TOOLKIT: Water-Sensitive Infrastructure Development

Polycentric Approaches of Urban Water Resources Management in South-East Asia

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Faculty of Spatial Development and Infrastructure Systems
Institute for Natural Resources Management and Technology
TH Köln, University of Applied Sciences
Gustav-Heinemann-Ufer 54 | 50968 Cologne

Suggested citation: Hoxha, Xh., Ziani, C., Mercado Leal, J. D., Hebbeker, F. A., Aswad Alobaidy, Z. S., Hume, S. E., Víquez Rodríguez, J. M., Perez Corredor, L. R., Abbazi, B., Yusufi, Y., Wilk-Pham, A., Ramirez Duval, J. L., Shiwakoti, S., Setyadi, B., & Marleni, Dr. N. N. N. (2025). Water-sensitive infrastructure development: Polycentric approaches of urban water resources management in South-East Asia. Ribbe, L., Hoxha, Xh., & Ziani, C. (Eds.).

For additional information, please contact:
xhesika.hoxha@th-koeln.de

Acknowledgement
The research is an output of the practice-oriented research project "Polycentric Approaches to the Management of Urban Water Resources in Southeast Asia – A Localization of the Sustainability Goals of Agenda 2030 and the New Urban Agenda at the City/Municipality Level" (PolyUrbanWaters, 01LE1907A-C1). PolyUrbanWaters is a project funded by the German Federal Ministry of Education and Research (BMBF). The views expressed in this toolkit are the authors' alone and its contents are the sole responsibility and do not necessarily reflect the views of the donors.

Editorial Team
Prof. Lars Ribbe, Xhesika Hoxha, Chahinaz Ziani

Contributors
Xhesika Hoxha, Chahinaz Ziani, Juan David Mercado Leal, Frederic Andreas Hebbeker, Zahraa Salem Aswad Alobaidy, Samuel Edward Hume, Juan Miguel Víquez Rodríguez, Lina Rocio Perez Corredor, Boutaina Abbazi, Yagana Yusufi, Ania Wilk-Pham, Juan Luis Ramirez Duval, Surendra Shiwakoti, Bisma Setyadi, Dr. Ni Nyoman Nepi Marleni

Cover Image
Xhesika Hoxha, 2023

Layout and Design
Anja Neufeind

URL: https://nbn-resolving.org/urn:nbn:de:hbz:832-epub4-30473
DOI: https://doi.org/10.57683/EPUB-3047

Cologne 2025

Sponsored by

FONA
Climate Research

Sustainable Development of Urban Regions

With funding from the:

Federal Ministry of Research, Technology and Space

Access to the Toolkit:
https://th-koeln.sciebo.de/s/tcvbMqaTkaXXjd3

TOOLKIT: Water-Sensitive Infrastructure Development

Polycentric Approaches of Urban Water Resources Management in South-East Asia

Preface

Water is fundamental to the health and sustainability of our cities. As urban populations continue to grow—now surpassing 50% of the global population—municipalities face increasing challenges in managing water resources effectively. From ensuring access to clean water and sanitation to mitigating the effects of climate change, local decision-makers are at the forefront of addressing these critical issues.

This toolkit is designed to provide pragmatic support for municipalities, equipping them with the necessary tools to assess their current situation and develop strategies that better integrate the water cycle into spatial development.

Urban areas across the world share common concerns, including the provision of essential infrastructure, the adaptation to demographic shifts, and the pressing impacts of climate change and ecological degradation. Many of these challenges are directly linked to water management—whether in securing water supply, handling wastewater, coping with climate extremes such as storms and droughts, or creating blue-green spaces that enhance biodiversity and public well-being. Addressing these challenges requires a holistic approach that considers water as an integral part of urban planning rather than a standalone sector.

This perspective is at the core of water-sensitive urban design, an approach that aligns with concepts such as the sponge city model and blue-green infrastructure development. These principles were central to the „Polycentric Approaches of Urban Water Resources Management in South-East Asia" (PUW) project, which served as the foundation for this toolkit. Through its work in three case study municipalities (Sam Neua in Laos, Sariharjo in Indonesia, and Kratié in Cambodia), the PUW project developed and tested a structured approach to integrated urban water management. The emphasis was on bridging conventional infrastructure solutions with nature-based approaches while embedding them within governance structures that support sustainable decision-making.

Developed collaboratively by scientists, municipal representatives, and NGOs, this toolkit follows a structured three-step methodology applied in the PUW project: baseline assessment, vision building, and transformation pathway development. These steps guide municipalities through a systematic process of identifying

challenges, setting long-term objectives, and implementing strategic interventions tailored to their unique contexts.

While the toolkit was initially developed for municipalities in Southeast Asia, the challenges it addresses are not confined to this region. The principles and methodologies outlined here are broadly applicable, making this a valuable resource for cities worldwide seeking to enhance their resilience and sustainability through integrated water management.

To maximize its impact, we are making this toolkit publicly available, inviting municipalities, professionals, and networks to use and adapt the tools as needed.

We recognize that ongoing collaboration and innovation are key to improving and expanding the toolkit's applications.

We encourage stakeholders to contribute their insights and experiences, helping to refine these tools and foster a broader community dedicated to sustainable urban water management. Together, we can build stronger, more resilient cities that embrace water as a vital element of urban development.

I extend my sincere gratitude to the contributors, partners, and the PolyUrbanWaters project team. Their expertise and dedication have been invaluable in shaping this toolkit. It is my hope that this toolkit will serve as a valuable resource for promoting water-sensitive infrastructure development and contributing to a more sustainable urban future in Southeast Asia and beyond.

We look forward to continued collaboration and collective progress in shaping water-sensitive cities for the future.

Prof. Dr. Lars Ribbe (editor)
Professor for Integrated Land and Water Resources Management
Faculty for Spatial Development and Infrastructure Systems
Institute for Natural Resources Management and Technology

Foreword

The major societal challenges of our time - like climate change, urban expansion, and social inequalities - require responses that are not only scientifically sound but also grounded in practice and guided by transdisciplinary collaboration. In this context, universities hold a distinct responsibility. As institutions of knowledge generation and education, we are also drivers for social innovation and critical partners in shaping pathways toward a more sustainable future.

The publication of the Toolkit on Water-Sensitive Infrastructure Development embodies our institution's commitment to advancing interdisciplinary research and practice in support of sustainable urban development and resilient water systems. The Toolkit exemplifies the kind of applied research and co-creation that is needed to address complex urban issues. It translates academic insights into practical, accessible tools for policymakers, public authorities, and civil society actors, supporting informed decision-making for water-sensitive urban development. In doing so, it contributes to the creation of cities that are more resilient, inclusive, and prepared for the future.

I am pleased that TH Köln – University of Applied Sciences was able to contribute its expertise in research and knowledge transfer to this project. The Toolkit stands as a strong example of our commitment to actively engaging in societal transformation – through evidence, collaboration, and a common good orientation. It reflects our commitment to working together, across disciplines and cultures, for societies that are prepared for the challenges of the future.

As institutions of knowledge generation and education, we are also drivers for social innovation and critical partners in shaping pathways toward a more sustainable future.

The Toolkit exemplifies the kind of applied research and co-creation that is needed to address complex urban issues.

Prof. Dr. Sylvia Heuchemer
President of TH Köln – University of Applied Sciences

Table of Content

Executive Summary

The Water-Sensitive Infrastructure Development Toolkit is designed within the framework of the Polycentric Approaches of Urban Water Resources Management in South-East Asia (PUW) project. This toolkit is tailored to support polycentric urban development and integrated water management in rapidly growing cities and peri-urban areas of Southeast Asia, with pilot projects in Kratie (Cambodia), Sariharjo (Indonesia), and Sam Neua (Laos).

The toolkit comprises 12 practical tools categorized into project management and stakeholder decision support. These tools facilitate three key planning phases: baseline assessment, vision building, and transformation pathways. The toolkit serves a diverse range of stakeholders, including government agencies, urban planners, researchers, private sector participants, and NGOs, ensuring inclusive and sustainable urban water management. Each tool is accompanied by a fact sheet, step-by-step usage guidelines, case studies from pilot cities, and access to full tools and related resources via links.

Notably, the toolkit leverages innovative technologies, such as drones, and utilizes open-source datasets to enhance data collection and analysis in regions where data is scarce. This approach enables more accurate assessments and informed decision-making.

The present report aims to achieve an effective implementation of water-sensitive infrastructure, recommending that cities adopt polycentric approaches that integrate blue, green, and grey infrastructures to enhance resilience and inclusivity. The use of Nature-based Solutions (NbS) for water resource management should be promoted, as they offer effective and sustainable ways to mitigate urban water challenges. Additionally, fostering collaborative governance structures that involve multiple stakeholders in decision-making processes is crucial for ensuring sustainable and equitable urban development initiatives. Finally, supporting capacity building among local stakeholders is essential to effectively implement and manage water-sensitive infrastructure, ensuring long-term sustainability and adaptability.

The toolkit also provides links to similar resources to facilitate broader learning and collaboration. These links connect users with global best practices in water-sensitive urban design, offering insights into successful projects and strategies that can be adapted to local contexts.

1. Introduction to the ‘Water-Sensitive Infrastructure Development’ Toolkit

Water-Sensitive Infrastructure Development Toolkit is developed as part of the *“Polycentric Approaches to the Management of Urban Water Resources in Southeast Asia (Polyurbwater)”* project (Website: https://polyurbanwaters.org/), funded by the Federal Ministry of Research, Technology and Space. The primary goal of the project is to localize the Sustainable Development Goals (SDGs) and the New Urban Agenda (NUA) at city and municipal levels in secondary and tertiary cities across Southeast Asia.

By bridging the gap between urban water management and urban planning, the project seeks to address the challenges of unplanned urban growth, climate change impacts, and fragmented governance structures. This toolkit embodies the project’s mission to foster inclusive, water-sensitive urban development through practical tools and methods that support integrated planning, collaborative decision-making, and sustainable transformation tailored to the unique conditions of fast-growing cities in the region.

The *Water-Sensitive Infrastructure Development Toolkit* is a compilation of tools which aim to provide practical methods for assessing, planning, and implementing sustainable water infrastructure in secondary cities within Southeast Asia and beyond. This toolkit has been designed to guide multi-stakeholders in integrating climate change adaptation measures (e.g. nature-based measures, green-blue infrastructure, etc.,) into urban planning and management processes. These tools explore the practical applications and adaptations within the project‘s case studies conducted in Sleman (Indonesia); Sam Neua (Lao PDR); and Kratié (Cambodia).

This *Water-Sensitive Infrastructure Development Toolkit* is structured to support three key phases of the planning process (Figure 1) as follows:

Baseline Assessment (BA) phase focuses on understanding the current state of the urban water environment and its ecosystem services. It includes tools to identify and evaluate ecosystem services, assess local perceptions of NbS, and conduct urban water accounting. Advanced methods like GIS and satellite imagery analysis, as well as drone surveys, are utilized to collect and analyse data efficiently.

