councils (RDCs)	Ministry of Local Government and Regional Development	Regional government bodies that are responsible for the development and management of drainage and irrigation systems within their respective regions. They work closely with the NDIA and Ministry of Agriculture to ensure that projects are implemented effectively, and resources are allocated appropriately.
Neighbourhood Democratic Councils (NDCs)	Ministry of Local Government and Regional Development	Local government bodies responsible for the maintenance and operation of drainage and irrigation systems within their communities. They work with the RDCs and NDIA to ensure that drainage and irrigation systems are properly maintained and function effectively.
Mahaica, Mahaicony and Abary Authority (MMA)	Ministry of Agriculture	A semi-autonomous agency that manages, operates and maintains all D&I infrastructure in region 5, while facilitating sustainable agricultural development through effective land and water resource management.
Water Users Associations (WUAs)	Civil society	Farmer-based organizations that are responsible for the management and maintenance of secondary drainage and irrigation systems in their respective areas. They play a crucial role in ensuring that drainage and irrigation systems are operated and maintained effectively, and that farmers have access to water resources.
Rice Producers Association (RPA)	Civil society	A non-governmental organization that represents the interests of rice farmers. This association plays an important role in advocating for the needs of farmers, providing training and technical support, and ensuring that policies related to rice production are favourable.
Guyana Sugar Corporation (GUYSUCO)	Ministry of Agriculture	A state-owned company responsible for sugar production in Guyana. They play a key role in water management for their sugar estates, and their water use can affect the availability of water for irrigation in neighbouring areas.
Pesticides and Toxic Chemicals Control Board	Ministry of Agriculture	Responsible for regulating the management, use, importation, and distribution of pesticides and toxic chemicals to ensure public health and environmental safety. By monitoring and managing risks associated with toxic chemicals, the PTCCB plays a critical role in safeguarding human health, agricultural productivity, and environmental sustainability.
Guyana Rice Development Board (GRDB)	Ministry of Agriculture	Responsible for the development and innovation in the rice industry through research relating to resilient grains and farmer extension services.
Guyana Livestock Development Authority (GLDA)	Ministry of Agriculture	Facilitates farmer training, market development, and sustainable production systems while ensuring compliance with national and international standards for livestock trade. By supporting policy development and delivering extension services, the GLDA strengthens food security, enhances rural livelihoods, and contributes to the growth and resilience of Guyana's agricultural economy.

6.4 Mapping the challenges for D&I systems in Guyana

Based on the strategic workshop sessions along with expert interviews and focus groups discussions as outlined in the methodology section, the following sections categories the types of challenges constraining resilience in D&I in Guyana.

6.4.1 Exploring region-wise issues

Region 2 officers reported droughts and saltwater intrusion that severely affect irrigation reliability in the Pomeroon area. Although mobile pumps are deployed to support drainage during dry spells, a lack of real-time water quality data, coupled with outdated pump infrastructure, has led to inefficiencies and service disruptions. This highlights a clear need for improved monitoring systems and early warning protocols.

In Region 3, engineers emphasized institutional overlap between the RDC and NDIA regarding asset ownership and maintenance responsibilities. This has created confusion over who is accountable for the routine upkeep of sluices and channels, especially in emergencies. One notable case involved the failure of a sluice gate at Canal No. 1, which was reported multiple times before its collapse. Because no systematic risk-ranking or inspection-tracking mechanism exists, NDIA's response was reactive rather than preventive—demonstrating the importance of institutional coordination and data centralization.

Region 4 revealed a significant human resource shortage, with only two engineers covering a large and flood-prone geography. In addition, the existing monitoring database used in the region is not uniformly applied by all engineers. They also expressed that civil society and vulnerable groups, including women and small-scale farmers, are sometimes engaged in D&I planning—indicating gaps in inclusive governance.

In the case of Region 6, a rice-dominated area, the limited availability of mobile pumps and lack of coordination among farmers to manage irrigation water equitably were noted. Engineers explained that due to minimal cooperation and weak farmer organization, upstream users often draw water before downstream areas are adequately supplied. This illustrates both technical and social coordination gaps that impede resilience.

Lastly, in Regions 7 and 10, the interviews revealed that formal D&I systems are almost non-existent. Region 7, for example, depends on a single pump for drainage in Bartica, while Region 10 relies primarily on rainwater harvesting. The absence of structured water governance and infrastructure makes these regions highly vulnerable to flash floods and climate variability. As NDIA expands into these areas under the 25 by 2025 initiative, identifying and addressing institutional and technical capacity gaps will be critical.

6.4.2 Technical challenges for D&I systems

Technical capacity is an important driver, and regional engineers lack the detail on water flow and silt built up in river and conservancies. Thus, it's imperative for mapping technologies like sonar, sensors, etc. to comprehensively address water level and conservancy depth.

1. Regional engineers lack precise data on water flow, water quality and silt accumulation in rivers and conservancies, impeding optimal water management. Accurate measuring devices to assess water quality including salinity levels and appropriate record-keeping of field data on interactive dashboards and databases would ensure reliable working conditions of D&I structures
2. Lack of holistic mapping of the connection state of the existing drainage channels and the level of groundwater and the status of utilization of groundwater
3. Key infrastructure such as sluice gates are becoming prone to frequent failures, exacerbating flood risks. Thus, management information systems for record-keeping purposes and other operational activities of existing systems to function independently of staff turnover
4. Unseasonal flooding[38] and prolonged droughts

38 Unseasonal flooding, as noted by the NDIA Chairman, refers to unexpected rainfall occurring outside the typical bi-annual wet seasons, and which has become increasingly frequent due to changing climate patterns.

indicate lack of accurate weather forecasting and associated nature-based water retention solutions for periods of unplanned drought

5. Unplanned development activities in hinterland regions leads to mismatch where access to water networks and drainage infrastructure are out of reach of the communities
6. Assessment of vulnerable areas needs to consider locations where grazing grounds are prevalent as most times, flooding in the back lands/grazing grounds transport diseases and contaminations to the fertile crop lands
7. Detailed study assessment of the true depth of conservancies and rivers to identify flow rate and silt built up. This could open opportunities to increase water retention and/or extend the length of the conservancies
8. Evaporation in conservancies and canals contribute to increased pumping hours and low water flow. The use of concrete lining on canals and canal covers either through floating solar or other means could reduce evaporation
9. Traditional practices of flood irrigation dominate water-intensive crops and leads to huge water losses in the fields, increasing salinity and longer working hours to diesel-powered pumps. Increasing the capacity of infiltration of key aquifers could lend itself to borewells at appropriate sites in conjunction with suitable water retention ponds. Government could provide technical support for implementing borewell irrigation where sustainable levels of aquifers exist
10. Unauthorized water diversions where people are diverting water from canals in a prohibited manner causing perpetual mismanagement of the canal system. Diversion of drainages into canals impacts the quality of water and subsequently leads to overflows where diversion control fails

6.4.3 Institutional challenges for D&I systems

There is a need for an enabling environment where decision making on drainage and irrigation including irrigation of DDIA has to be done by considering the values and priorities of all the involved agencies to achieve the maximum satisfaction of the public.

1. Multiple agencies within the MOA require critical D&I machinery under the control of NDIA thereby limiting the scope of operational and rehabilitation works
2. Lack of localised/district wise weather forecast for preventative planning and maintenance schedule affects planning for intensive rainfall and prolong drought scenarios
3. Socio-economic and environmental indicators to grade and prioritize work programs for rehabilitation and to check structures
4. Contractors in the D&I space do not necessarily follow the engineering TOR or design specifications leading to mismanagement of water flow, legal troubles and delay assistance to the communities
5. Lengthy process and procedures to regulate the time to respond to an event, especially in cases of emergency events
6. Regional engineer reports on the state of D&I infrastructure are not taken into action as there is limited funding and lack of prioritization criterions for rehabilitation and maintenance works.

6.4.3.1 Institutional fragmentation

The D&I sector operates under a fragmented framework involving multiple agencies, including the National Drainage and Irrigation Authority (NDIA), the Mahaica-Mahaicony-Abary Authority (MMA), and Regional Democratic Councils (RDC's). Figure 10 shows how different agencies manage various parts of the drainage and irrigation infrastructure, and how they make investment decisions based on their limited cost-benefit analysis that seldomly considers the wider D&I issues in the country. Taking into account, the individual fragmented decisions and investment strategies, it is unlikely to produce an efficient and effective approach to flood management. Floods due to river overbank flow and intensified rainfall are not isolated events but closely interlinked with climate variability and overall basin characteristics.

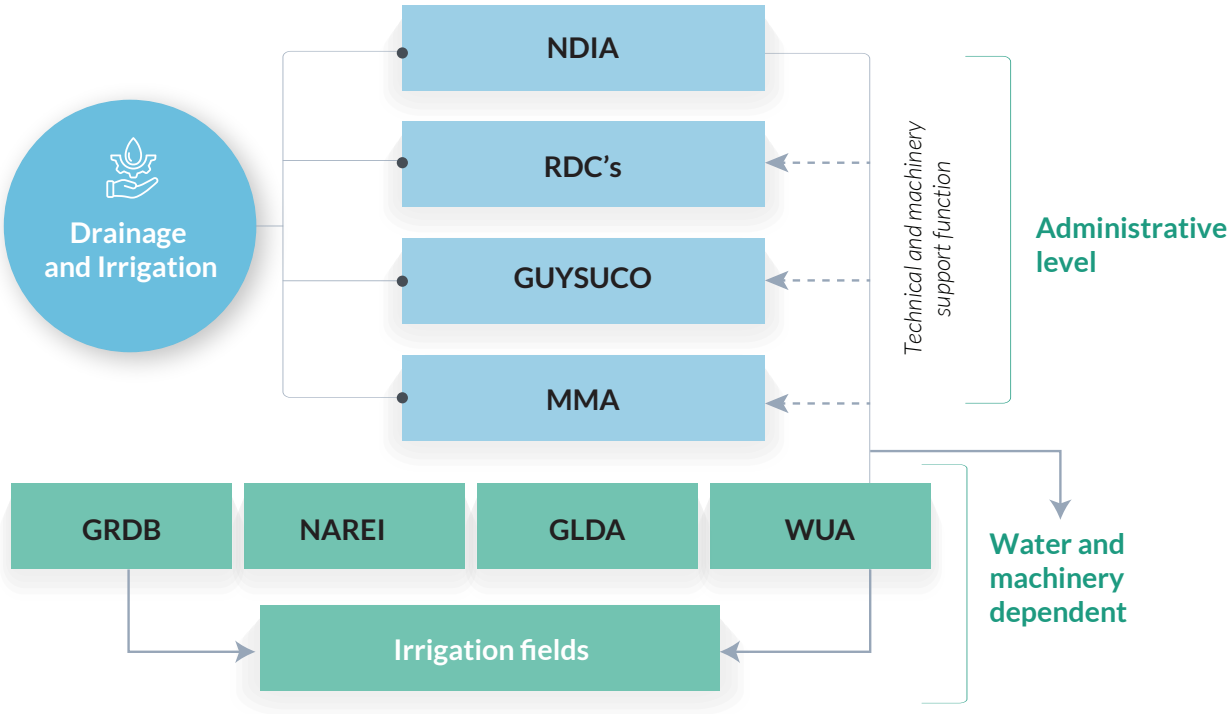


Figure 10. Schematic of the current structure of resource sharing in the D&I sector

Therefore, comprehensive and coordinated approach to flood management, particularly in understanding data needs among all stakeholders at various administrative levels can promote and build resilience in flood management. Similarly, when we consider irrigation for agricultural practices, the water requirements can be estimated based on different land use patterns, cropping systems, climate, hydraulic characteristics of the water distribution system and the amount of water resources available for irrigation[39]. Against this backdrop, the efficient management of D&I resources in flood management requires comprehensive knowledge of many variables whether it relates to soil, climate, water quality, etc. Many of the data entry points are distributed among different agencies and their integration and use in D&I planning can promote knowledge-driven decision making.

The existing components in Figure 10 need to undergo transformation to include research and development partners who are not responsible for D&I but rather contribute to the performance and sustainability of the D&I systems. In combating deterioration and aid in modernization priorities, performance assessment of large-scale systems must be prioritized. To be effective, institutions such as the University of Guyana becomes critical to support these functions (Figure 11). This includes evaluating actual performance against established design criteria, determining whether the system requires modernization or extensive maintenance, etc[40]. Regulating the use of appropriate and safe pesticides by the Pesticide and Toxic Chemicals Control Board (PTCCB) for vegetation clearing at sluice gates is also important for resilient agriculture as pesticides tend to leach into water, in soil and in agricultural produce. The National Data Management Authority (NDMA) could also support integrating performance indicators with predictive analytics that could guide resource allocation and ensure that systems meet evolving needs.