Vision Building (VB) phase emphasizes collaboration and co-creation among stakeholders. Tools in this phase include stakeholder mapping and engagement frameworks, NbS compendium tailored to secondary cities in the Southeast Asia region, and methodologies for selecting and assessing the potential of NbS.

Transformation Pathways (TP) phase focuses on translating vision into actions by providing tools to evaluate the impact and effectiveness of selected NbS. It also offers practical calculators, such as the rooftop rainwater harvesting calculator, and data-sharing platforms to ensure long-term monitoring and management.

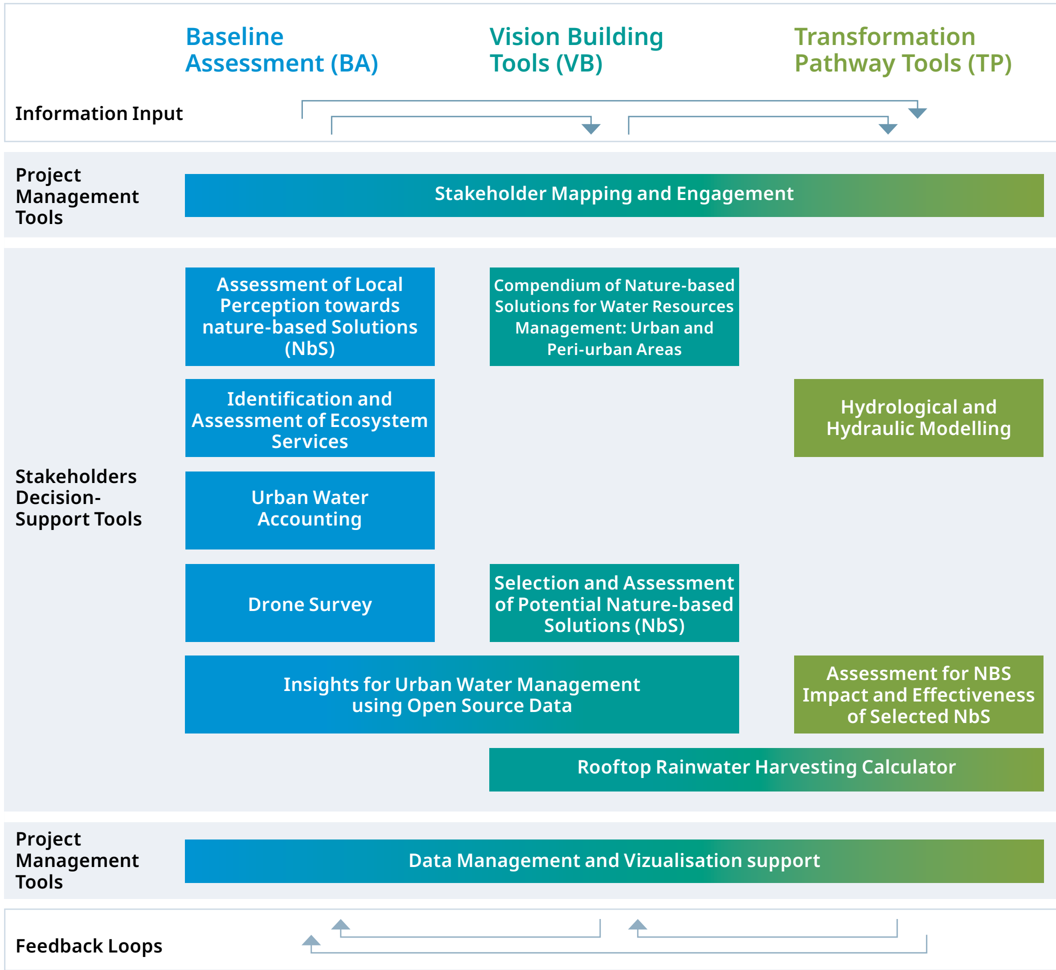

Figure 1: *Overview of Water-Sensitive Infrastructure Development and Management Toolkit*

The toolkit is structured around these phases, with each tool systematically presented in tabular format for clarity. The tables outline the objectives, content, requirements, and key points of each tool to help users understand how to apply them effectively. This modular approach allows stakeholders to adopt and tailor the tools based on their specific needs and their unique local contexts, enabling them to integrate it seamlessly into ongoing or future projects.

By fostering inter- and trans- disciplinary collaboration and engaging stakeholders throughout the planning process, this toolkit equips users with the resources needed to develop water-sensitive urban environments. It empowers cities to adopt adaptive, inclusive, and sustainable practices, ensuring long-term ecological and social resilience.

The following chapter is an overview and description of the tools corresponding to Work Package (WP) III 'Tools and methods for assessing and monitoring urban water resources and Work Package (IV) 'Options for sustainable water-sensitive infrastructure development and polycentric water management' within the frame of PolyUrbanWaters Project. We invite urban planners, policymakers, researchers, and other stakeholders to explore and adapt these tools to address the unique challenges of their cities.

Table 1: The tools and their applications across diverse study areas

Phases	Tools	Case Study area for Toolkit
Baseline Assessment (BA)	**Tool 1:** Stakeholder Mapping and Engagement	Sariharjo – Sleman
	Tool 2: Identification and Assessment of Ecosystem Services	Sariharjo – Sleman
	Tool 3: Assessment of Local Perception of NbS and Hybrid Solutions	Sariharjo – Sleman Kratié – Cambodia and Sam Neua, Laos
	Tool 4: Urban Water Accounting	Sariharjo – Sleman
	Tool 5: Insights for Urban Water Management using Open-Source Datasets	The Prek Te watershed Kratié – Cambodia
	Tool 6: Drone Survey	Kratié – Cambodia
Vision Building (VB)	**Tool 1:** Compendium of Nature-based Solutions for Water Resources Management: Urban and Peri-urban Areas of Southeast Asia	SEA region
	Tool 2: Selection and Assessment of Potential Nature-based Solutions	Sariharjo – Sleman
	Tool 3: Assessment of Impact and Effectiveness of Selected NbS	
Transformation Pathways (TP)	**Tool 1:** Rooftop Rainwater Harvesting Calculator	Sam Neua, Laos
	Tool 2: Hydrological and Hydraulic Modelling	Sariharjo – Sleman
	Tool 3: Data Management and Visualization Support	Sariharjo – Sleman Kratié – Cambodia and Sam Neua, Laos

1.1 Who can use this toolkit?

The *"Water-Sensitive Infrastructure Development Toolkit"* is tailored for a wide range of stakeholders engaged in the management and development of sustainable urban water resources, with a specific focus on secondary and tertiary cities in Southeast Asia.

The toolkit serves government agencies such as urban planning departments, public works entities, and municipal to national water managers, providing them with structured methodologies for integrating water-sensitive solutions into their planning processes. Additionally, it supports practitioners like urban planners and water resource managers by offering practical tools and frameworks that can be customized to local contexts.

Beyond institutional users, the toolkit is designed to offer academic researchers, social and environmental scientists, and students with resources to assess and monitor urban water systems. It also invites collaboration with private sector participants, including engineers, investors, and funders, to drive innovation and investment in water-sensitive practices.

By including community members and non-governmental organizations, the toolkit fosters inclusive, participatory approaches to urban water management, ensuring that the suggested solutions address local needs while promoting long-term ecological and social resilience.

1.2 How to use this toolkit?

This toolkit is designed to guide stakeholders through a structured process for integrating sustainable water management practices into urban planning processes. It is organized into three key phases: Baseline Assessment, Vision Building, and Transformation Pathways, each phase offers specific tools tailored to the needs of secondary and tertiary cities in Southeast Asia.

This toolkit emphasizes the importance of **trans- and inter-disciplinary collaboration** by incorporating expertise from diverse fields and engaging stakeholders at different levels of governance. The active participation of government officials, urban planners, researchers, community members, and private sector representatives ensures that tools are both practical and locally relevant.

Understanding the steps in the planning process and identifying where stakeholders can contribute is crucial to this toolkit. By clarifying roles and contributions, the toolkit encourages meaningful involvement throughout the process, fostering co-creation and shared ownership of pathways.

Each tool in the toolkit is presented with clear objectives, step-by-step guides, and case studies to demonstrate its application in real-world contexts. While the toolkit is designed as a comprehensive framework that can be applied step-by-step to achieve an integrated approach to water-sensitive urban planning, the tools can also be used independently.

1.3 How to use the tool?

Each tool within the Water-Sensitive Infrastructure Development Toolkit has been systematically developed to ensure clarity, usability, and comprehensive guidance for users. The structure of the tool sections includes:

a. Headers

The headers provide a concise overview of the tool, including the scope and field of application, application scale, time and skills requirements, helping users quickly understand tool's application within the broader context of the toolkit.

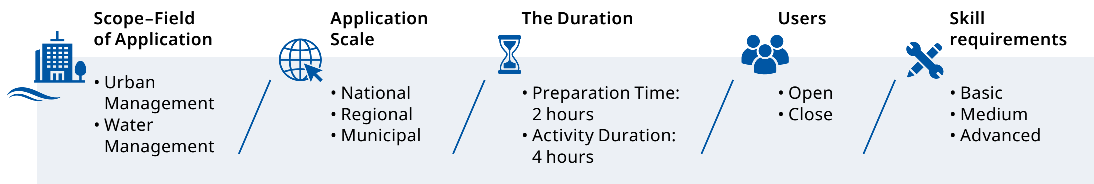

Figure 2:
Headers sample (Source: ITT, 2024)

Scope-Field of Application:
The specific area or sector where the tool is designed to be used or implemented. It defines the primary focus or domain of the tool's functionality.

Application scale:
The geographical or administrative level at which the tool can be effectively applied or utilized. It indicates the spatial scope of the tool's applicability.

The duration:
The timeframe associated with the tool's implementation, including both the preparation phase and the actual period of use. It provides insight into the time investment required for setup and ongoing utilization.

Users:
The targeted audience or group of individuals who will interact with or benefit from the tool. This category may indicate whether the tool is designed for a specific set of users (closed) or is accessible to a wider audience (open).

Skill requirement:
The level of expertise or technical knowledge necessary to effectively use or implement the tool. This helps potential users understand the learning curve or background knowledge required to utilize the tool successfully.

b. Factsheet of the tool

A detailed factsheet accompanies each tool, which acts as a comprehensive reference for understanding and applying the tool. The factsheet is meticulously designed to offer users a clear snapshot of the tool's purpose, methodology, and application context. It typically includes the elements as shown in Table 2.

Table 2. Tool description template

What?	Definition of the tool, followed by the main characteristics of the tool
Why? / Purpose	Summary of the importance of using this tool
Field of Application (Scale of Application)	Examples of major applications of the tool (from PUW experience within SEA context
End users	This section specifies the scale of the tool's application, such as whether it is suitable for government agencies, practitioners, academia, or private sector. It highlights its applicability to different urban and peri-urban contexts, ensuring users can align it with their unique project requirements.
Background	Short historical overview of how the tool has been developed and how it is adapted to fit for PUW (if this is the case)
Description	General description of the tool, explanation of the main characteristics are these were listed in "what"
Strengths and Limitations	Description of general strengths and limitations of the tool (as observed in the SEA context). To offer a balanced perspective, the factsheet outlines the tool's key advantages, such as its ability to foster stakeholder collaboration or its adaptability and applicability to different contexts. It also notes potential challenges, like resource-intensive data collection or reliance on technical expertise, helping users plan accordingly.

Requirements (Instruments used)	The factsheet provides a list of prerequisites for using the tool, including skills, time, technical resources (e.g., GIS software, datasets, etc,.), and financial considerations. This enables users to assess the feasibility of implementing the tool within their projects.
Keywords	Relevant keywords are included to facilitate cross-referencing with other tools and related concepts within the toolkit.

c. Tool Manual Section

The purpose of the *"Tool Manual"* section in the context of the document is to provide users with a structured guide for applying specific tools included in the *"Water-Sensitive Infrastructure Development " Toolkit*.

The primary purpose is to assist users with the application of each tool by outlining its structure, scope, field of application, skill requirements, and the resources necessary for successful execution. This ensures that stakeholders can easily understand and utilize the tools in real-world contexts.

In addition to clarifying usage, the Tool Manual Section is designed to support the practical implementation of tools by offering step-by-step instructions and illustrative examples. These enable users to conduct baseline assessments, engage in vision-building processes, and develop transformation pathways tailored to their specific urban water management and urban planning challenges. The manual emphasizes adaptability by encouraging users to customize tools based on their local contexts, ensuring that the solutions are context-relevant.

d. Case Study

The *'Case Study'* section is a component of the toolkit that provides the readers with real-world examples of how the tools have been applied, demonstrating their practicality and relevance in specific contexts. The primary purpose is to illustrate the tools' functionality and outcomes in various urban settings, thereby serving as a guide for stakeholders who wish to adopt similar approaches.

By presenting concrete applications, the section bridges the gap between theoretical frameworks and practical implementation, offering users a clear overview of how the tools can be adapted and utilized to address challenges in their local contexts. Moreover, the case studies highlight the challenges encountered, solutions applied, and the results achieved, allowing users to learn from the experiences of others and avoid potential difficulties.

In addition to serving as a practical reference, the 'Case Study' section promotes inspiration and innovation among users. By showcasing diverse applications across different regions, such as stakeholder mapping in Kratié, Cambodia, or urban water accounting in Sariharjo, Indonesia, the section demonstrates the versatility and adaptability of the tools.

The case studies not only validate the effectiveness of the tools but also encourage stakeholders to explore creative solutions tailored to their unique circumstances.

e. Access to the tool

The *'Access to the Tool'* section in the Toolkit is designed to provide users with open access to the files of respective tools and additional information required for applying them, such as software platforms, datasets, and detailed step-by-step instructions. For each of the tools, there is detailed information specifying where and how the tools can be downloaded or accessed, enabling users to directly integrate the tools into their planning and management processes. It emphasizes ease of use and inclusivity, offering to diverse audiences, from government officials to community members, by providing clear directions for integrating these tools into their local contexts.

f. Further reading

The *'Further Readings'* section offers additional resources for users who wish to deepen their understanding of the tools, methodologies, and concepts presented. This section serves as a repository of scholarly articles, technical guides, case studies, and relevant frameworks that support the tool's objectives.

It is particularly useful for users seeking to expand the practical applications of the tools. This section support users to connect to broader literature.

In the last chapter, *'Similar Tools'* section in the report serves as a resource to highlight additional tools or frameworks that complement or align with the tools presented in the Water-Sensitive Infrastructure Development Toolkit.

This section offers a comparative perspective, showcasing tools developed by other organizations, research initiatives, or projects that address similar objectives, such as sustainable urban water management, stakeholder engagement, or nature-based solutions.

By presenting these alternatives, the section provides users with broader options to select tools that best fit their specific needs or local contexts. Additionally, the *'Similar Tools'* section helps users understand how the tools in the report relate to and build upon existing methodologies.

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2. Baseline Assessment Tools (BA)

Tool 1 Stakeholder Mapping and Engagement

Tool 2 Identification and Assessment of Ecosystem Services

Tool 3 Assessment of Local Perception towards Nature-based Solutions (NbS)

Tool 4 Urban Water Accounting

Tool 5 Insights for Urban Water Management using Open-Source Datasets

Tool 6 Drone Survey

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Institute for Natural Resources Technology and Management

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Tool 1:
Stakeholder Mapping and Engagement

Authors: Ania Wilk-Pham, Xhesika Hoxha, Juan David Mercado Leal

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• **Urban Management** • **Water Management**	• **National** • **Regional** • **Municipal**	• Preparation Time: **2 hours** • Activity Duration: **4 hours**	• **Open** • Close	• **Basic** • **Medium** • Advanced

The *Stakeholder Mapping and Engagement Tool* is an essential instrument designed to enhance the planning and execution of water resource management and sustainable urban development projects, particularly in secondary and tertiary cities of Southeast Asia (SEA). Its core objective is to streamline the processes of identifying, assessing, and engaging stakeholders while ensuring alignment with relevant legal frameworks.

What?	Stakeholder Mapping Tool for Secondary and Tertiary Cities in the SEA Region
Why? / Purpose	This tool facilitates the systematic identification and analysis of stakeholders involved in urban development projects in secondary and tertiary cities in the SEA region. The main purpose is to improve decision-making by understanding key influencers, collaborators, power, and potential challenges to ensure inclusive and effective project implementation.
Field of Application (Scale of Application)	Examples include stakeholder mapping in urban development projects in Sleman (Indonesia); Sam Neua (Lao PDR); and Kratié (Cambodia)

End users	• Government agencies (urban planners, environmental agencies, Public Works Department, City planning departments, Municipal-Provincial-Regency-National water managers, Local government) • Practitioners (urban planners, and water resources managers) • Academia (researchers, social and environmental scientists, students) • Privat Sector (engineers, investors, funders)
Background	The tool has evolved in response to the recognition of the central role of stakeholders in urban development. Adaptations for the PUW include tailoring the mapping process to local contexts and incorporating lessons learned from historical stakeholder engagement in project cities.
Description	The tool involves a systematic process of identifying, categorising, and analysing stakeholders relevant to urban development projects. Features include a comprehensive understanding of stakeholder interests, influence and potential impact on project outcomes.
Strengths and Limitations	**Strengths:** Improved communication, enhanced collaboration, informed decision-making. **Weaknesses:** Potential bias in representation, time-consuming, dynamic nature of stakeholder relationships.
Requirements (Instruments used)	**Time:** Moderate to extensive, depending on the complexity of the project. **Skills:** Research and analytical skills, facilitation of consultations. **Equipment:** Computers for data analysis and map visualization. **Costs:** Moderate for research and consultation activities.
Keywords	Stakeholder mapping, Stakeholder Engagement

Tool Manual

This tool enables users to systematically identify and evaluate the various stakeholders involved in urban planning and water resource management initiatives. Stakeholders may include government agencies, local communities, NGOs, and private sector entities. By analyzing stakeholders' interests, influence, and potential impact on the project, the tool helps users design interventions that are equitable, inclusive, and effective.

The stakeholder mapping process involves both desk research and participatory methods, following a systematic approach to ensure inclusivity and comprehensiveness. These stakeholders are categorized based on their interests, level of influence, and the potential impact of the project on them. Their relationships and dynamics are analyzed to understand interconnections, dependencies, and power structures. This information is synthesized into a visual stakeholder map that clearly illustrates their roles, relationships, and influence within the project ecosystem, providing a valuable reference for decision-making.

These steps aim to provide a comprehensive overview of the stakeholder landscape and facilitate the creation of a stakeholder matrix. The matrix simplifies the analysis of key stakeholder profiles and their level of influence over the problem. This is a step-by-step guide to the process.

Step 1: Define the scope and objectives

This step involves describing the scope and objectives of the project, including specifying its boundaries and stating clear goals. Clearly outline the project's goals, boundaries (e.g. national, reginal, and municipal levels, etc,.), and focus areas (e.g., water resources management, urban planning).

State the purpose of stakeholder mapping, such as identifying roles, interests, and relationships of stakeholders in the project context.

Step 2: Initial Questioning

The Questioning phase is crucial in developing the data collection process that follows. It helps to define a clear system of interacting stakeholders and identify main problems that could impact the project development. Key questions to consider include:

Identification of Stakeholders

- Who are the stakeholders?
- Who are the prominent individuals or organizations involved in water resources management and urban planning at national, regional, and local levels?
- How can stakeholders that are directly impacted or influenced be involved (e.g. methods and tools)?
- Are there any foreign actors or institutions involved?

Stakeholder Roles and Involvement

- How are they involved in planning, management, implementation, financial and operational areas?
- What type of interaction do they have with other stakeholders?

Prioritization of Stakeholders

- Can their importance be prioritised? If so, what are the criteria for prioritisation?
- Can their power be prioritised? If so, what indicators will be used to assess power?
- Are there any stakeholders that could have a significant impact on the project outcomes?

Stakeholder Interests and Expectations

- What are the interests, motivations, and expectations of the stakeholders?
- Are there any potential conflicts of interest among them?
- How might their interests and expectations change over time?

Stakeholder Influence and Relationships

- How are they affected by the concerns of other stakeholders?

Step 3: Identification of relevant stakeholders through Desktop Research, Local Partners, and broader professional network

Desktop analysis involves examining all available previous data and information to determine the interests and positions of each representative of society regarding the project. This includes academic papers, books, research papers, industry reports, media, and online resources such as journals, blogs, and websites.

In addition, this identification process can be performed with local partners and broader professional network, to ensure the broader mapping of the stakeholders.

Step 4: Description of skills, needs, interests, and role of identified stakeholders

Information obtained from primary and secondary sources is cross-checked with other sources and processed to create a preliminary stakeholder map. Compile findings into a preliminary stakeholder matrix, categorizing stakeholders by (Figure 3):

- Interests, and influence (High/Medium/Low).
- Roles and responsibilities
- Engagement strategy for each stakeholder.

Stakeholder Analysis Matrix

Focus Area:

Date:
Name of Area/ Village:
Project Staff:
Local Technical Staff/ Committee:
Village Staff:

Stakeholder	Interest	Influence	Role/Responsibility	Engagement Strategy	Comments/ Concerns
Name/Group	High/Medium/Low	High/Medium/Low	Specific roles and responsibilities in the project	How you plan to engage this stakeholder	Any specific concerns or issues raised by the stakeholder
Example: Local Community	High	Medium	Provide local insights, participate in discussions	Community meetings, surveys, participatory mapping	Concerned about environmental impact
Example: City Planners	Medium	High	Policy implementation, regulatory oversight	Regular updates, formal meetings, workshops	Interested in long-term urban development
Example: NGOs	High	Low	Advocate for sustainable practices, offer expertise	Collaboration on specific initiatives, joint workshops	Focused on social and environmental sustainability
Example: Funding Agency	Low	High	Provide financial support, ensure budget compliance	Formal reports, budget reviews, strategic meetings	Concerned about financial accountability
Example: Academic Institutions	Medium	Medium	Conduct research, provide data and analysis	Research partnerships, academic conferences	Interested in research outcomes and publications

Figure 3:
Stakeholder Identification Matrix Template (Source: F12-THK and HU-TUB, 2022)

Step 5: Evaluation of stakeholders based on Power-Interest

Use frameworks like the *Power-Interest Grid* to evaluate stakeholders based on their level of interest in the project and their influence or power to affect outcomes.