39 Todorovic, M., & Steduto, P. (2003). A GIS for irrigation management. Physics and Chemistry of the Earth, Parts A/B/C, 28(4-5), 163-174.

40 Schultz, B., & De Wrachien, D. (2002). Irrigation and drainage systems research and development in the 21st century. Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage, 51(4), 311-327.

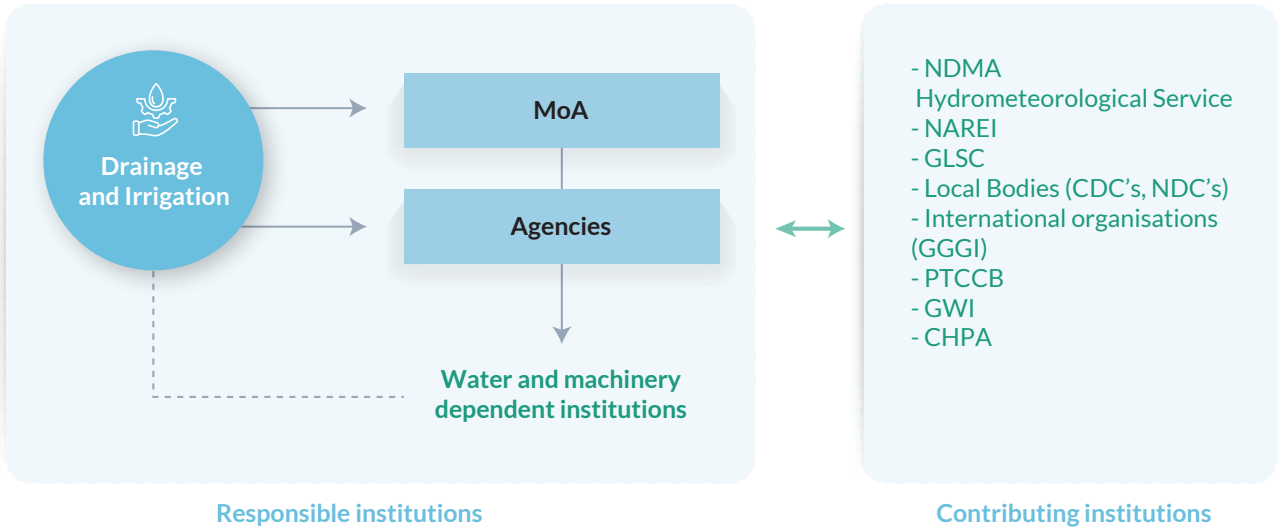


Figure 11. Inclusion of emerging actors in the D&I interface

While the NDIA has a great share of technical capacity and machinery compared to other agencies, it is facing increasing challenges of climate change which is further compounded with its resource sharing with the different responsible agencies for drainage and irrigation. Another challenge expressed by government agencies and regional engineering departments is the down time of key machinery, logistical challenges and stock logs for emergencies. At the same time, the challenges posed by unpredicted weather events highlight the need for a comprehensive collaboration network. Such networks, while urgent, are a catalyst for opportunities when it comes to early warning systems.

6.4.4 Other challenges – Biodiversity and Social Inclusion

Construction of drainage and irrigation infrastructure are found to be a problem towards human-wildlife conflict, disturbing the natural biodiversity in certain areas.

1. Diversion of drainages into canals impacts the quality of water and subsequently leads to overflows where diversion control fails
2. Mining activities transport silt downstream and fills up reservoirs and rivers, increasing erosion and water pollution
3. Use of chemical fertilizers in clearing vegetation in canals and channels reduces water quality and destroys biodiversity in addition to leaching in crop lands and fields
4. The performance and benefits of D&I infrastructure should be evaluated on the basis of seasonal cultivations or in line with the cropping season as the benefits generated by the project can be correlated with the farmers income generation
5. Inclusive and participatory farmer cooperatives and D&I authorities. Revamping organizations like the RPA to have mutual understanding with authorities in managing water usage would minimize operational and maintenance conflict and give control of irrigation to farmers. Establishing a water sharing system based on zoning and crop system could also reduce unnecessary water wastage and pump operations.

A buildup of silt at the mouth of the drainage canal often requires dredging to increase outflow.



7. Entry Points for Integrating Resilience into Drainage and Irrigation Planning

7.1 Prioritizing D&I investments based on risk, exposure and vulnerabilities

Given the hazards and vulnerabilities discussed in the previous section, it is essential to conduct detailed flood risk hazard and vulnerability mapping before implementing any drainage and irrigation (D&I) interventions. Annexure 5 provides the spatial analysis method used in the study. Such mapping enables decision-makers to identify priority areas at greatest risk, understand the nature and drivers of flooding, and assess the social and economic exposure of communities and agricultural zones. It will also provide the evidence base for designing tailored, climate-resilient solutions, whether through engineered infrastructure like pumps and sluices or nature-based interventions such as buffer zones or restored wetlands or sedimentation ponds[41]. Without such an analysis, investments in hard infrastructure or nature-based solutions may be misdirected or insufficiently responsive to actual risk dynamics, leading to ineffective or flood management strategies.

7.1.1 Data Sources[42]

The flood risk analysis was conduct using best available data (Table 4). Many data were provided by national sources, including the NDIA, the Ministry of Agriculture, the Hydrometeorological Service, and other government agencies. Where local/national data was not available, supplementary data were acquired from global sources, including the World Resources Institute, European Commission, and other sources. Data was collated using the best available scale to inform on-the-ground decision making. Refer to Annexure 6 for flood risk data and diagram.

Table 4. Data and sources for each variable and its corresponding component.

	Variable	Data Source	Reference
	Hazard		
1	**Historical Flooding**	JRC Global River Flood Hazard Maps	Baugh, Calum; Colonese, Juan; D'Angelo, Claudia; Dottori, Francesco; Neal, Jeffrey; Prudhomme, Christel; Salamon, Peter (2024): Global river flood hazard maps. European Commission, Joint Research Centre (JRC)
2	**Future Riverine Flooding**	WRI Aqueduct Floods Hazard Maps - Coastal Inundation Projections	Ward, P.J., H.C. Winsemius, S. Kuzma, M.F.P. Bierkens, A. Bouwman, H. de Moel, A. Díaz Loaiza, et al. 2020. "Aqueduct Floods Methodology." Technical Note. Washington, D.C.: World Resources Institute.
3	**Future Coastal Flooding**	WRI Aqueduct Floods Hazard Maps - Riverine Inundation Projections	Ward, P.J., H.C. Winsemius, S. Kuzma, M.F.P. Bierkens, A. Bouwman, H. de Moel, A. Díaz Loaiza, et al. 2020. "Aqueduct Floods Methodology." Technical Note. Washington, D.C.: World Resources Institute.

41 World Bank. (2023). Sectoral Recovery Capacity Assessment report for Guyana's Agriculture Sector. Washington, D.C.: The World Bank Group

42 Justin VanderBerg. (2025). Flood Risk Mapping Report. Consultant report prepared for Global Green Growth Institute.

	Exposure		
4	**Population Distribution**	Global Human Settlement Layer (GHSL) - European Commission Joint Research Centre	Pesaresi, M. et al. (2024) "Advances on the Global Human Settlement Layer by joint assessment of Earth Observation and population survey data", International Journal of Digital Earth, 17 (1)
5	**Population Density**	HDX WorldPop 2020 Density - Guyana - Global High Resolution Population Denominators Project (UN Adjusted)	WorldPop (www.worldpop.org - School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018).
6	**Agricultural Lands**	Guyana National Land Use Plan (NLUP) - Agricultural Areas	
	Vulnerability		
7	**Operable Infrastructure**	National Drainage and Irrigation Authority (NDIA) - Infrastructure	
8	**Inoperable Infrastructure**	National Drainage and Irrigation Authority (NDIA) - Infrastructure	
9	**Female Population (%)**	OCHA HDX WorldPop - Guyana Age and Sex Structure (2015-2023)	Bondarenko M., Priyatikanto R., Tejedor-Garavito N., Zhang W., McKeen T., Cunningham A., Woods T., Hilton J., Cihan D., Nosatiuk B., Brinkhoff T., Tatem A., Sorichetta A.. 2025. Constrained estimates of 2015-2030 total number of people per grid square broken down by gender and age groupings at a resolution of 3 arc (approximately 100m at the equator) R2024B version v1.
10	**Young Population u15 (%)**	OCHA HDX WorldPop - Guyana Age and Sex Structure (2015-2023)	Bondarenko M., Priyatikanto R., Tejedor-Garavito N., Zhang W., McKeen T., Cunningham A., Woods T., Hilton J., Cihan D., Nosatiuk B., Brinkhoff T., Tatem A., Sorichetta A.. 2025. Constrained estimates of 2015-2030 total number of people per grid square broken down by gender and age groupings at a resolution of 3 arc (approximately 100m at the equator) R2024B version v1.
11	**Multi-dimensional Social Vulnerability**	Global-Empirical Social Vulnerability Index - Globe SoVi -	Reimann, L., Koks, E., de Moel, H., Ton, M.J. and Aerts, J.C., 2024. An empirical social vulnerability map for flood risk assessment at global scale ("GlobE-SoVI"). Earth's Future, 12(3)

7.1.2 Mapping coastal hazard risk

According to the World Bank Report on Sectoral Recovery Capacity in Guyana, a hazard is a "process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation". To capture flood hazard, three data sets were integrated to identify 1) historical flooding based on satellite observations provided by the European Union Joint Research Council, and 2) future expansion of riverine flooding and 3) future coastal inundation under climate change from the World Resources Institute Aquaduct Program. Together, these datasets identify the broadest set of areas likely to experience flood hazard in the next century.

The primary hazard in this analysis in Figure 12 is the potential for current and future flooding. Integrating current flooding with future inundation of rivers and coasts produces an integrated flood hazard map. The map shows a concentration of high flood hazard around rivers and coasts with the hazard decreasing with distance from these water bodies. Other flatter areas also have increased hazards due to the reduced ability of lands to shed water quickly after rains and flood events.