Based on the quadrat positioning, visualization of stakeholders' positions helps to inform engagement strategies, as follows (Grégoire, 2024):

- **High Power, High Interest:**
  Stakeholders that are key players with whom it is necessary to actively engage and manage closely.
- **High Power, Low Interest:**
  stakeholders that are crucial to keeping satisfied by addressing their concerns without over-involvement.
- **Low Power, High Interest:**
  stakeholders that are important to keep informed with regular updates and opportunities for involvement.
- **Low Power, Low Interest:**
  stakeholders that need to be monitored and observed for potential future changes, with minimal involvement.

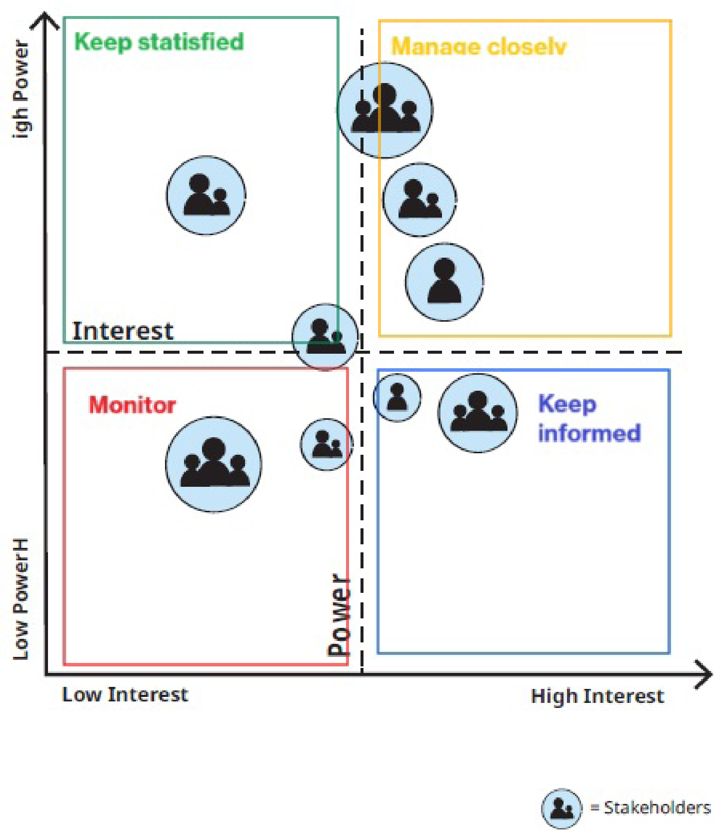

Figure 4:
Power-Interest Grid (Source: F12-THK and HU-TUB, 2022)

Table 3. Example of Stakeholder Engagement Strategy Matrix

Stakeholder Group	Engagement Method	Frequency	Notes
Local Community	Community meetings, participatory mapping	Monthly	Address environmental concerns proactively.
City Planners	Workshops, formal presentations	Quarterly	Focus on aligning with urban planning goals.
NGOs	Collaborative initiatives, joint events	Bi-annual	Highlight shared sustainability objectives.
Funding Agency	Formal reports, budget reviews	Annually	Ensure transparency and accountability.

Step 6: Validation and Feedback

Once the preliminary stakeholder map is prepared, share it with the identified stakeholders for their review and input. Facilitate open discussions to gather insights, address any discrepancies, and incorporate their perspectives.

This collaborative validation process ensures the map accurately reflects stakeholders' roles, influence, and relationships within the project ecosystem.

By refining the map based on their feedback, you enhance its credibility and relevance, creating a tool to guide engagement strategies and decision-making processes.

Tools and Materials Required

Stakeholder mapping exercise can be carried out using primary and secondary research methods, each based on different tools and materials.

- **Desktop Research Tools:**
  JSTOR, Google Scholar, or other databases.
- **Engagement Tools:**
  Zoom, Microsoft Teams, Google Forms, or in-person materials like sticky notes and whiteboards.
- **Visual Representation Tools:**
  Lucidchart, Miro, or Microsoft Visio for creating diagrams and matrices.
- **Recording Tools:**
  Audio or video recording for participatory sessions (with consent).

Study case

Stakeholder mapping ensures the identification of the stakeholders and maps out their relative power, influence and interests in a certain domain or about a specific initiative. It identifies the role and action arena of each stakeholder and indicates the relative priority to be given to meeting the interests of the stakeholders, thus assessing the importance of each stakeholder to the success of the project (Morgan, 1997, (Brugha & Varvasovszky, 2000)).

Step 1: Identification of relevant stakeholders through Desktop Research

The systematic literature review was carried out by making structured queries in the official open data webpages of the different ministries of Indonesia. As well as commonly used academic search engines such as Google Scholar, Microsoft Academic, BASE and CORE. A combination of keywords was used on the topic search, for instance: "WRM", "Governance", "Legal framework", "Stakeholders" and "Water Sector" in Indonesia, Yogyakarta, Sleman Regency and Sariharjo village to get any research or publication regarding the governance around water resources in Indonesia.

The data obtained from online searches is cross-checked with other sources and processed to create a preliminary stakeholder map. This map should provide stakeholders with a broad overview of the power, status, influence, and associations of different stakeholders (Figure 5).

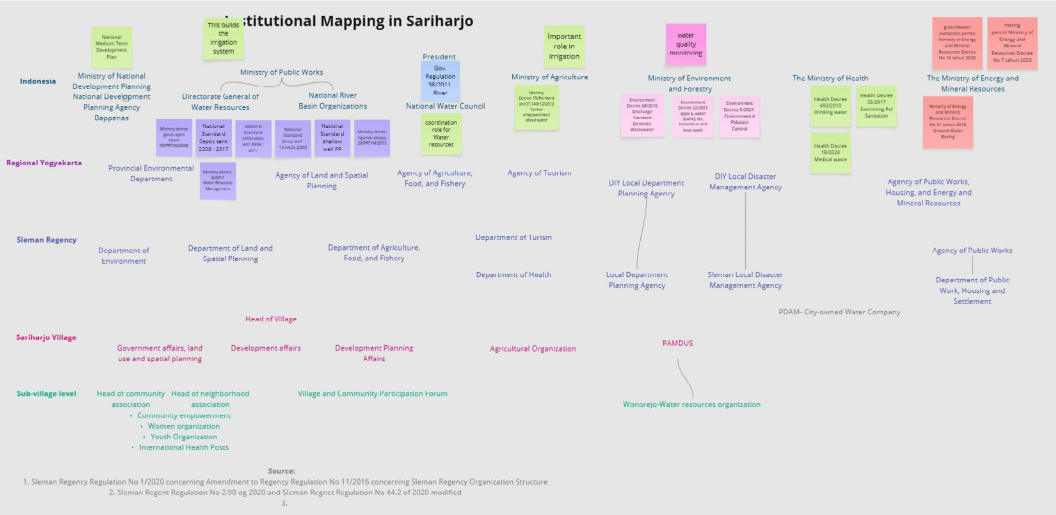

Figure 5:
Example of Characterization and Identification of Stakeholders in Sariharjo - Indonesia

Step 2: Sharing information with Local Partners, while consulting broader professional network

The information collected was shared at the different meetings with our local partners and consulted with a broader professional network.

Any information related to governance in terms of legal framework, stakeholders and decision-making process was compiled in the assessment while providing specific information on the roles and responsibilities of each stakeholder.

Step 3: Description of skills, needs, interests, and role of identified stakeholders

A comprehensive overview of the key stakeholders involved in water resource management and urban water governance in Indonesia was elaborated. It categorizes stakeholders based on their interests, influence, roles, and responsibilities, highlighting the multi-level nature of water management.

National-level actors, such as the Ministry of Public Works and Housing and the Ministry of Environment and Forestry, are identified as high-influence stakeholders responsible for policymaking, infrastructure development, and pollution control. Regional and local actors, including provincial water councils and community-based organizations, play critical roles in implementing strategies and addressing local needs. Non-governmental organizations and academia contribute expertise and innovation, while community-based organizations and water user associations ensure grassroots-level participation and operational efficiency.

Engagement strategies for these stakeholders range from collaborative workshops and public consultations to technical capacity-building and data-sharing initiatives, demonstrating the need for inclusive and coordinated efforts to achieve sustainable water management outcomes

Table 4. Example of summarizing the actors, their interests, influence, roles/responsibilities, and engagement strategies

Actor/ Stakeholder	Interest	Influence	Role/ Responsibilities	Engagement Strategies
Ministry of Public Works and Housing	Infrastructure development, water resource exploitation, and policymaking.	High	Formulate legal frameworks for water conservation, implement water resource projects.	Regular consultation meetings, policy workshops, progress reviews.
Ministry of Environment and Forestry	Pollution control, surface water quality, and watershed management.	High	Monitor/report surface water quality, manage catchments, enforce pollution controls.	Collaboration on environmental policies, joint monitoring programs, and data sharing sessions.
Ministry of Health	Public health, drinking water quality standards.	Medium	Establish/monitor drinking water standards, raise public awareness.	Health campaigns, workshops on water safety, regular feedback loops.
Ministry of Women's Empowerment and Child Protection	Gender equality and protection of women and children's rights.	Medium	Implement policies for gender equality, maintain gender/child data systems, promote women's empowerment.	Awareness campaigns, stakeholder forums, and empowerment workshops.
National Water Resource Council (DAS)	Integrated water resource management and policymaking.	Medium	Develop national strategies and policies for watershed management, oversee water disputes.	Advisory meetings, multi-stakeholder dialogues, regular reporting mechanisms.
Provincial Water Councils (Dewan SDA)	Regional coordination of water resource management (WRM).	Low	Advise on provincial basin plans, support water dispute resolution.	Regional council meetings, collaborative basin planning sessions, public consultations.

Local Governments	Urban water management, community water provision.	Low	Manage urban water systems, regulate water tariffs, provide access to clean water.	Community engagement programs, local water management workshops, and progress tracking sessions.
Non-Governmental Organizations (NGOs)	Advocacy for sustainable practices and community-focused water management.	Medium	Provide expertise, advocate for sustainability, implement local water projects.	Collaborative initiatives, capacity-building programs, participatory workshops.
Academia and Practitioners	Research and innovation in water management practices.	Medium	Conduct research, provide technical data, and develop WRM strategies.	Research partnerships, academic conferences, collaborative pilot projects.
Community-Based Organizations (CBOs)	Improved access to water, better community participation.	Medium to Low	Represent community needs, assist in local water project implementation.	Participatory planning, capacity-building exercises, local-level monitoring.
National Disaster Management Board	Disaster risk reduction, management of natural hazards like floods.	High	Formulate policies for disaster management, coordinate relief efforts.	Disaster readiness training, stakeholder collaboration in response planning, and regular coordination meetings.
Water User Associations (WUAs)	Efficient irrigation and water use.	Low	Design, construct, operate, and maintain water-use systems, especially irrigation.	Participatory irrigation management training, community meetings, and feedback mechanisms.
Kotaku Program (under Ministry of Public Works)	Urban water and sanitation improvements.	High	Implement strategies to provide safe drinking water, eliminate slums, and enhance sanitation.	Multi-level collaboration with communities, governments, and stakeholders through planning forums and resource-sharing sessions.