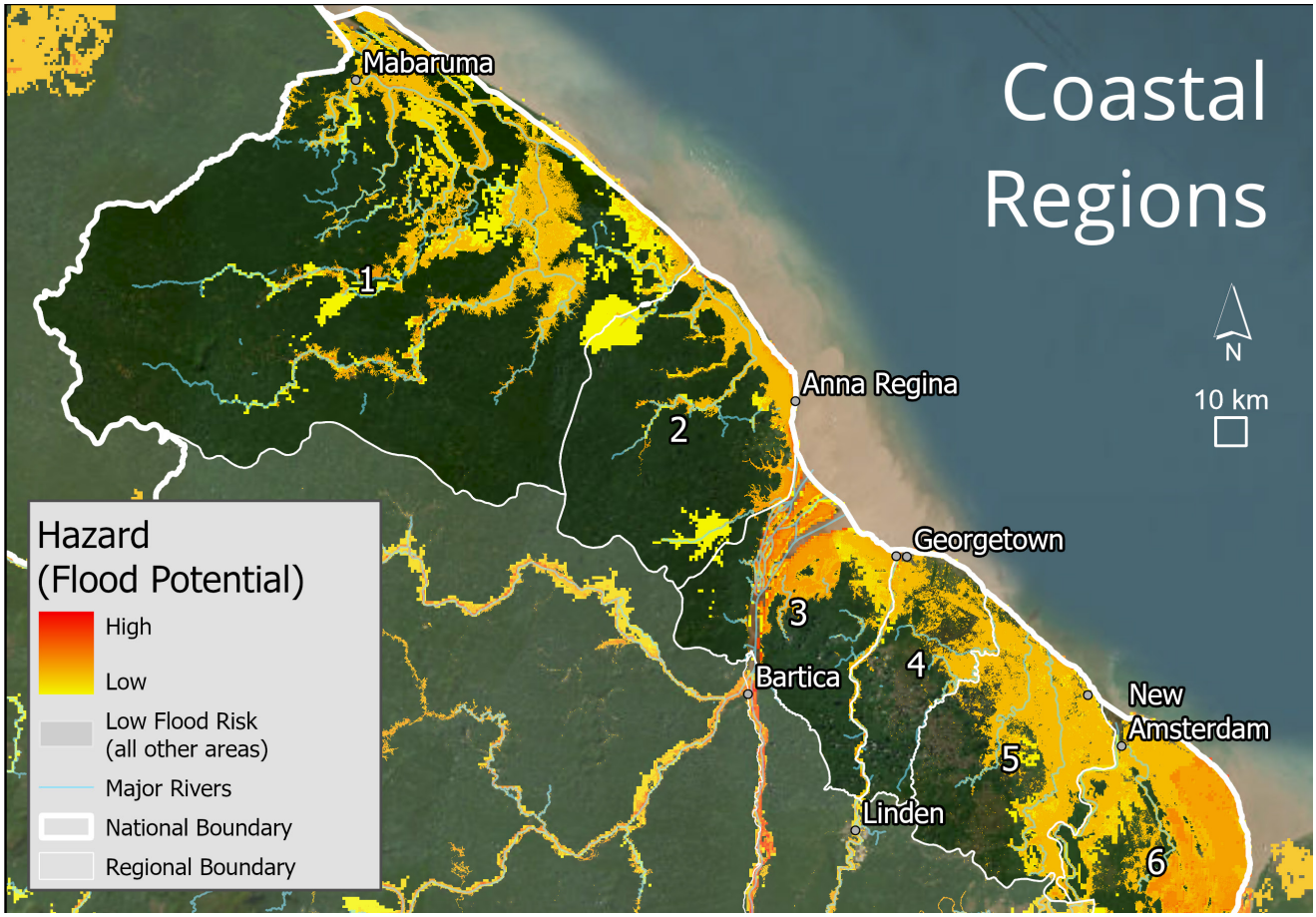


Figure 12. Flood hazard map

7.1.3 Mapping vulnerability risk

The National Integrated Disaster Risk Management Plan and Implementation Strategy for Guyana, defines vulnerability as the "characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard"[43]. To capture flood vulnerability, five indicators were used including 1) the location of operable drainage infrastructure such as pumps, sluices, bridges, and channels provided by NDIA, 2) inoperable drainage infrastructure provided by NDIA, 3) the percentage of female population and 4) young (under 15) population as identified by WorldPop Age and Sex Structure Dataset, and 5) multi-dimensional social vulnerability as captured by the Global-Empirical Social Vulnerability Index (Globe SoVi). Globe SoVI incorporates education, elderly, income gap, ruralness, and walking time to healthcare facility to compare vulnerability globally. These datasets are capture at the district and region levels and compiled into an overall measure, which is included here to facilitate broader comparison across the regions.

Vulnerability indicates how severe the impacts of flood events are likely to be. Vulnerability is often reduced from the services offered in urban areas such as access to emergency services and infrastructure investments in areas that deliver the most aggregated benefit. As such, the vulnerability map in Figure 13 shows the lowest levels in urban areas with increasing vulnerability inland.

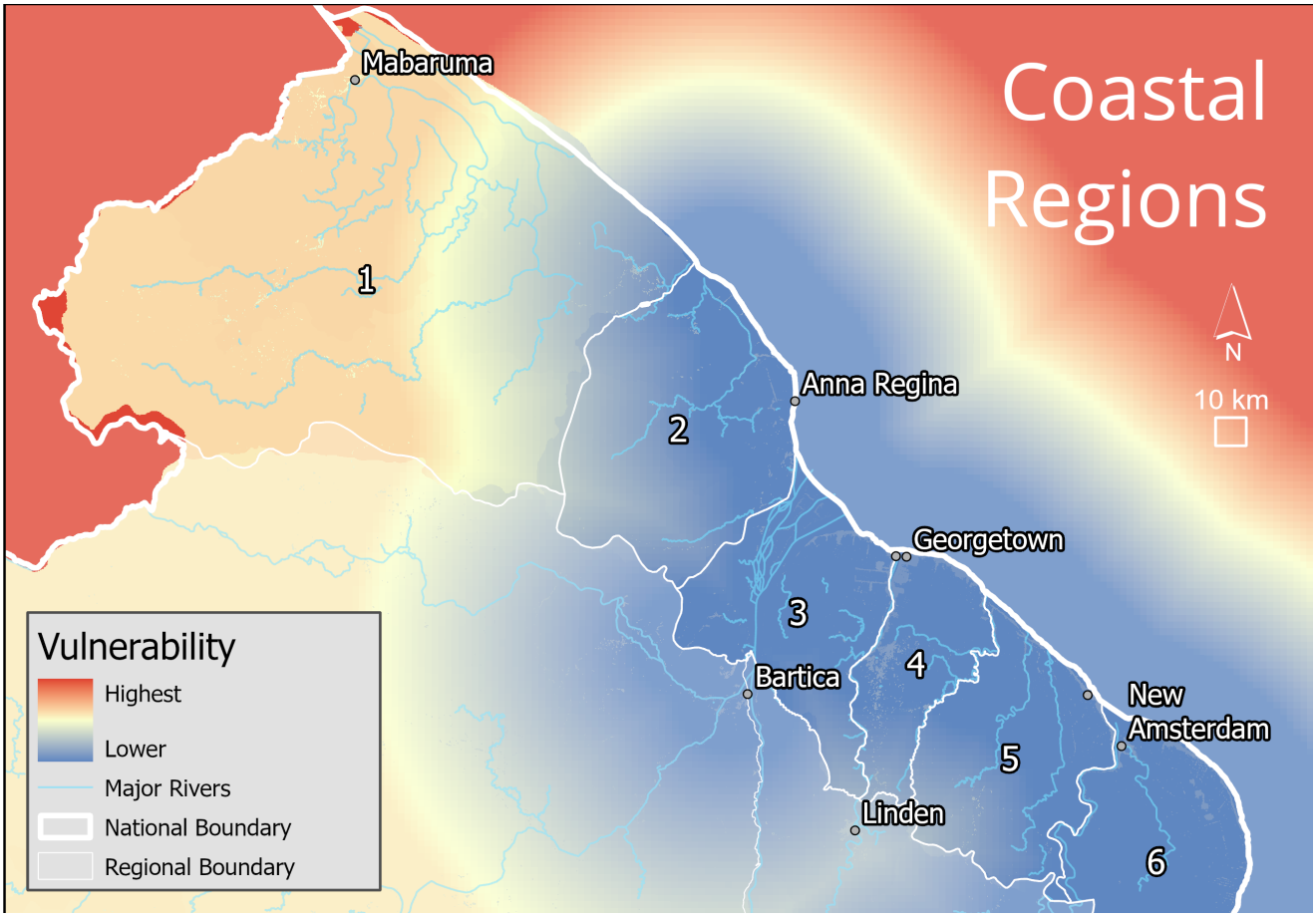


Figure 13. Flood vulnerability map

43 Civil Defence Commission. (2013). National Integrated Disaster Risk Management Plan and Implementation Strategy for Guyana

7.1.4 Mapping exposure risk

Exposure refers to "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas"[44]. To capture flood exposure, three additional datasets were brought together including 1) population distribution from the Global Human Settlement Layer, 2) Population density from the WorldPop 2020 dataset, and 3) agricultural areas from the Guyana National Land Use Plan. Population distribution identifies the core areas of populated areas, while the density captures the broader populated areas to help understand where people are exposed to flooding, while agricultural areas help capture where vital productive lands are exposed to flooding. Combining these together presents a picture of where flooding would cause damage to humans and human systems.

In the analysis, exposure is a function of people and assets, mostly agricultural lands, that may be harmed by future flooding events. Floods occurring in areas without people or agriculture assets have a natural function of slowing water flows, fertilizing flood plains, and reducing sediment within streams and river courses—beneficial outcomes that are often the objective of Nature based Solutions. Looking at the integrated area of people and agricultural assets, Figure 14 shows the location of people and agricultural assets with a strong concentration of people along the coast supported by adjacent agricultural lands extending inland.

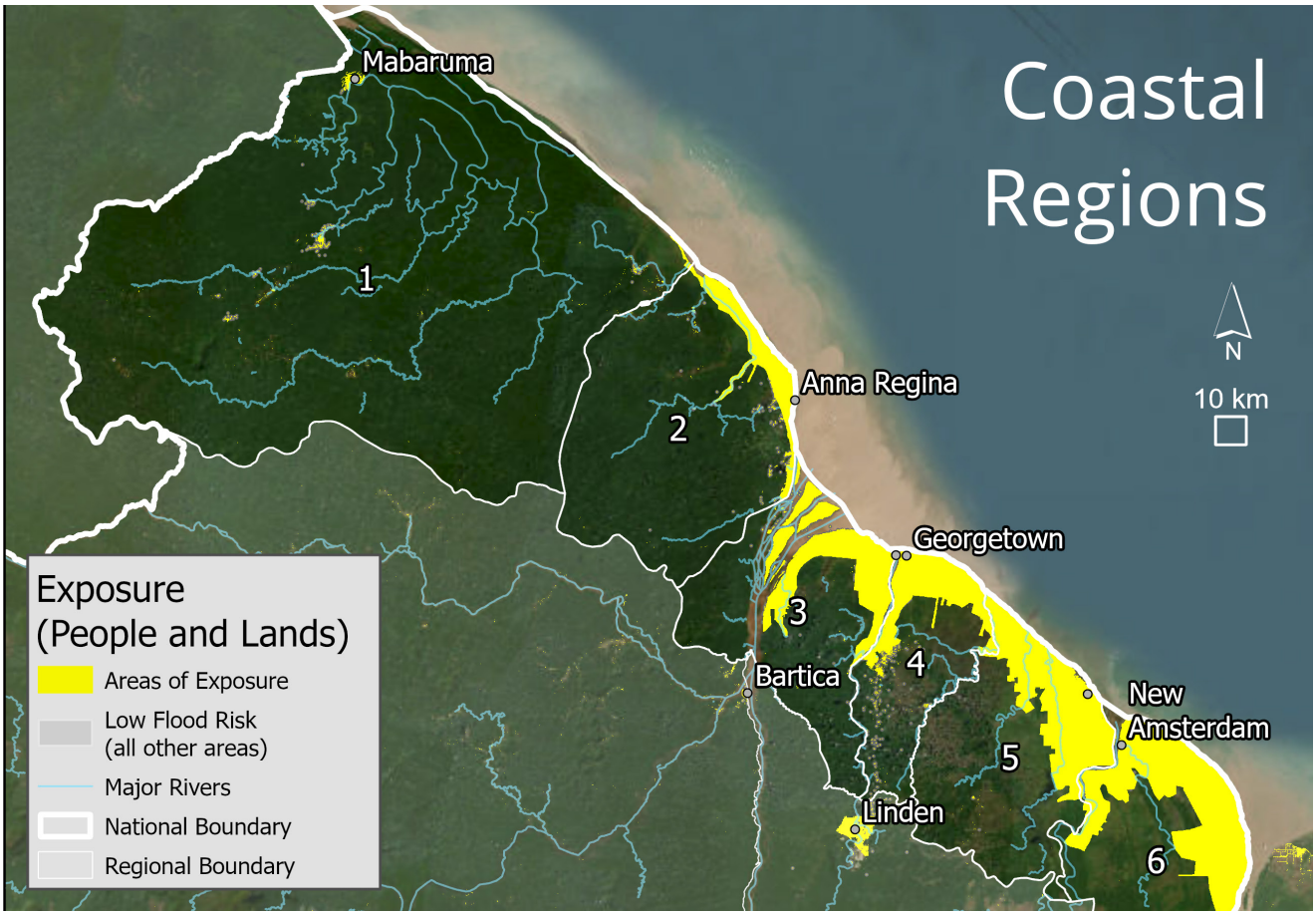


Figure 14. Flood exposure map

44 United Nations General Assembly. (2016). Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction.

7.1.5 Integrated flood risk

The variables for each component – hazard, exposure and vulnerability – were normalized from 0 to 1 with low values equating to low risk and high values equating to high risk. Within each component, the variables for each component were then averaged together to determine a component score. The three component scores were multiplied together. The resultant flood risk map in Figure 15 identifies people/assets that are exposed to flooding and captures the differences in vulnerability amongst those areas.

From Figure 15, flood risk across the coastal regions is concentrated along coastal areas and major rivers with major areas of risk along the Essequibo River and farther to the south along the Corentyne River within region 6. Notably underrepresented in this flood risk map is flood risk in region 1. As risk is a function of exposure, areas with no population and no agricultural areas are not identified as having flood risk. Such results must be further examined and verified, as population and agricultural assets almost certainly do not capture all areas of exposure. Across all regions, region 5 had the largest flood hazard with over 50% of its area potentially experiencing flooding and more than a quarter (29%) of its area containing people or agricultural areas at risk of flood damage. Refer to Annexure 7 for the integrated flood risk assessment of Administrative Regions 1 to 6.

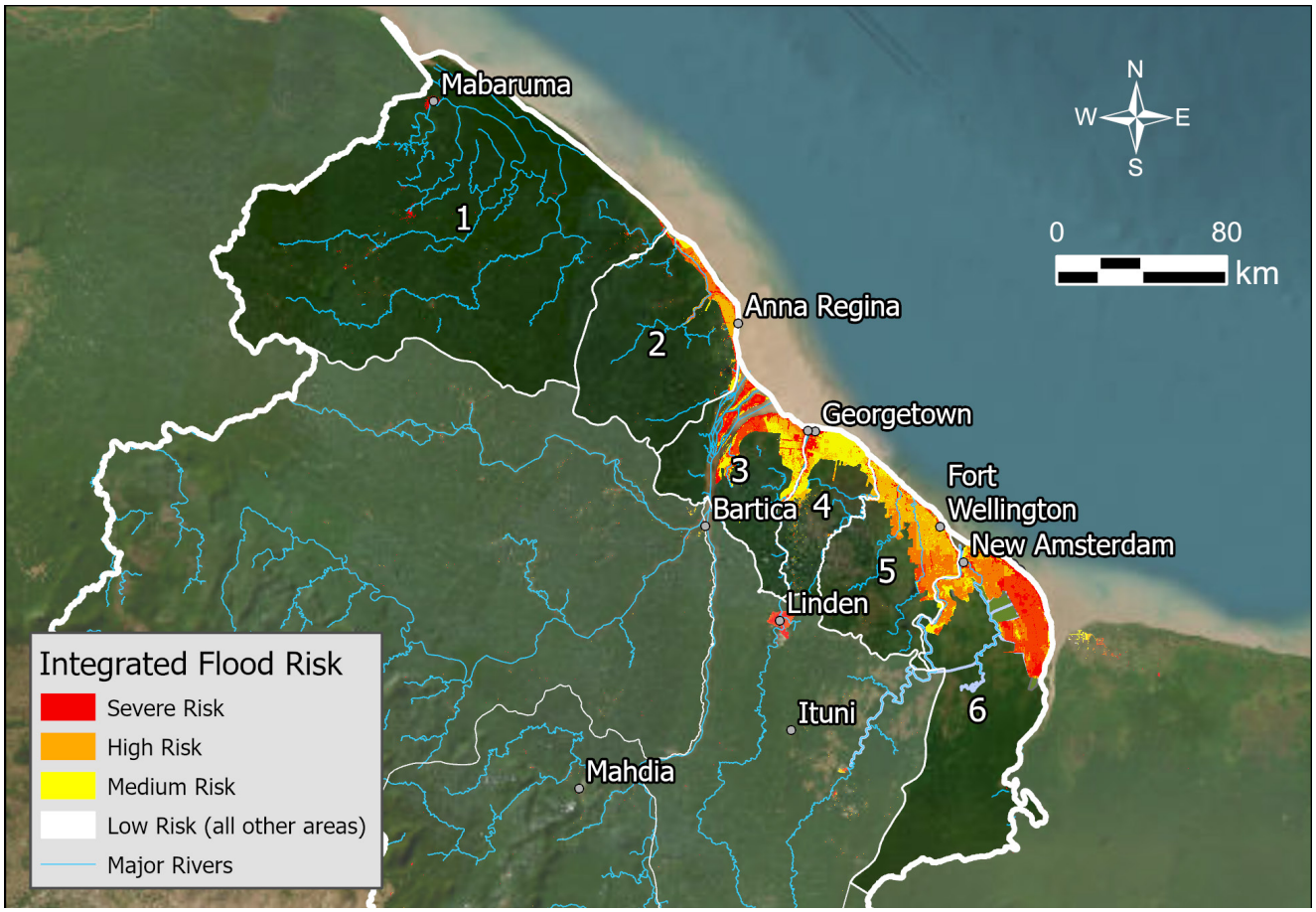


Figure 15. Flood risk map

7.1.6 Infrastructure risk

Measuring risk at existing drainage infrastructure points provides a novel perspective on the distribution of risk despite the risk reducing influence of those infrastructure. Of the coastal regions, regions 1 and 4 have the highest average risk (Figure 16) both with risk scores above 0.8 (out of 1). However, when assessing risk at existing infrastructure locations, region 4's risk decreases back towards the national mean, suggesting the flood reduction infrastructure in this region is effective in reducing flood risk. Conversely, in regions 2, 3, and 6, the average risk level at infrastructure sites is slightly higher than the overall risk suggesting that infrastructure improvements in these regions could produce enhanced flood risk reduction.

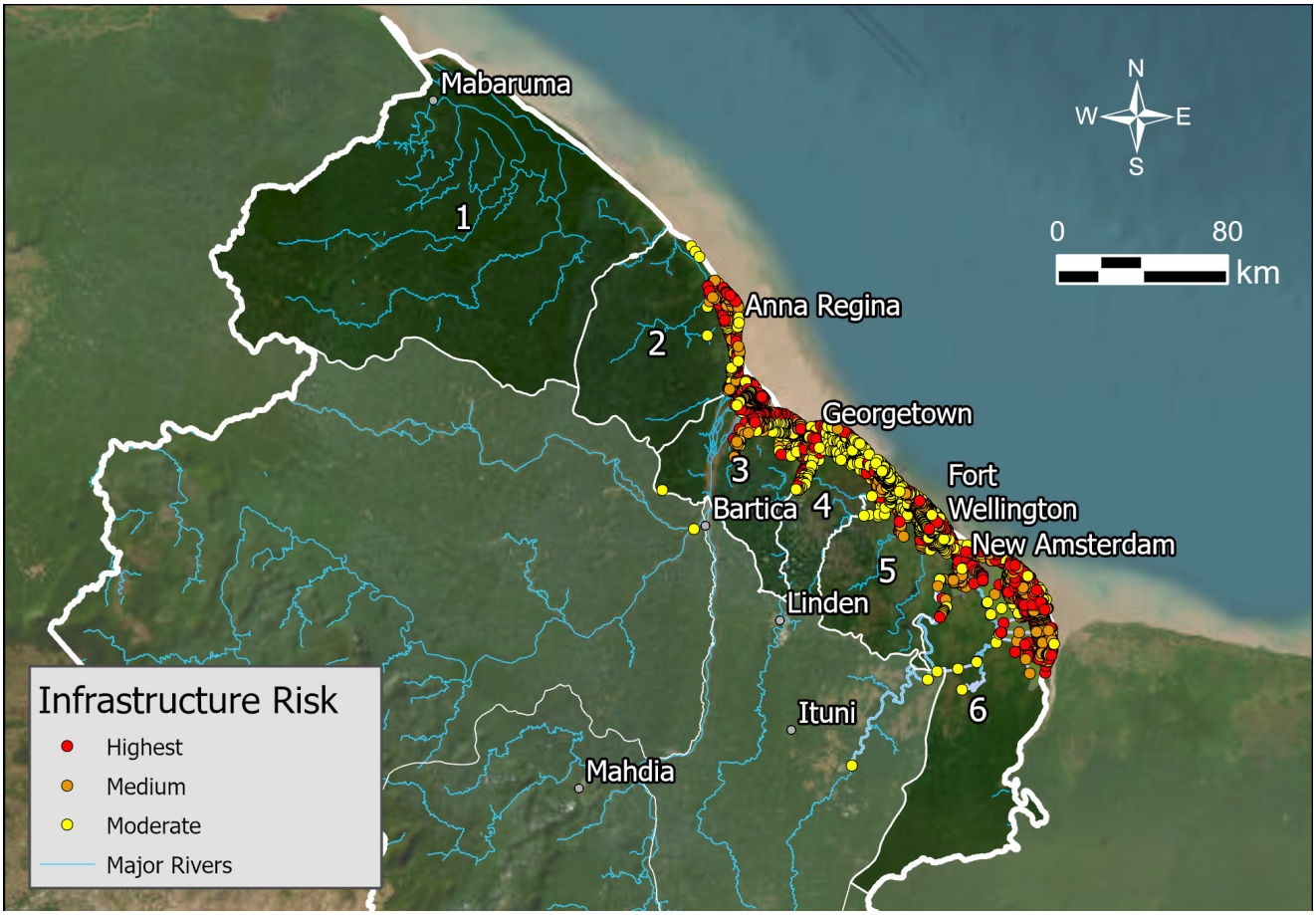


Figure 16. Risk distribution across D&I infrastructure

7.1.7 Farmland risk

Examining risk at specific farm locations highlights the challenges faced by Guyana's agricultural sector and the people that rely on that industry for their livelihoods. General patterns of high risk being concentrated near water sources and lower risk being found further away from water continues in this sector, with the exception of all agricultural areas within region 1 falling with the highest risk category (Figure 17). This is due to compounding drivers of risks, and particularly in region 1, very high levels of vulnerability. Region 6 also experiences higher than usual risk due to the confluence of flood hazards with higher levels of social vulnerability. Farmlands within regions 2-5 have a mix of high risk down to areas of lower risk. Please refer to Annexure 8 for the cross-section of region-wise statistics of risk by focus.