Step 4: Evaluation of stakeholders based on Power-Interest

Based on the desk research, small FGD was organized with local partners to fine-tune and validate the stakeholders mapping. The aim is to gain a comprehensive understanding of the stakeholders' viewpoints, motivations, and willingness to participate and work together to meet their needs.

Figure 6:
Example of Stakeholder Mapping in Indonesia based on Power and Interest
Source: Gutterer. et al,. (2023)

Access to the tool

https://th-koeln.sciebo.de/s/oJ2pU4lhVjLQ2az

Further readings

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Tool 2: Identification and Assessment of Ecosystem Services

Authors: Xhesika Hoxha, Juan David Mercado Leal

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 2 hours • Activity Duration: 4 hours	• Open • Close	• Basic • Medium • Advanced

The Identification and Assessment of Ecosystem Services Tool is a systematic approach to assessing the benefits provided by ecosystems in secondary and tertiary cities in Southeast Asia (SEA). The tool focuses on urban planning, water management and sustainable development by identifying, mapping, and analysing ecosystem services (ES). It uses a combination of desktop research and participatory approaches to ensure inclusivity and local relevance.

What?	Identification and Evaluation of Ecosystem Services Tools for Secondary and Tertiary Cities in the Southeast Asia (SEA)
Why? / Purpose	This tool aims to systematically identify and assess the existing ecosystem services in secondary and tertiary cities in the SEA region. It helps to understand the benefits provided by nature and supports urban planners in sustainable development and decision-making process.
Field of Application (Scale of Application)	**Scope of application:** Secondary and tertiary cities in the SEA region. Examples include the assessment of ES in Sariharjo, Sleman, Indonesia, through participatory workshops, and in Kratié, Cambodia, through desk-based research and interviews.

End users	• Academia (researchers, social and environmental scientists, students) • Government agencies (urban planners, environmental agencies, Public Works Department, City planning departments, Municipal-Provincial-Regency-National water managers, Local government) • Practitioners (urban planners, and water resources managers) and NGOs • Privat Sector (engineers, investors, funders)
Background	The tool has been developed in response to the growing recognition of the importance of integrating ecosystem services into urban planning. Adaptations for PUW include adapting participatory approaches to the local context and incorporating desk-based research methods based on PUW experience in SEA cities.
Description	The tool involves a multi-method approach: participatory workshops in one city and desk-based research with interviews in another. Features include local engagement, diverse data sources and a comprehensive understanding of ecosystem services that contribute to urban well-being.
Strengths and Limitations	**Strengths:** Local insights, diverse data sources, deep understanding, adaptability, replicability and regional focus **Weaknesses:** Potential bias, data accuracy challenges, time-consuming participatory processes and expertise required for GIS analysis.
Requirements (Instruments used)	**Time:** Moderate to extensive depending on complexity. **Skills:** Facilitation of participatory workshops, research and interviewing skills. **Equipment:** Computers for desk research, maps of the study area for the mapping, ArcGis/QGIS to digitize collected information, and data analysis. **Costs:** Moderated. Materials for workshop organisation, travel expenses, and data collection.
Keywords	Ecosystem services, Participatory Approaches, Desk-based Research, Blue-Green Infrastructure (BGI)

Tool Manual

Below is an integrated step-by-step guide that interlaces together the instructions on using the Excel-based identification and assessment tool for Ecosystem Services (ES) with the methodological framework involving desktop research and participatory workshops. This approach ensures inclusivity and local relevance by actively engaging stakeholders and aligning the technical classification (CICES) with local terminology and priorities. Such an approach is consistent with the principle that everyone who has a stake in the intervention can have a voice, either in person or by representation, while also serving as an introduction to participatory research methods.

Overview and Preparation

Tool Integration of Desktop Research and Participatory Approaches:

- Desktop Research helps you establish a conceptual baseline of the ecosystems in the study area.
- Participatory Workshops allow for the validation, contextualization, and mapping of the ecosystem services, ensuring the assessment meets local context needs and promotes ownership among stakeholders

Read the Accompanying Word Document and Examine Excel File (Refer the Access to the tool section for the documents links):

- Review the Word document for the overall methodology and an example of how to interpret your Excel findings.
- In the Excel file, you will see several worksheets, some for reference only ("NOTES_CICESV5.1" and "CICES_CLASS_V5.1") and others that you will modify.

> **Tip:** Maintain clear objectives about the Ecosystem Services you want to identify and assess before using the tool.

Step 1: Desktop Research

Purpose:

Define the Land Use, Land Cover (LULC), and Blue-Green Infrastructure (BGI) in the study area, creating a conceptual baseline of the ecosystem.

Methods & Materials:

Use satellite imagery (e.g., Google Earth), GIS platforms (e.g., QGIS, ESRI), scientific journals, maps, and relevant policies.

Actions:
1. Identify all crucial BGI, including forests, rivers, green spaces, agricultural lands, and other vegetation.
2. Correlate the identified BGI to Ecosystem Services using the Common International Classification of Ecosystem Services (CICES v5.1). Consult "NOTES_CICESV5.1" and "CICES_CLASS_V5.1" in Excel but do not edit these sheets.
3. Note key ES in the "CICES_ES_CLASS_SEL" sheet (see Section 3.1).

> **Tip:** At this stage, you gain a broad understanding of which ES exist and why they might be important, but you will refine your knowledge through participatory methods in later steps.

Step 2: Design of participatory workshops

Purpose:
Bridging the gap between formal CICES categories and local understanding, ensuring local stakeholders help shape and validate the ES selection.

Methods & Materials:
Develop workshop agendas, gather visual aids (maps, charts), and create user-friendly explanations of CICES categories.

Actions:
1. Introduce CICES Classes in Local Language: For example, "Forests moderate temperature" → "Trees provide shade and reduce temperature."
2. Use the "WORKSHOP_SHEET" in Excel to translate technical categories into lay-person-friendly language, so no prior technical knowledge is required.
3. Engage participants in specifying Ecosystem Service Providing Units (SPUs)—the habitats or areas that supply the services (e.g., rivers, parks).
4. Incorporate the three key dimensions for ES assessment:
   - Value of Importance (VOI): Perceived importance or priority level of the service.
   - Scale of Users (SOU): Spatial range of beneficiaries (local, regional, national, or international).
   - Value of Trend (VOT): Whether the ES is declining, stable, or improving

> **Tip:** Including stakeholders in the assessment ensures improved quality of data and local acceptance.

Step 3: Validation workshops with local partners

Purpose:
Validate the methodology, terminologies, and workflow with local experts and stakeholders.

Actions:
1. Check the clarity of the "Workshop Sheet" categories and the rating scales for VOI, SOU, and VOT.
2. Gather feedback on any ambiguous terms, suggested modifications, or non-relevant ES categories. Update the "CICES_ES_CLASS_SEL" sheet and other relevant sheets accordingly.
3. Review how SPUs have been identified. Ensure that local partners confirm the process and data are credible and relevant.

> **Tip:** Such validation workshops not only refine accuracy but also build trust and cooperation with local partners, which is critical for obtaining quality data EXCEL SHEETS: WHEN AND HOW TO USE THEM.

Step 4: Workshops development

Develop the participatory workshops supported with the Excel sheet files as follows:

Reference-Only Sheets:
→ "NOTES_CICESV5.1"
→ "CICES_CLASS_V5.1"

Purpose:
Provide definitions, principles, and examples of ES categories using CICES v5.1.

Action:
Consult these sheets regularly for correct classification, but do not modify them.

Table Construction and Examples Sheets (Highlighted in Yellow):
→ "CICES_ES_CLASS_SEL"
→ "VOI_SOU_VOT"
→ "WORKSHOP_SHEET"
→ "SPU_GUIDE"

→ CICES_ES_CLASS_SEL:
- Select and list relevant ES identified in Step 1 and refined in workshops.
- Provide a brief explanation or rationale for each ES.

➔ **VOI_SOU_VOT:**
- Assign scores for Value of Importance, Scale of Users, and Value of Trend for each ES.
- Reference Table 5(see below) or your adapted version to ensure consistency in scoring

➔ **WORKSHOP_SHEET:**
- Translate CICES terminology into local language and simpler descriptions for stakeholder engagement.
- Prepare prompts or discussion questions for workshops.

➔ **SPU_GUIDE:**
- Show how SPUs can be located geographically.
- Describe how you will use a GIS platform to map these SPUs.

Tip: Such validation workshops not only refine accuracy but also build trust and cooperation with local partners, which is critical for obtaining quality data
→ EXCEL SHEETS: WHEN AND HOW TO USE THEM

Table 5: Assessment criteria for VOI, VOT, and SOU to me completed in the Workshop Sheet

Level of importance of Ecosystem Services		Scale of Users		Classes of Ecosystem Services Trend	
Importance	**Value**	**Scale**	**Value**	**Class**	**Value**
Non existent	0	Non existent	-	Non existent	0
Very low	1	On-site	O	Heavily increasing	1
Low	2	Local	L	Increasing	2
Medium	3	Regional	R	No change	3
High	4	National	N	Decreasing	4
Very High	5		Heavily decreasing	Heavily decreasing	5
Not Relevant	6				

Step 5: Data analysis and visualization

Develop the data analysis and results visualization supported by the Excel sheet files as follows:

RESULTS SHEET:
- Compile final ES classifications, VOI, SOU, and VOT values after workshops and validation.
- Summarize relevant notes or detailed justifications.

PIVOT_GRAPHS:
- Produce pivot tables and charts (bar graphs, pie charts, etc.) to visualize trends and patterns.
- Filter or group ES by synonyms (e.g., cultural vs. provisioning) to observe patterns more clearly.

Tip: These sheets are examples; adapt them with your real data and categories so they accurately reflect your case study's outcomes

Step 6: Final Check and Word document Integration

Consolidate Findings:
Use the "RESULTS_SHEET" and "PIVOT_GRAPHS" to summarize all key results

Writing the Report:
Combine Excel outputs with the guidance in the Word document to produce a comprehensive discussion of your findings explaining trends, importance, and recommendations for sustainable development.

By combining desktop research with structured participatory engagement, the tool helps identify and assess ES in a way that is both scientifically comprehensive and locally grounded The Excel sheets guide you in classifying, scoring, and mapping these services; the workshop methodology ensures these processes reflect local realities and knowledge. Together, they provide a reliable and actionable framework for sustainable planning and decision-making.

Study case

Sariharjo located in Sleman – Indonesia, as a case study village, has diverse Blue-Green Infrastructure (BGI) features ranging from forest patches to rivers and agricultural lands. Understanding and classifying these as Ecosystem Services (ES) follows the earlier steps of desktop research (Step 1), GIS-based mapping (Step 1 & 2), and preliminary design of participatory workshops (Step 2). Drawing on best practices, it is essential to integrate local residents' awareness and perception of ES from the outset, ensuring that the assessment reflects real-world conditions and stakeholder priorities.