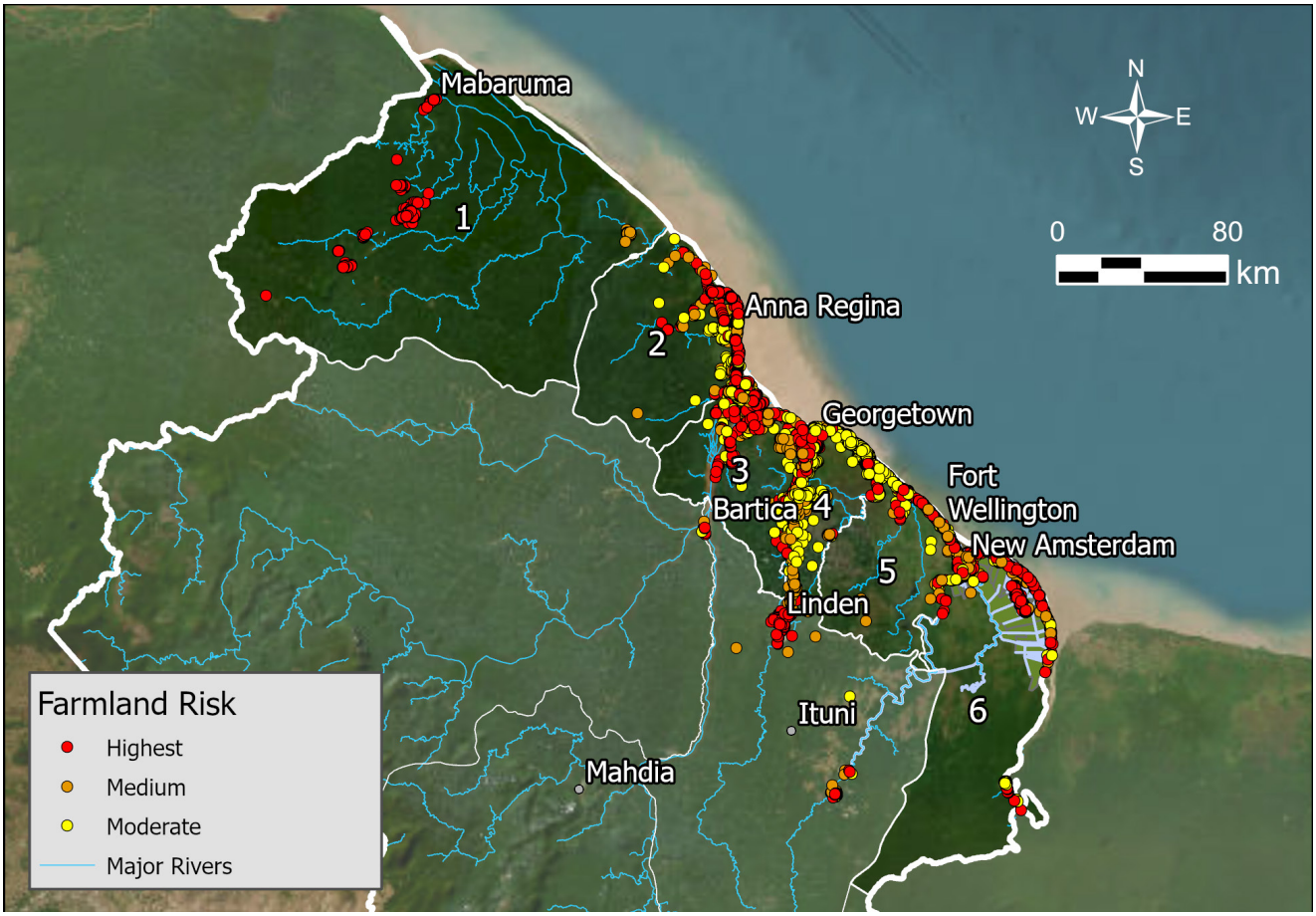


Figure 17. Flood risk at individual farm locations

8. Recommendations

8.1 Incorporating resilience in NDIA's Strategic Plan for 2025-2030

There is nothing definite about climate change and predictions keeps changing based on complex global systems and political influence. Nevertheless, countries like Guyana, need to cushion themselves against the vast possible scenarios that climate change can present. This means, ensuring that government strategies are proactive and can anticipate the multiple future scenarios of climate change. For example, Singapore, considered to be a benchmark for urban water resilience has recently been faced with unpredictable rainfall and flood risk to the extent the Minister for Sustainability and the Environment emphasized, it was no longer practical or prudent to continue building more drains or expanding drainage infrastructure[45]. This is because D&I infrastructure are capital intensive and require land to establish these facilities. The continuous rebuilding of D&I infrastructure also slows economic development with the repeated impacts of floods making it ever more challenging to maintain the existing capital stock[46]. Therefore, what is required is a multi-pronged integrated approach to effectively build Guyana's flood resilience at a system level, giving homeowners, housing developers and wider community a part to play alongside the government. Investment in D&I infrastructure including finding suitable land will need to consider flood events that don't occur regularly and in places where it doesn't occur regularly, making it not so financially wise to prepare for such events. It must be done to protect the livelihood of citizens and government can look towards nature-based solutions involving stakeholder engagements to tackle the systemic problems of flood management. Figure 18 provides a list of the best practices for D&I planning against established guidelines of the current NDIA strategy. This allows for better identification of the gaps that needs to be incorporated in building resilience.

Thematic areas of best practices in D&I

- prioritize comprehensive and integrated D&I planning
- strategic transformative approach
- empowering water users' association
- financing and prioritizing irrigation projects
- data accuracy and validity
- Interministerial coordination
- detailed drainage network assessment
- simulation scenarious and validation
- low-impact development options
- infrastructure and maintenance
- public engagement
- watershed management in rain-fed irrigation
- farmer-led irrigation development
- irrigation scheme development and modernization
- unconventional water use for irrigation

Focus areas of NDIA strategy

- flexibility to respond to unforeseen events
- PP partnerships and cost recovery
- data collection and analysis
- inter-agency collaboration
- strenghtening water users association
- prioritizing maintenance and rehabilitation
- flood risk management
- development of comprehensive GIS mapping
- sustainable landuse

Figure 18. Thematic areas of best practice against NDIA strategy

45 https://www.channelnewsasia.com/singapore/150-million-drainage-projects-2025-flood-resilience-4915201

46 The World Bank. (2024). People in a Changing Climate: From Vulnerability to Action - Insights from World Bank Group Country Climate and Development Reports covering 72 economies

During a high-level discussion on the Low Carbon Development Strategy (LCDS), President Dr. Irfaan Ali emphasized to stakeholders that while global best practices offer valuable insights, they should not be adopted wholesale. Instead, he underscored the importance of developing context-specific models tailored to Guyana's unique hydrological, climatic, and socio-economic conditions, drawing lessons from both developed and developing nations. Building on this principle, the National Drainage and Irrigation Authority (NDIA) strategy would need to integrate relevant best practices into its strategic framework, ensuring that policy decisions were data-driven and aligned with long-term resilience objectives. This approach would allow for a critical assessment of existing D&I systems, identification of gaps, and refinement of strategies to enhance infrastructure efficiency, climate adaptation, and institutional coordination. By leveraging international experiences while adapting them to local realities, Guyana aims to strengthen its integrated water resource management (IWRM) framework, improve flood resilience, and establish sustainable water governance mechanisms suited to its evolving environmental challenges.



View of a sluice used for drainage and irrigation of farmlands in Berbice, Guyana.

8.2 Evaluating measures for integrating resilience

The technical and institutional challenges and needs identified in this study have informed the recommendations of potential strategic priorities for implementation by NDIA under its Integrated Strategy for Drainage and Irrigation. Figure 19 below establishes the six priorities and provides justification for why they are of utmost importance in building resilience in D&I. In addition, the study also recommends targeted interventions to proactively respond to identified hazards and vulnerabilities constraining D&I in Guyana. These interventions were developed through various consultations with agencies having vested interests in D&I. The following section identifies the categories of interventions.

8.2.1 Technology Integration

- Sensor technology - Collaborate with NDMA for installation of accurate sensor-based measurement devices to detect water levels and water quality at conservancies to aid in irrigation of fields and maintain check on operational activities. Incorporation of sensor-devices can be used to detect remotely, the operational status and duration of operation of D&I pumps and fuel consumption
- Build capacity with NDMA on to solar-powered high-resolution CCTV to capture, analyse and independently grade the conditions of sluices/ checked structures
- In this regard, collaborate with the Hydrometeorological Service to produce localized weather files and flood risk maps.

8.2.2 Data Management Systems

- Integrated databases - The development of a geo-referenced national GIS D&I database and its further evaluation through the creation of irrigation scenarios and the estimate of irrigation requirements, and the location of excessive and deficient water. Collaboration is essential to address flood management and irrigation requirements and to build a more resilient Guyana. Due to the complexities of the D&I interface, quality and geo-referenced data from stakeholders will be required, in addition to technical resources
- Develop systems for a multi-stakeholder online database comprising of de-silting, clearing, rehabilitation, etc of structures and channels from the RDC's, MMA, and NDIA
- Predictive Analytics for interpreting historical and real time data and aid in scenario planning, flood risk assessment and D&I optimisation
- Watershed topography and hydrological characteristics should be considered when planning and designing D&I infrastructure.

Groundwater usage and recharge

- So far, NDIA has not formulated any plans on aquifers. Risk of rising groundwater in shallow aquifers could be a serious flood problem that reduces absorption of rainwater into soils. Formulating plans for efficient usage of groundwater resources and their consequent recharge is necessary.
- The NDIA needs to plan the usage of shallow aquifers to prevent waterlogging. At the same time, it needs to recharge the deeper aquifers with rainwater. At the moment, there isn't any mapping of national ground water levels and deep and shallow aquifers. It is time for the government to think of a water plan to recharge its aquifer and solve the water logging issues.

Creating Drainage Development Plans (DDP) for individual administrative regions

- Coastal regions are becoming urban clusters and therefore require individual drainage development plans based on existing infrastructure risk levels and risks to farmlands and livelihoods.
- Dedicated budget should be made available to prepare region-wise drainage development plans and leading agencies should include NDIA, NAREI, GRDB, GLDA, EPA, MoPW, CH&PA
- A separate monitoring and evaluation unit could be formed to drive the development and implement of DPPs across all regions.

Regulating building codes for offseting infiltration

- With rapid land use conversion to residential plots, innovative mitigation measures such as offsetting the forgone land infilration by soil can be replaced through rooftop piping that guides rainwater underground and goes into the soils for recharge.
- Installation of large rainwater storage tanks in residential complexes where rooftop pipes are interconnected and leads to a storage tank, which in turns provides water to the homes. This will increase the capacity of drainage and consequently reduce floods.

Nature-based Solutions

- Integrating NbS such as wetlands, riparian buffers to help in reducing flood. With planned activities at Hope-like structures, NbS can provide afforable alternatives using natural topography of land.
- Possibility of exploring sponge city concept in new and emerging building areas.

Community-led D&I planning

- Role of NDCs and CDCs are required in making community awareness. With increased NDIA outreach through sister agencies extension officers and government programmes, communities are aware of dredging and de-silting practices. However, many are not aware of the encroachment of conservancy land for drainage and clearing.
- Strengthening civil society organisations such as RPA and WUA to have decentralise management of D&I infrastructure with could benefit spatial planning for floods and drought.

Capacity building and awareness

- Build community capacity in structural failures of D&I infrastructure, preparedness for localised hazards based on seasonal rainfall risk and climate-smart agriculture to account for rainfall variability
- Increase spatial mapping capacity to enhance data-driven decisions

Build Back Better

- This is not only about post disaster but more towards anticipating hazards before they materialise and having plans to respond in the event of a localised flood event.

Figure 19. Priority areas for actions

8.2.3 Community Engagement and Social Inclusion

- Public awareness programmes for the general public on efficient drainage and irrigation methods and adhering so specific D&I standards at the local and national level. Having appropriate legal mechanisms for reporting and taking legal actions would minimise the unauthorised water diversion
- Need for an enforceable legal framework and well-defined legislations to ensure the Apex D&I body plan, designate and manage water in D&I sector
- A redressal system to accommodate the concerns and source critical information on the condition of D&I infrastructure in the country

8.2.4 Environmental Safeguards

- EIA and EMP is suggested for new D&I projects to predict and minimize the adverse environmental impacts of D&I projects and to monitor the effectiveness of measures taken
- Develop NbS such as wetlands restoration and mangroves to complement D&I infrastructure
- Collaborate with the PTCCB to discourage the use of harmful chemical fertilisers in water management

8.2.5 Impact and Project Outcomes

- Better resilient infrastructure and improved reliability of D&I systems thereby increasing trust of citizens
- Improved prioritization of annual work programs for rehabilitation and introduction of new D&I installation
- Data repository for reliable decision making, making actions less reactive and more proactive
- Community empowerment by having greater inclusion of stakeholders in the management of D&I resources
- Environmental sustainability through minimized ecological impacts

9. Annexures

ANNEXURE 1. LITERATURE SURVEY QUESTIONS

Background

1. What are the existing studies conducted on the state of D&I in Guyana?
2. What are the challenges and possible recommendations identified in the studies?
3. Are the studies comprehensive or only dealt with specific regions or locality?
4. Who are the stakeholders in these studies?

Technical

1. What are the technical challenges affecting D&I and how much of it has been documented?
2. Have previous studies modelled technical recommendations for D&I improvements?
3. What aspects of existing technical studies have been implemented in strategic documents of NDIA?
4. What are the new and emerging technical challenges facing D&I in terms of irrigation of farmland and drainage of excess water?

Institutional

1. Who are the stakeholders in D&I and what are their role?
2. What are the challenges at the institutional level both in terms of within agencies and across Ministries?

ANNEXURE 2. INTERVIEW SCHEDULE

PILLAR 1

OWNERSHIP

1. What is the structure of operation and maintenance when water mandates involve different ministries/agencies assets?
2. In the event of an emergency, where a key asset, for example, a koker/sluice is damaged leading to flooding, what is the procedure, and do you see areas where the process can be improved?
3. Are WUAs users regularly trained in O&M procedures and how often do NDIA conduct oversight of WUA practices?
4. What are the important vulnerabilities that you consider important in your region? For example, livestock, large farming areas, indigenous people, low-income, etc.
5. Are the D&I resources in the region adequate to address the vulnerabilities in your region?
6. Are women and youth able to voice their concerns on potential adaptation measures or in the conceptualization and design of D&I systems?
7. Which groups would you identify as vulnerable in the drainage & irrigation sector?
8. How do current drainage and irrigation projects consider the needs of vulnerable groups (e.g., women, low-income communities, indigenous groups)?
9. Are there any adjustments you've had to make to accommodate the needs of underrepresented groups in D&I infrastructure or maintenance?