Step 1: Desktop Research

In Sariharjo, desktop research began by reviewing local government land-use maps, free satellite data, and existing environmental policy documents. The research team used QGIS to delineate significant BGI, including rice paddies, small community forests, and a perennial river cutting across the village (Figure 7). By comparing these features with CICES V5.1 categories, they compiled a preliminary list of ES, noting provisioning services (e.g., rice and horticulture), regulating services (e.g., erosion control by forest patches), and cultural services (e.g., recreational fishing at the riverbank).

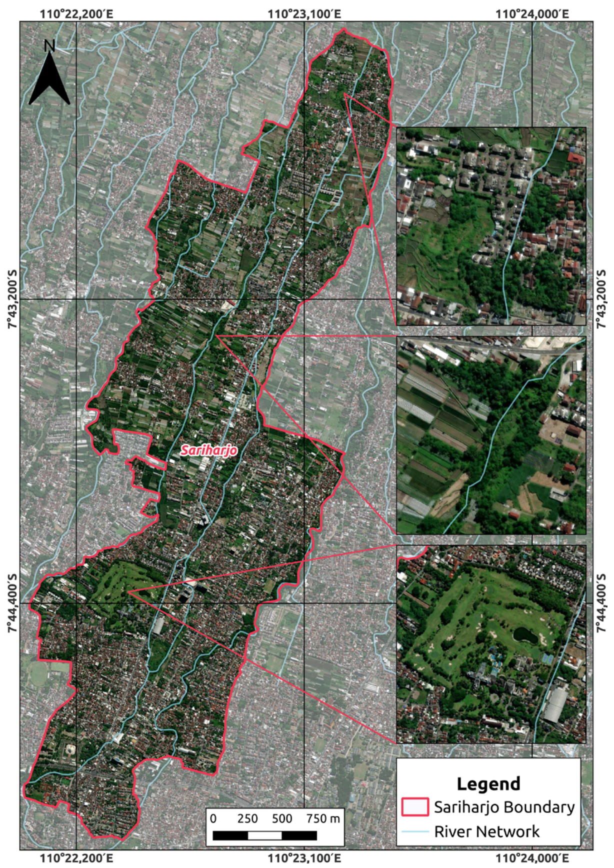

Figure 7:
Blue and Green areas identification
Source: F12-THK, 2022

Step 2: Design of the Participatory Workshops

During this phase, local leaders in Sariharjo (e.g., village council members) helped to draft an agenda for the workshops, and to ensure that key community members were invited. Large-scale maps from Step 1 were printed out to facilitate the visualization of the identified BGI, for the participants. Simplified CICES descriptors—such as "clean water for drinking and irrigation"—were used to clarify the formal ES classification codes.

Step 3: Validation Workshops with local partners

Prior to the main participatory workshop, a smaller validation session was held with representatives from the municipal planning office and local NGOs. They confirmed that the SPUs identified—forests, river segments, small wetland areas—matched both local knowledge and official municipality data. Feedback led to refining some ES descriptions (e.g., "seasonal flood regulation" was emphasized after local accounts of flood-prone areas) (Figure 8).

Figure 8:
Photographic record of the interactive validation of the workshops with the local partners
Source: F12-THK, 2022

Step 4: Workshops Development

The participatory workshops are at the heart of the tool's approach and involve incentives of numerous stakeholders for ES assessment. These workshops were generally organized at the community level, for example, at the village, neighbourhood, or district level and should involve people from different stakeholder groups including the citizens, municipal government, and environmental groups (Figure 9). In the same context, the participants were also involved in evaluating the VOI, VOT, and SOU of each of the SPU that has been identified and recommended during the workshops using worksheets and maps provided. They are conducted in the form of an open discussion to allow for all the participants to be given an opportunity to express their opinions.

Insights:

- The "VOI_SOU_VOT" sheet was shown in tabular form, so every participant could see how (and why) certain ES might be, for example, Highly Important (VOI=4) yet only serving Local scale users (SOU=L).
- Attendees used the "WORKSHOP_SHEET" to clarify terminology they found complex, ensuring dialogue remained accessible.
- GIS-based instructions in "SPU_GUIDE" directed participants and facilitators in pinpointing the exact location of fields, riverbanks, and forests on a shared digital map.

Figure 9:
Example of photographic record of ES mapping FGD
Source: F12-THK, 2022

Documentation is a vital aspect of the participatory workshops that must be adopted for the processes. Documents such as photos, maps and worksheets which are filled upon completion are also gathered to have complete records of the whole process and the outcome. These records are further employed for assessment and accounting purpose, as it offers clear disclosure of the results obtained at the workshop. The focus group discussions not only give rich information but also cultivate a spirit of ownership and accountability among the stakeholders thus making them remain active in ecosystem service provision and protection.

Step 5: Data Analysis and Visualization

After the workshops, the collected data is aggregated and becomes the basis for creating a set of recommendations. The first attempt is to make a results sheet which would encompass all SPUs, their VOI, VOT, and SOU values in addition to their respective CICES classifications. This results sheet forms the basis for various other analyses, for instance, determining the most significant ecosystem services (Figure 11), the location of these services (Figure 10), and whether there is any evident change in these services over some time. The location of SPUs can be represented using tools like QGIS or Google Earth which allow one to see where ecosystem services are likely to be located (Figure 10 below).

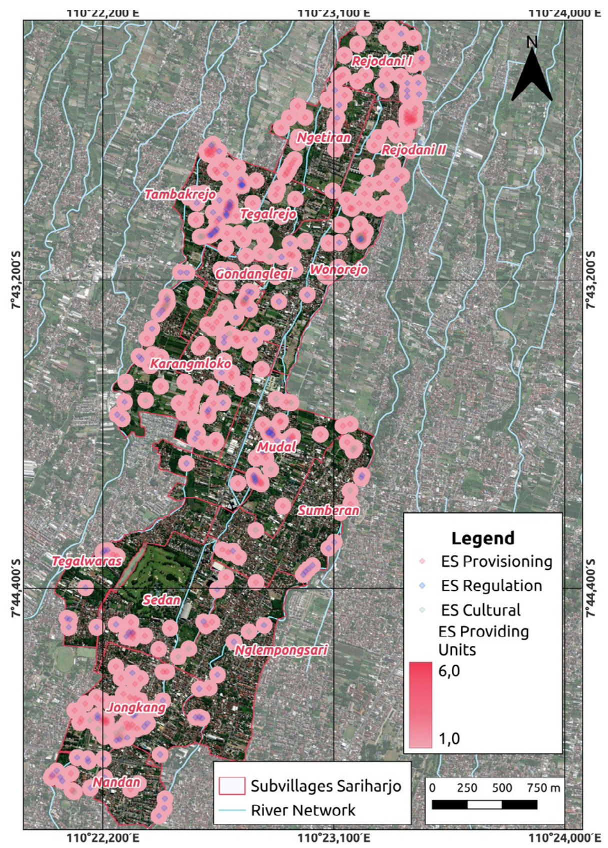

Figure 10:
Example of a geographical distribution of SPU that provide different ecosystem services. Study case: Sariharjo-Indonesia
Source: F12-THK, 2023

One must also analyse patterns in the VOI, VOT, and SOU data. For instance, it may show that provisioning services like water provision are highly preferred but have a declining trend – this suggests that they deserve attention. Likewise, the analysis might reveal cultural assets including recreational areas that appear to have been overlooked but can be developed further. Through these analyses, the tool allows decision-makers to have a holistic overview of how ecosystem services are affected to guide their choices on what actions should address the conservation or restoration of impaired services.

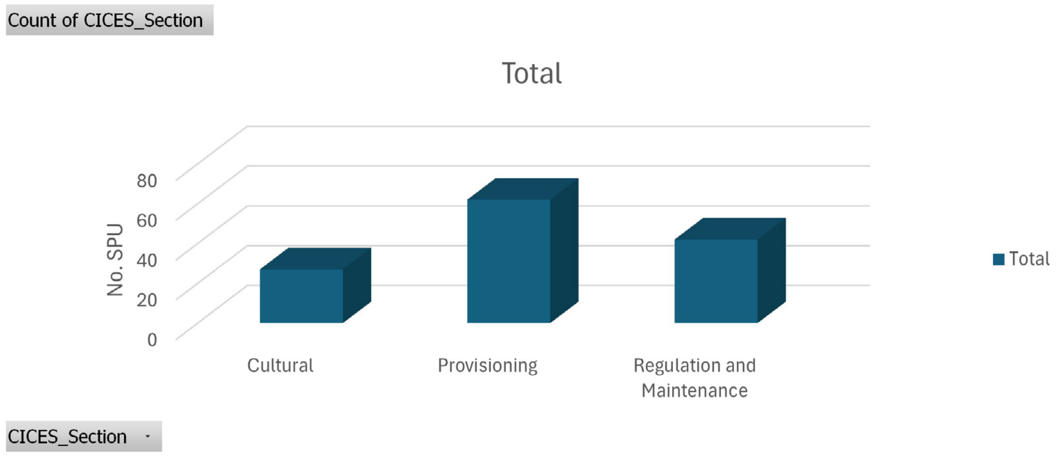

Figure 11:
Example of a Graphical Analysis of the SPUs, categorized by Cultural, Provisioning, and Regulation & Maintenance sections of ecosystem services

Access to the tool

https://th-koeln.sciebo.de/s/0nsJUzrv7EmkXEy

Further readings

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Tool 3: Assessment of Local Perception toward Nature-based Solutions (NbS)

Authors: Xhesika Hoxha, Zahraa Salem Aswad Alobaidy, Juan David Mercado Leal

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 1 hours • Activity Duration: 2 hours	• Open • Close	• Basic • Medium • Advanced

This tool aims to support the development of the Nature-based Solutions (NbS) perception surveys (Interviews and Questionnaires). It consists of a brief description and background of the surveys as a research method, some recommendations of how to conduct the survey correctly, and finally the different questions that make up the surveys presented in concrete terms.

What?	Assessment of Local Perception of Nature-Based Solutions (NbS) and Hybrid Solutions Tool for Secondary and Tertiary Cities in the SEA Region
Why? / Purpose	This tool systematically evaluates local community perceptions of nature-based and hybrid solutions in secondary and tertiary SEA cities. Understanding these perceptions is vital for aligning NbS with community needs. Strengths include engagement, while weaknesses may involve response subjectivity.
Field of Application (Scale of Application)	**Scope of application:** Secondary and tertiary cities in the SEA region. Examples include assessing how communities perceive and accept NbS interventions in urban greening initiatives.