PILLAR 2

OVERSIGHT AND COORDINATION

1. Are they guidelines to collaborate with other agencies and ministries in areas where D&I infrastructure is present? How often do you encounter challenges where different agencies/authorized contractors impede drainage and irrigation systems. Can you give an example?
2. Previous reports have cited concretization of narrow drains and channels as leading causes of flooding. Are they guidelines for continuous monitoring of drainage channel construction by NDIA contractors?
3. Do you see D&I resilience planning being integrated in urban development planning, particularly with new housing projects and road construction?
4. How often are you involved in the planning process with other Ministries or agencies where they work involve or impacts D&I assets in your region?

PILLAR 3

INFRASTRUCTURE PLANNING AND MAINTENANCE

1. More capacity is required in the maintenance and operation of D&I assets. Who are the local stakeholders that could enhance capacity and strengthen efficiency?
2. Are there any predictive or warning systems of expected flooding to inform planning in the region. How do you disseminate this information?
3. How much of a challenge is sedimentation of D&I infrastructure? Are you able to keep up with dredging? Where are dredged sediments deposited?
4. Are there areas where sedimentation and/or water retention ponds could be constructed?
5. Are sluices often blocked up by debris? How is this generally managed?

PILLAR 4

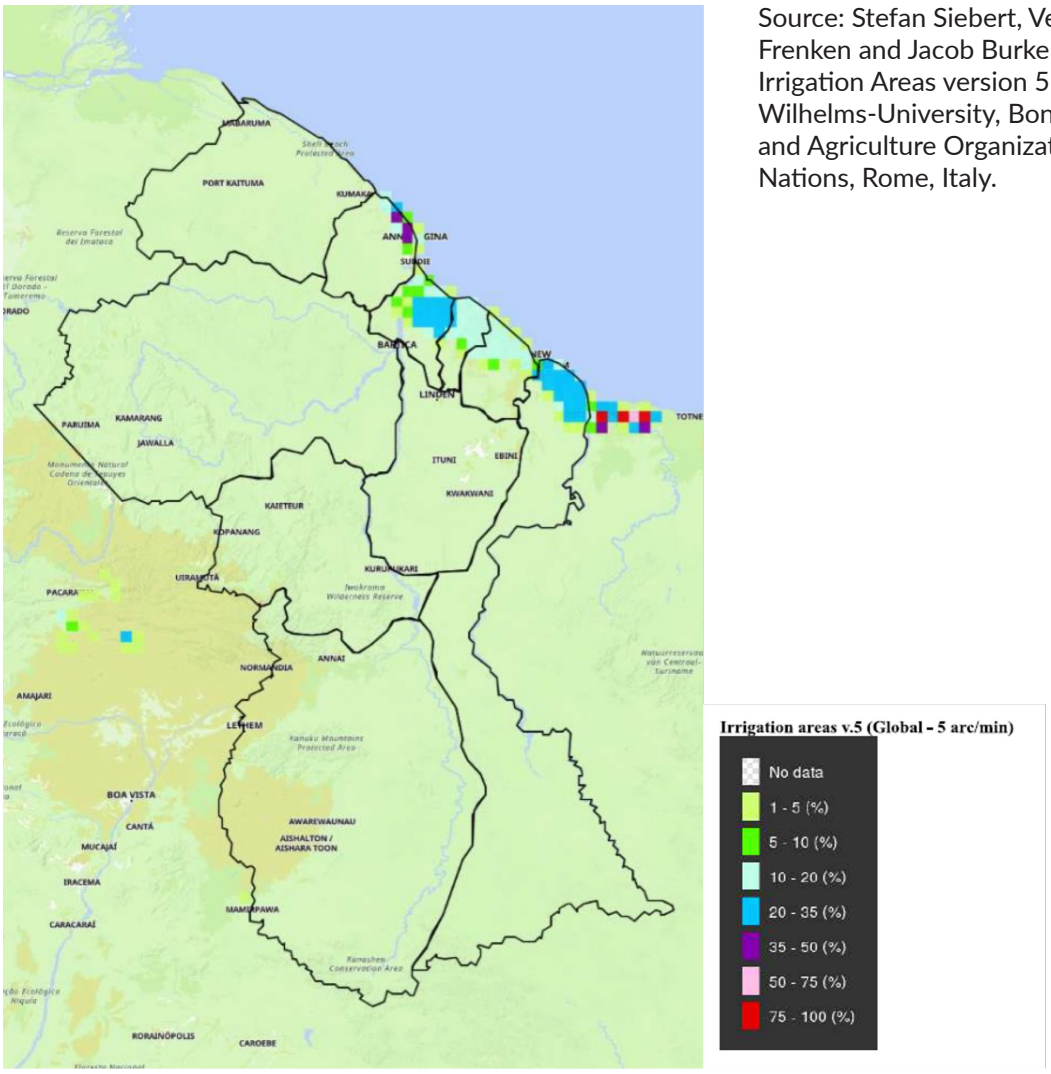
DATA MONITORING SYSTEMS

1. With plans to propose stainless steel doors for kokers/sluices, how is the monitoring of the infrastructure operator managed? Should there be a real-time system of water level indication that automatically manages the sluices gate? How do you see such enhancement in flood management and creating confidence in communities?
2. What specific challenges do you encounter when integrating gender equality or social inclusion into project design or implementation?
3. How can the NDIA ensure that D&I projects are more inclusive in terms of both access and benefits to vulnerable communities?
4. What kind of training or capacity-building would help engineers better implement GESI-focused approaches in their work?

Open Discussion of possible pillars:

- Human Resources
- Technology in D&I

ANNEXURE 3. PERCENTAGE OF AREA EQUIPPED FOR IRRIGATION THROUGH GROUNDWATER, SURFACE WATER OR OTHER SOURCES OF WATER.



Source: Stefan Siebert, Verena Henrich, Karen Frenken and Jacob Burke (2013). Global Map of Irrigation Areas version 5. Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy.

ANNEXURE 4. PERCENTAGE OF IRRIGATION AREA SUPPLIED THROUGH GROUNDWATER.

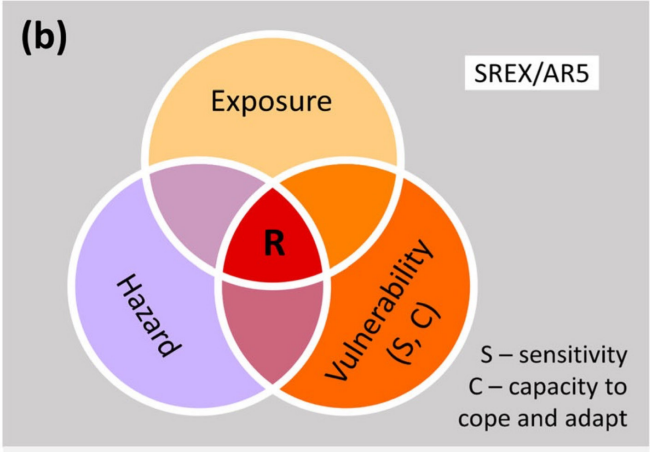


Source: Stefan Siebert, Verena Henrich, Karen Frenken and Jacob Burke (2013). Global Map of Irrigation Areas version 5. Rheinische Friedrich-Wilhelms-University, Bonn, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy.

ANNEXURE 5. SPATIAL ANALYSIS METHOD.

To develop comprehensive flood risk maps for Guyana's coastal regions, an integrated spatial analysis was conducted using the IPCC Special Report on Emissions Scenarios (SREX) definition of risk combining Hazard, Exposure, and Vulnerability components to determine overall Risk[1]. Variables were determined through consultation with partner organizations, key stakeholders, and government representatives from the National Drainage and Irrigation Authority (NDIA).

Each variable was normalized from 0-1 with 1 representing the highest flood risk. Within each component, all variables were averaged to provide a 0-1 score. The averaged scores for each component were multiplied together to determine overall flood risk, scored between 0-1 with 1 indicating the highest risk. Multiplying these component scores together means areas outside of flood zones receive a 'zero' score and areas within flood zones are ranked based on the vulnerability within those areas.

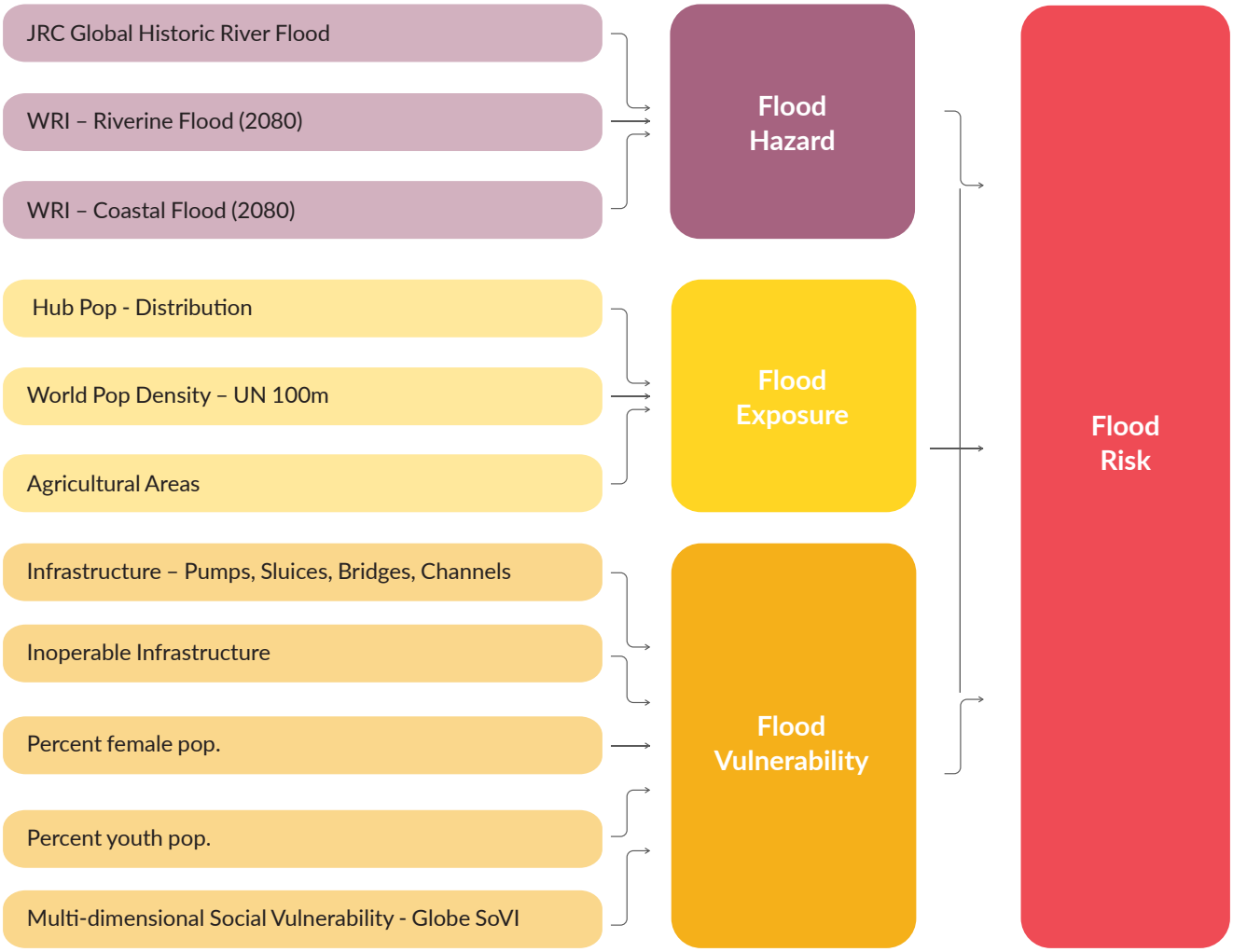


IPCC Risk Vulnerability conceptual diagram[1]