End users	• Academia (researchers, social and environmental scientists, students) • Government agencies (urban planners, environmental agencies, Public Works Department, City planning departments, Municipal-Provincial-Regency-National water managers, Local government) • Practitioners (urban planners, and water resources managers) and NGOs • Private Sector (investors, funders)
Background	The tool has evolved in response to the growing emphasis on community engagement and the recognition of the importance of aligning urban projects with local perceptions. Adaptations for PUW include incorporating lessons learned from previous participatory approaches.
Description	The tool offers a comprehensive analysis of local perceptions of NbS and hybrid solutions, aiming to identify community attitudes, preferences, and concerns. Features include a focus on participatory methods such as surveys and community workshops to gather diverse perspectives.
Strengths and Limitations	**Strengths:** Community involvement, insights into local preferences, improved project acceptance. **Weaknesses:** Subjectivity of responses, potential bias, time-consuming community engagement processes.
Requirements (Instruments used)	**Time:** Moderate to extensive, depending on community size and level of involvement. **Skills:** Survey design, facilitation of community workshops. **Equipment:** Computers for data analysis. **Costs:** Moderate for survey administration, workshop organisation and data analysis.
Keywords	Nature-based solutions (NbS), Survey, Questionnaires, Interviews

Tool Manual

A combination of interviews and questionnaires were adopted to gather the data. This dual approach allows to explore the local perceptions comprehensively, leveraging the strengths of both qualitative and quantitative methods. Figure 12 illustrates the used methodologies which are also described briefly below.

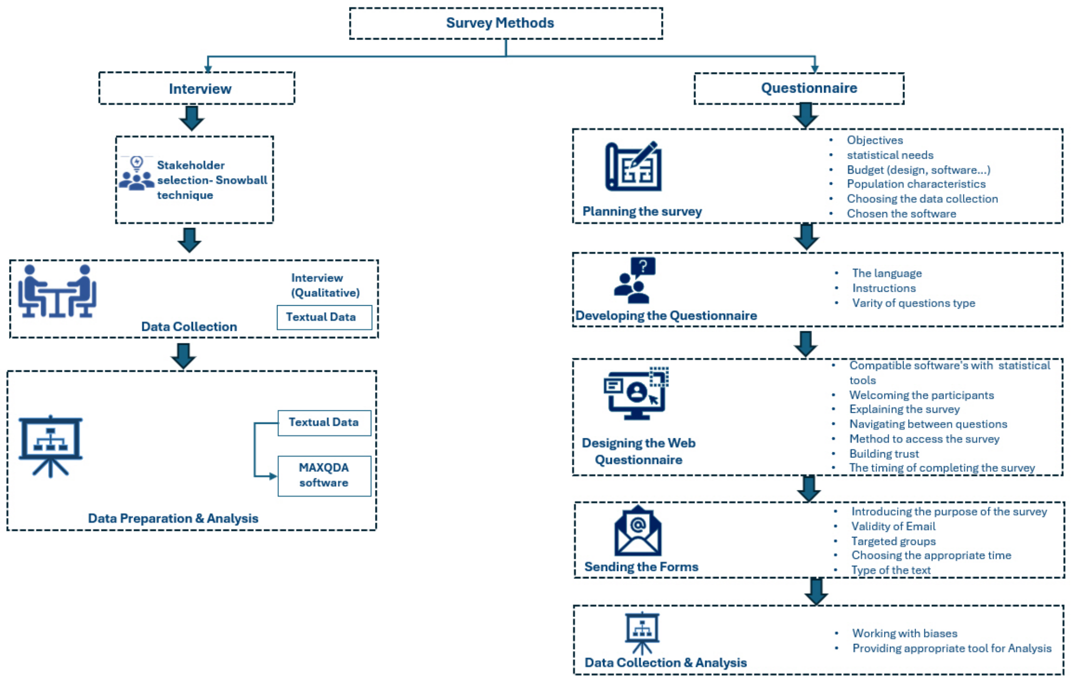

Figure 12:
Overview on the used methodological steps to conduct the survey
Interview-based Survey

Interview-based Survey

The main objective of conducting interview survey is to collect the different perceptions (ideas, opinions, believes) of the NbS possible implementation in the territory, aiming to identify the benefits, challenges and potential risk of this type of solutions. Three steps were developed to conduct the Interview: stakeholder selection process, data collection process, data preparation and analysis.

The Interview questions are divided into six subjects: Identifying the Study Area Condition (Ecologically, socially, and technically), identifying the challenges, Introduction of Interventions (Nature-based Solutions (NbS), and recommendations. This categorization of questions ensures a holistic approach from problem identification to recommendation.

Questionnaire-based Survey

The main objective of this survey is to identify the perception of people towards the NbS through: Identifying the current and future challenges, gather participants' insights on NbS potential implementation to address water management issues, including NbS benefits, challenges, and resource requirements, and finally identify key priorities and stakeholders essential for successful implementation of green-grey, blue-grey, and green-blue infrastructure.

To assess the perception of the main stakeholder's regard to NbS in the study areas, the questionnaire survey design and implementation can be divided into five main steps (shown in Figure 13): Planning the survey, developing the questionnaire, designing the web questionnaire, sending invitations, and data collection.

The survey is conducted, using Google Forms. The questionnaire is processed within 10-15 minutes and is available in local languages, with participants' consent and confidentiality ensured.

The questions are divided into three subjects: demographics section (general information about the respondent, identifying the challenges, and Introduction of Interventions (NbS). The survey includes demographics, close-ended, scaled, binary (yes/no), and image questions, in order to gather qualitative insights. Additionally, some questions are directing respondents to relevant sections of the survey based on their answers which are called filtered questions.

Study case

To gain a deeper understanding of how communities perceive NbS, a study combining interviews and questionnaires was conducted in three distinct regions: Sariharjo, Kratié, and Sam Neua. The study employed a mixed-methods approach, integrating quantitative questionnaire with qualitative interviews to capture a comprehensive view of community attitudes and experiences.

Participants were introduced to the study during community meetings, where the purpose and confidentiality of the survey were clearly explained. Interviews were held in familiar, comfortable settings to foster open and honest discussions. The questions covered various aspects of NbS, including general information about the region within the framework of Social, Environmental, and Technological (SET) framework. The survey also sought to measure participants' awareness and willingness to engage in NbS projects. Additionally, participants were encouraged to share the challenges they currently face, anticipate future issues, and propose recommendations to better address their needs and priorities.

To ensure the inclusion of all relevant stakeholders, the questionnaire was also distributed to local residents and/or governmental departments. This broader outreach aimed to gather diverse perspectives and provide a holistic understanding of perceptions toward NbS. During the interviews, residents shared valuable insights about the natural environment in their regions and the pressing challenges they encounter, both present and anticipated. Discussions revealed varying levels of awareness about NbS. Some participants highlighted the potential of solutions such as wetland restoration, while others underscored the necessity of integrating natural approaches with traditional infrastructure to tackle issues like water scarcity, flooding, and non-water-related challenges such as soil erosion.

The data collected from these interviews and surveys were carefully analysed to uncover common themes and unique viewpoints across the three regions. The findings underscored the critical need to tailor NbS initiatives to align with local priorities and ensure active community participation throughout the planning and implementation processes. By incorporating local knowledge and addressing specific challenges, the study aimed to offer actionable recommendations for the successful implementation of NbS projects in Sariharjo, Kratié, and Sam Neua. These insights not only highlighted the transformative potential of NbS but also emphasized the importance of inclusive and context-sensitive approaches to environmental and social resilience.

Access to the tool

https://th-koeln.sciebo.de/s/CICZgtjJJiCBdpF

Further readings

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Tool 4: Urban Water Accounting

Authors: Chahinaz Ziani, Boutaina Abbazi, Dr. Ni Nyoman Nepi Marleni, Xhesika Hoxha

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: Weeks (rely on data providers) • Activity Duration: 2–3 hours	• Open • Close	• Basic • Medium • Advanced

Urban water accounting is a comprehensive analytical tool designed to systematically quantify, track, and evaluate water flows and stocks within urban environments. Consisting of an Excel-based file and user guidelines, it transforms complex water accounting into an accessible municipal resource management instrument.

What?	Urban water accounting is a comprehensive analytical tool designed to systematically quantify, track, and evaluate water flows and stocks within an urban environment. This tool comprises two key components: • An Excel-based analytical file • Accompanying user guidelines serving as a manual
Why? / Purpose	The tool transforms complex water accounting into an accessible, practical municipal resource management instrument. • Simplify urban water accounting process • Provide clear, actionable water management insights • Support data-driven decision-making • Enhance water resource management efficiency • Facilitate basic water flow tracking with minimal complexity
Field of Application (Scale of Application)	Urban environment in secondary and tertiary cities in the SEA region.

End users	• Municipal water managers • City planning departments • Local government water resource teams • Small to medium-sized municipalities
Background	The development of the tool establishes a simplified method that provides quantitative assessment of water interactions in urban areas. The tool is based on the studies of (Kenway et al., 2011; Torres López et al., 2019) combined and adapted to the context of urban water management system in the three case studies.
Description	The Excel file, which forms the core of the tool, is structured into four interconnected sheets: • **Water Sources and Supply:** Quantifies water extraction from various environmental sources and its distribution to different user categories within the urban system. • **Water Discharge:** Assesses the volume and nature of water discharged back into the environment, categorized by user types and treatment status. • **Flow Diagram:** Provides a visual representation synthesizing the data from the previous two sheets, illustrating the comprehensive water flow within the urban ecosystem. • **Performance Indicators:** Calculates key metrics to evaluate the efficiency and effectiveness of urban water management practices.
Strengths and Limitations	**Strengths:** Comprehensive Framework, User-friendly format, Communicative tool, Enhanced stakeholder engagement, Decision support tool, Minimal training. **Weaknesses:** Data dependency, limited advanced analytical capabilities, time investment for setup, potential for oversimplification.
Requirements (Instruments used)	Software: Microsoft Office – Excel (Excel 2016 or later is recommended)
Keywords	Water Balance

Tool Manual

Tool overview

The Urban Water Accounting tool is a systematic quantitative assessment framework designed for municipalities to track and manage the flow of water within urban environments.

This tool facilitates the accounting of water quantities sourced from natural bodies (like rivers and groundwater), utilized by various sectors (e.g., households, industries, and commercial units), and returned to the environment

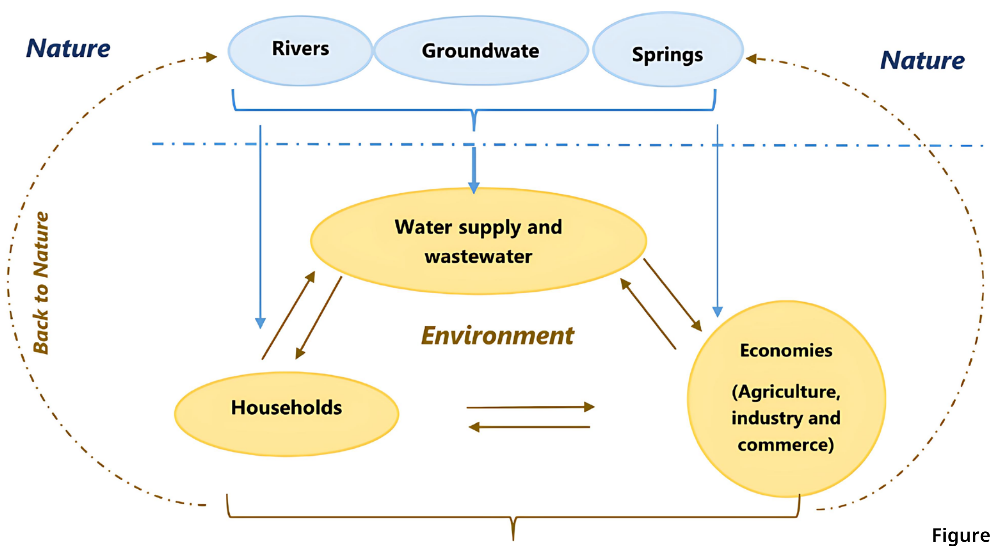

Figure 13:
Diagram explaining the Urban Water Accounting tool concept.