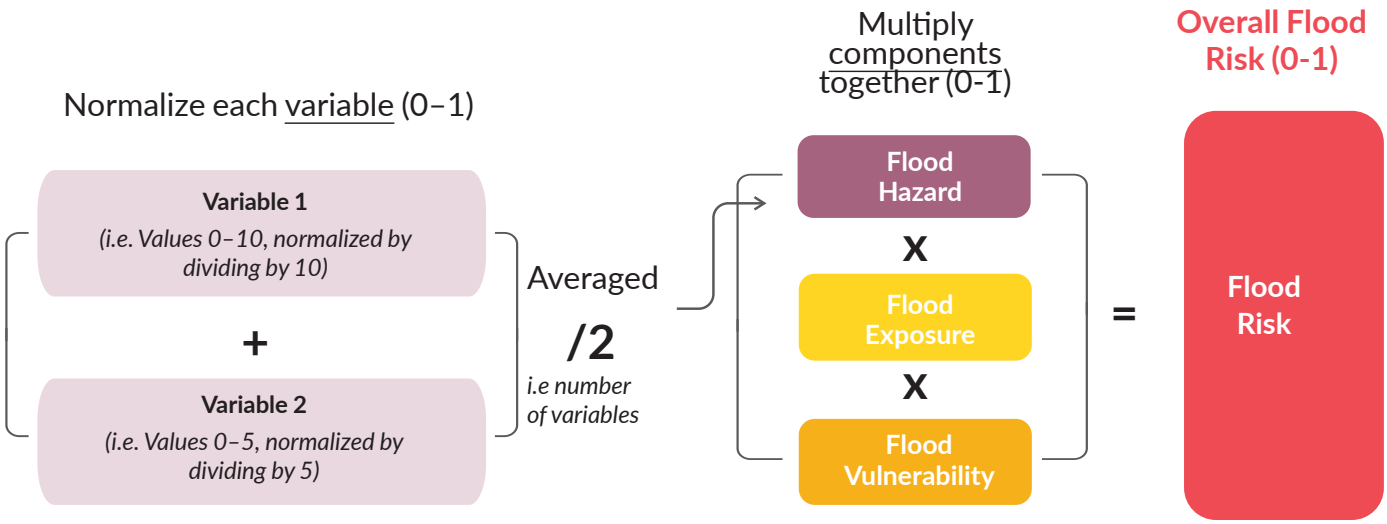
1 Estoque, R.C., Ishtiaque, A., Parajuli, J., Athukorala, D., Rabby, Y.W. and Ooba, M. (2023). Has the IPCC's revised vulnerability concept been well adopted?. Ambio, 52(2)

ANNEXURE 6. FLOOD RISK DATA AND DIAGRAM

Flood risk diagram



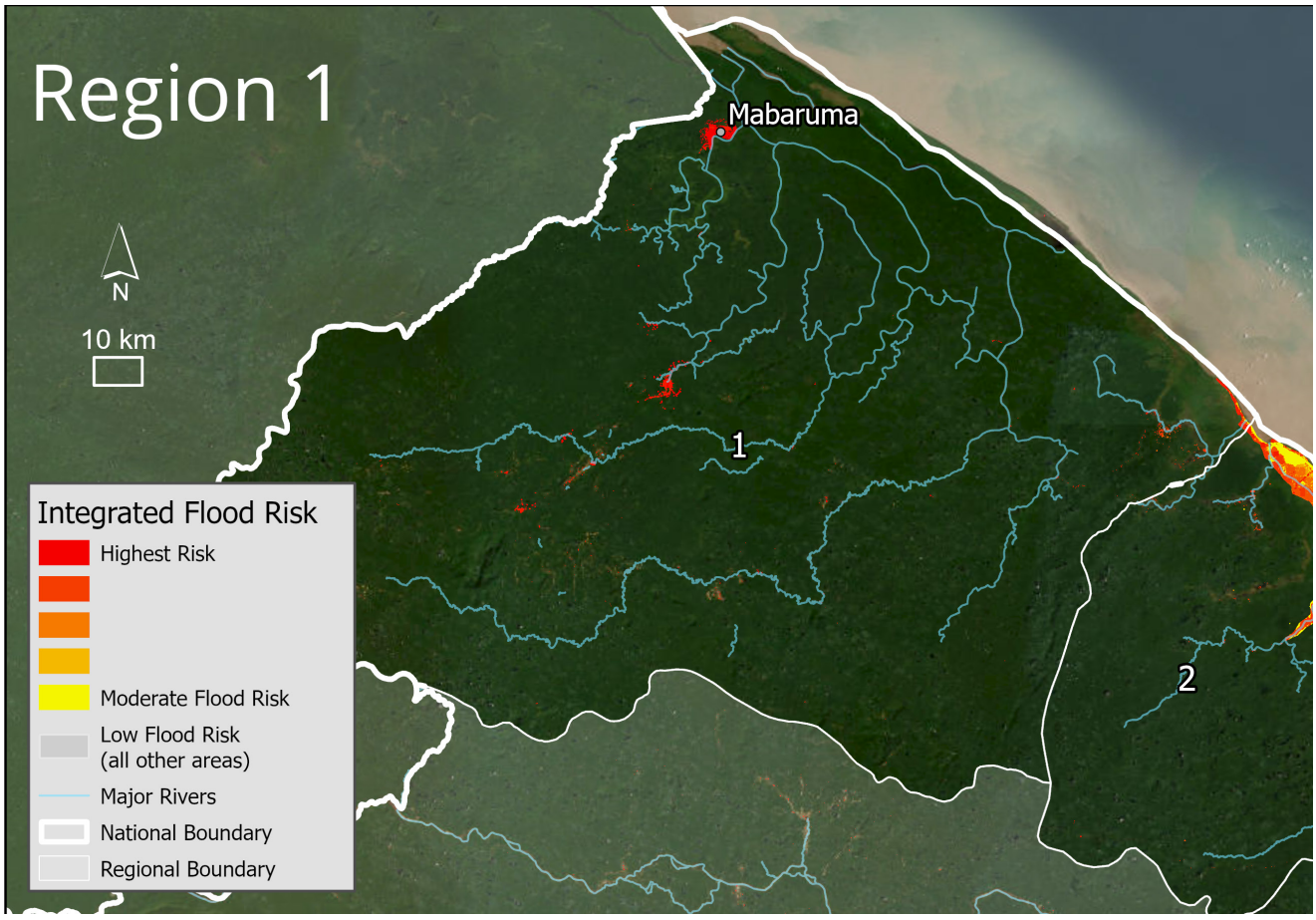
Illustrative example of flood risk computation



ANNEXURE 7. INTEGRATED FLOOD RISK ASSESSMENT OF ADMINISTRATIVE REGIONS 1 TO 6.

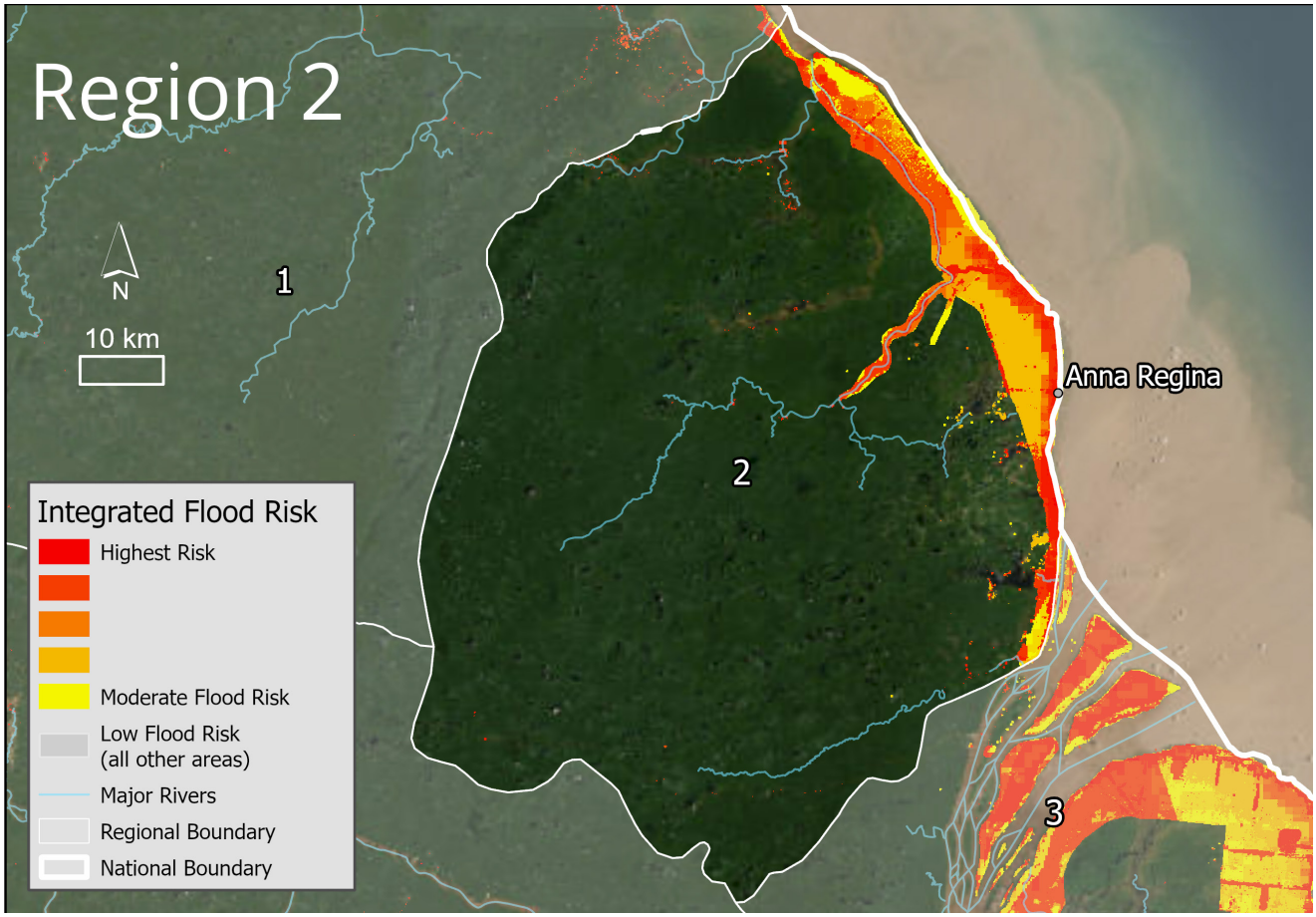
Region 1 Flood Risk Map

Region 1 was found to have the largest area of flood hazard (nearly 20,000 square kilometres), but one of the lowest areas of risk (<1%). This is attributed to limited data capturing the population and agricultural assets in region 1. Additional data and analysis would be useful in validating these results. Regardless of the limited areas of flood risk, due to the very high social vulnerability, the areas that do experience flood risk are in very high need of assistance. The current analysis suggests region 1 would be an area of low priority for interventions as based on the limited areas of 'exposure' as flooding in these areas is a natural process causing limited damage to humans and assets. However, those limited areas are very much at risk.



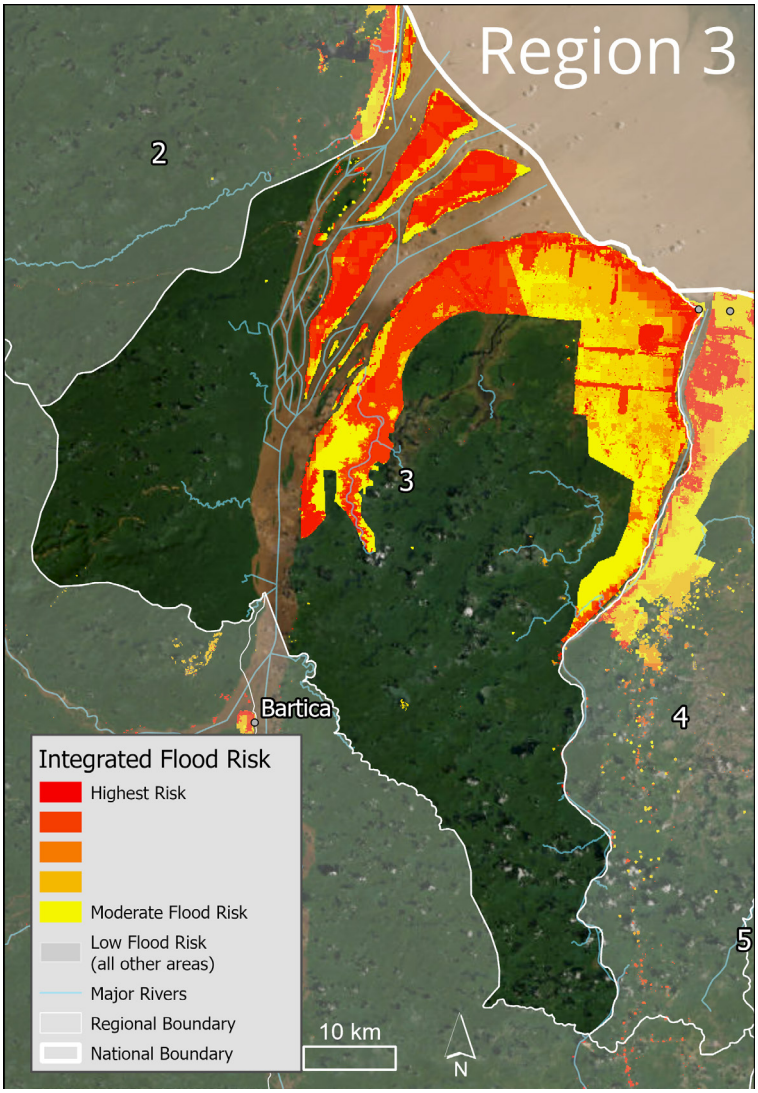
Region 2 Flood Risk Map

Region 2 had the second highest level of social vulnerability among the coastal regions. Flood risk within region 2 is concentrated along the coast with additional areas of hazard extending inland along the main river courses. The main areas of high risk extend along the coast from approximately 25km north of Anna Regina down to the mouth of the Essequibo River with an additional area of flood risk along the Pomeroon River corridor.



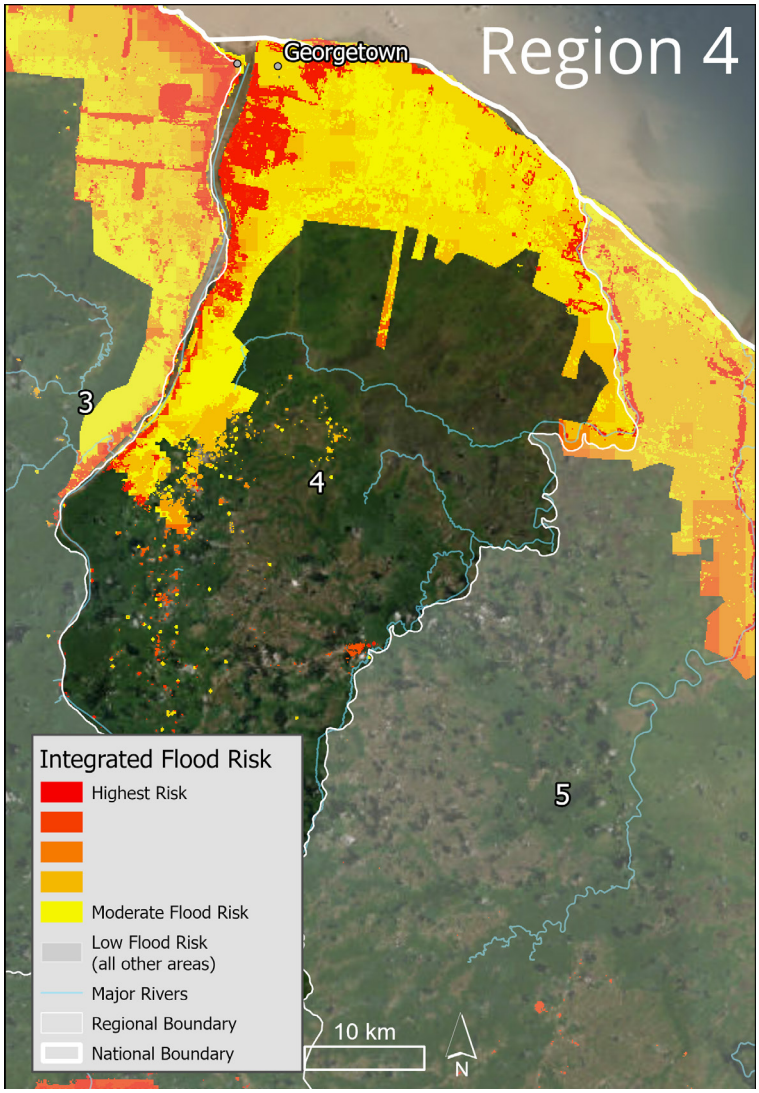
Region 3 Flood Risk Map

Nearly 1/3rd of region 3 was identified as a flood hazard area with over 1/5th of its area having flood risk. Being located along the mouth of the Essequibo River with the Demerara River along its eastern boarder makes this region prone to flooding. Despite overall relatively moderate vulnerability compared to other regions, the islands and areas adjacent to the river are some of the most at-risk areas across all of the coastal regions.



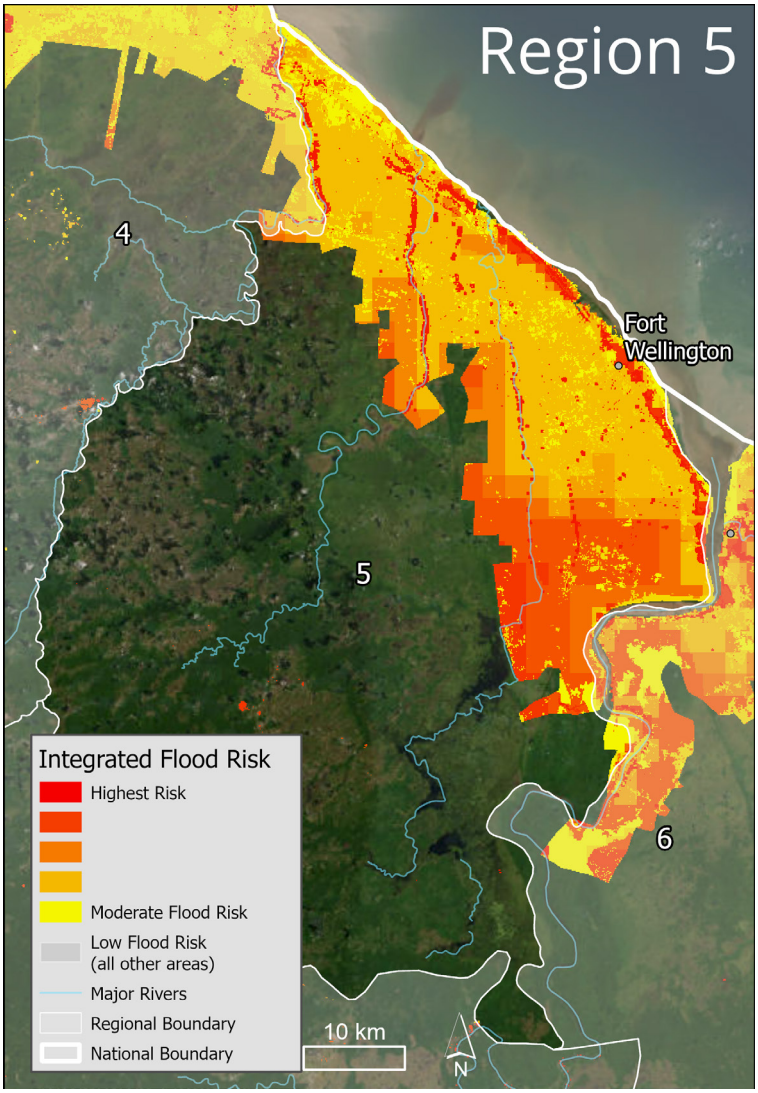
Region 4 Flood Risk Map

The high population of region 4 leads to a significant proportion of area experiencing flood risk. Water from the Demerara River and water courses creates an intersection of people and water which leads to over 30% of the region falling within a flood hazard area. The highest levels of flood risk are found along the eastern bank of the Demerara River with decreasing levels of risk to the east and inland. Despite this, the presence of drainage infrastructure and other attributes increase the capacity to handle flood waters thereby reducing vulnerability within these areas leading to moderate levels of overall risk.



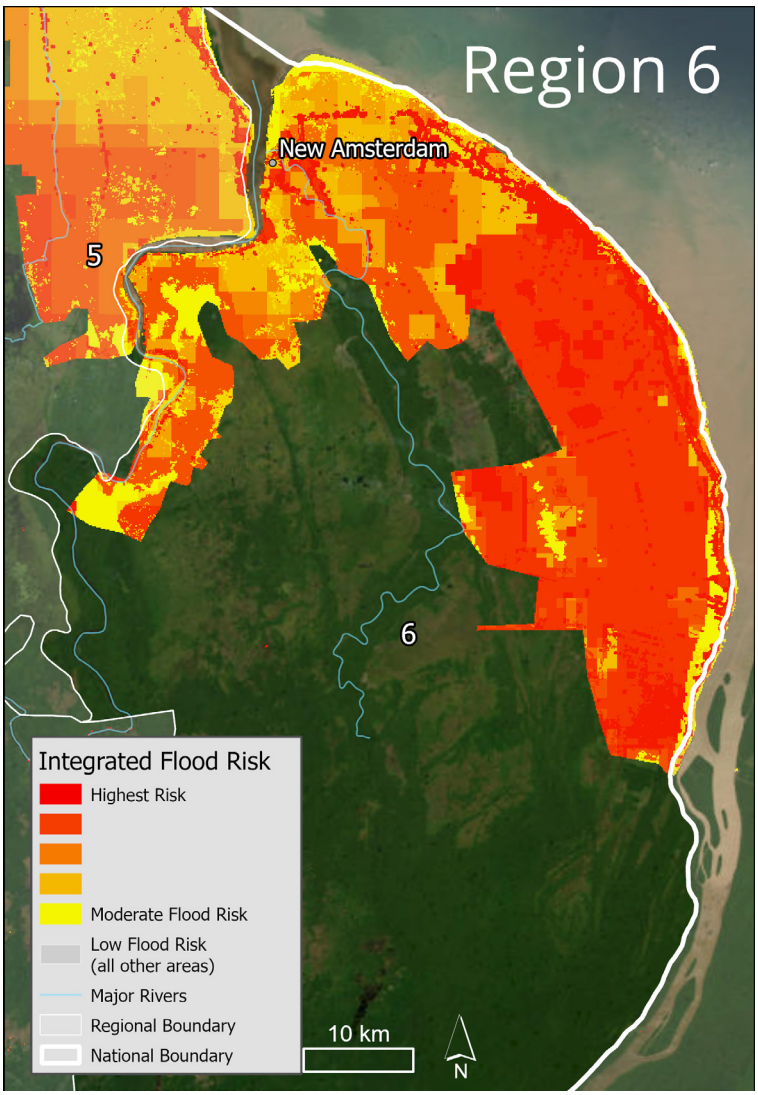
Region 5 Flood Risk Map

With the largest proportion of any region falling with a flood hazard area, and moderate level of social vulnerability, region 5 has the largest area of flood risk area of any region. This risk is highest along the coastal regions northwest of Fort Wellington in inland along the Berbice River. Agricultural lands are the major source of exposure as they extend inland away from the coast. The presence of drainage infrastructure creates areas of lower flood vulnerability, particularly in the northern coastal areas and within the agricultural areas surrounding Fort Wellington.



Region 6 Flood Risk Map

Due its large area extending inland, region 6 has the lowest proportion of flood hazard and flood risk area, but the highest vulnerability of all the coastal regions. As with all of the coastal regions, region 6 faces very high flood hazards from both coastal inundation and inland flooding, specifically from the Corentyne River. The large agricultural areas and coastal population create a relatively large exposure to those flood hazards, and despite flood abatement infrastructure, moderate flood vulnerability in this area combines to produce a high level of overall flood risk.



ANNEXURE 8. CROSS SECTION OF REGION-WISE STATISTICS OF RISK BY FOCUS

Region	Overall Risk Score (Relative[2] Average out of 1)	Infrastructure Risk Score (Relative Average out of 1)	Agricultural Risk Score (Relative Average out of 1)	Male-Led Agricultural Risk Score (Relative Average out of 1)	Female-Led Agricultural Risk Score (Relative Average out of 1)	Gender Risk Difference in Agricultural Scores (Female/Male %)
1	0.80	-	0.81	0.79	0.82	(3.92)
2	0.43	0.51	0.57	0.57	0.57	0.12
3	0.35	0.50	0.51	0.52	0.51	0.87
4	0.82	0.40	0.41	0.42	0.41	1.32
5	0.40	0.41	0.48	0.49	0.47	1.90
6	0.45	0.51	0.57	0.59	0.56	2.81
7	0.59	-	0.54	0.51	0.55	(3.61)
8	0.72	-	0.82	-	-	-
9	0.55	-	0.82	0.82	0.79	2.58
10	0.42	0.42	0.63	0.62	0.63	(1.42)

Relative value compared to 99th percentile to remove influence of outliers

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