Tool usage steps

Users of the Urban Water Accounting Tool must systematically navigate three critical phases: boundary definition, comprehensive data collection, and precise data entry, which collectively provide a holistic approach to urban water system analysis

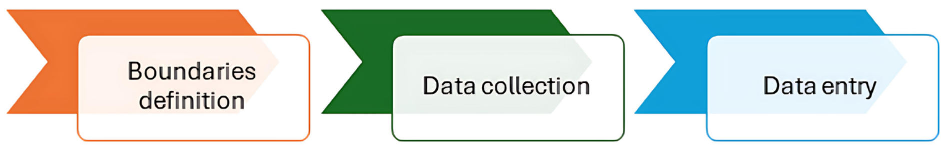

Figure 14:
Key steps for using Urban Water Accounting.

> **Boundaries Definition**

Define the spatial and temporal boundaries of your urban water system:

- **Spatial:** Determine the geographical area covered by your analysis (e.g., city limits, watershed boundaries).
- **Temporal:** Specify the time period for data collection (e.g., annual, monthly).

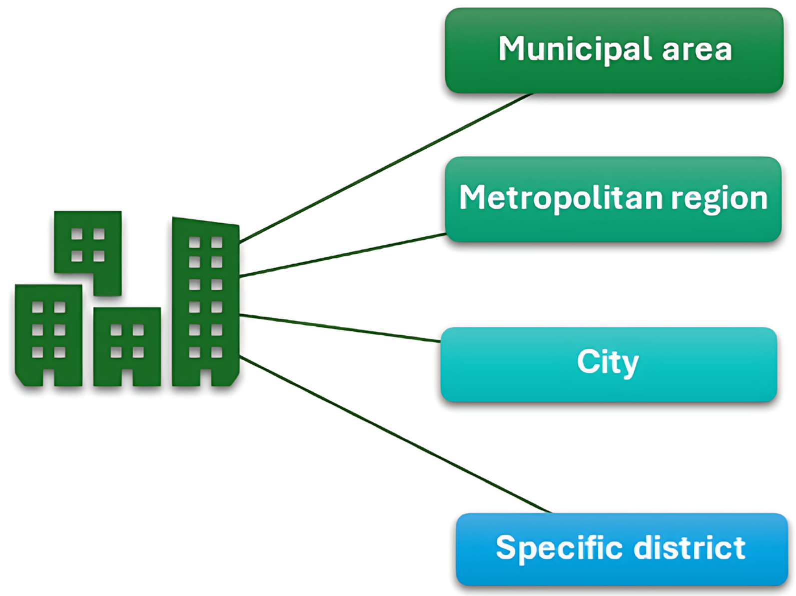

Figure 15:
Examples of spatial boundaries for the Urban Water Accounting tool

> **Data Collection**

Before entering data, it is crucial to understand the key components of the urban water system:

- **Water Sources:** Natural or artificial reservoirs from which water is extracted for urban use, including surface water (rivers, lakes) and groundwater aquifers.
- **Water Supply:** The infrastructure and processes used to collect, treat, and distribute water to users, including treatment plants and distribution networks
- **Water Users:** Various sectors consuming water, such as residential, commercial, industrial, and public facilities
- **Water Treatment:** Facilities and processes that clean and purify wastewater before it's returned to the environment
- **Water Discharge:** The release of treated wastewater back into natural water bodies or for reuse purposes.

To gather the necessary data:

1. Identify relevant stakeholders for each component (e.g., water utilities, industrial users, treatment plant operators).
2. Contact these stakeholders directly to request the required information.
3. Consult the guidelines provided with the Urban Water Accounting Tool for specific data sources and collection methods.

> **Data Entry**

Once you have collected the necessary information, proceed to enter the data into the four sheets of the Excel file:

1. Water Supply Sheet:

- Enter data on water sources, extraction volumes, and supply infrastructure.
- Include information on water treatment processes and distribution networks.

2. Water Discharge Sheet:

- Input data on wastewater collection, treatment processes, and discharge volumes.
- Include information on any water reuse or recycling initiatives.

3. Flow Diagram Sheet:

- Use this sheet to create a visual representation of water flows through your urban system.
- Ensure all major components and connections are accurately depicted.

4. Performance Indicators Sheet:

- Enter relevant data to calculate key performance indicators.
- These may include water use efficiency, treatment effectiveness, and system losses.

By following these steps and utilizing the Urban Water Accounting Tool, municipalities and water managers can gain valuable insights into their water systems, enabling more informed decision-making and sustainable water resource management.

Study case

In the case study of Sariharjo, Indonesia, where we applied our urban water accounting tool on an annual base, Figure 16 illustrates a portion of the water flows between different components (environment, economies, and households), while Table 6 presents the values of some of the performance indicators. Unfortunately, due to data scarcity, we were unable to compute all elements of the urban water accounting framework for this case study.

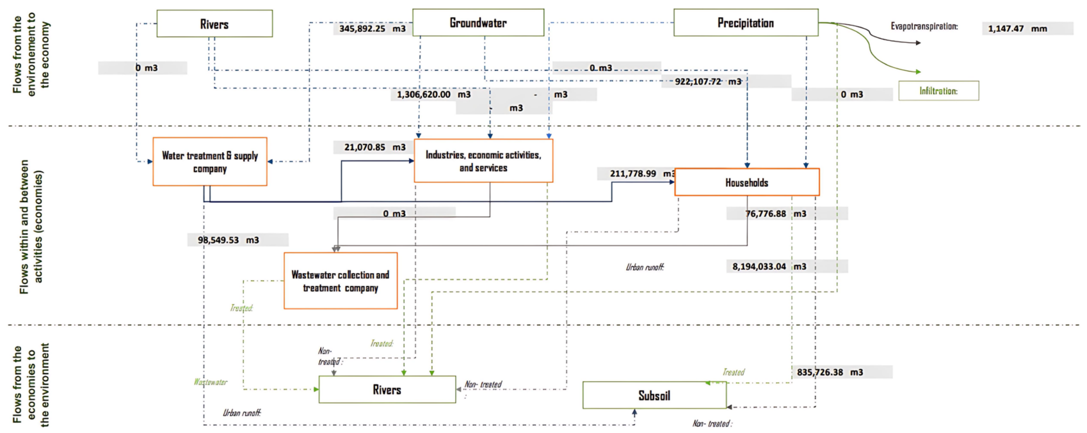

Figure 16:
Flow diagram resulting from the water accounting in Sariharjo-Indonesia

Table 6: Performance indicators of water supply and discharge systems in Sariharjo- Indonesia

Indicator category	Indicator name	Definition	Units	Value
Population and water use intensity	Intensity of water use	The ratio of the sum of water utilized by the different sectors divided by the total area.	GL/year/Km²	0.44
Overall balance of inputs and outputs	Inputs/outputs	The ratio of the total volume of water flowing from environment to the economies divided by the water flowing from the economies to the environment	-	99.826%
Water system centralization	Supply centralization (%)	Ratio of total water supplied from municipal water collection, treatment and supply to the different users	%	8%
	Supply decentralized (%)	Ratio of total water either extracted directly from nature (from rivers, groundwater, rainfall harvesting) or supplied from trucks.	%	92%
Wastewater potential for water supply	Total use replaceability	Ratio of the total water discharged from the economies to the environment (except urban runoff) divided by the total water volume used by the different users	%	65%

Based on the provided performance indicators we can conclude that:

- **Intensity of water use (0.44 GL/year/Km²):**
  This low value suggests that a large portion of the annual precipitation likely follows natural water cycles (infiltration, runoff, evapotranspiration) rather than being consumed by human activities. While for the built-up areas, it could indicate limited water infrastructure and usage in the developed parts of the village.
- **Inputs/outputs ratio (99.826%):**
  The near-balance between water inflows and outflows implies minimal water retention or loss within the system, suggesting efficient water cycling.
- **Supply centralization (8%) vs. decentralization (92%):**
  The high decentralization rate indicates heavy reliance on direct extraction methods (i.e., groundwater) rather than municipal supply, which may present challenges for water quality control and sustainable management.
- **Total use replaceability (65%):**
  This moderate value suggests significant potential for wastewater reuse, indicating opportunities to enhance water efficiency and reduce freshwater demand.

Based on the provided performance indicators and their interpretations, we can recommend the following:

- **Enhance Water Infrastructure in Built-Up Areas:**
  The low intensity of water use (0.44 GL/year/Km²) suggests limited water infrastructure. Investments in expanding and upgrading water supply systems in Sariharjo could improve access and efficiency.
- **Promote Decentralized Water Management:**
  With 92% of water supply being decentralized, efforts should focus on improving the quality, monitoring, and sustainability of decentralized sources especially groundwater. This could include implementing regulations, providing technical support, and encouraging community-based management.
- **Increase Wastewater Reuse:**
  The 65% total use replaceability highlights significant potential for wastewater reuse. Introducing or expanding wastewater treatment facilities and promoting treated wastewater for non-potable uses (e.g., irrigation or industrial processes) could reduce freshwater demand.
- **Integrate Nature-Based Solutions (NBS):**
  To complement existing systems, consider implementing NBS such as permeable pavements to enhance water retention, reduce runoff, and improve water quality.

- **Strengthen Data Collection Systems:**
  The near-balance in inputs/outputs (99.826%) indicates efficient water cycling but may also mask unaccounted losses due to limited data. Installing metering systems at the village level and improving data collection on water flows would provide more accurate insights for planning.
- **Encourage Public-Private Partnerships:**
  Collaborations with private entities can bring expertise and funding to improve infrastructure, implement innovative technologies, and enhance system efficiency.
- **Promote Awareness and Community Engagement:**
  Educating communities about sustainable water use practices and involving them in decentralized water management can foster long-term resilience.

Access to the tool

https://th-koeln.sciebo.de/s/0BWiIsYFdskCYPh

Further readings

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Manzardo, A., Loss, A., Fialkiewicz, W., Rauch, W., & Scipioni, A. (2016). Methodological proposal to assess the water footprint accounting of direct water use at an urban level: A case study of the Municipality of Vicenza. Ecological indicators, 69, 165-175.

Tool 5: Insights for Urban Water Management using Open-Source Datasets

Authors: Chahinaz Ziani

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 2 days • Activity Duration: 3–4 days	• Open • Close	• Basic • Medium • Advanced

Insights for Urban Water Management using Open-Source Datasets is a comprehensive assessment tool designed for urban and peri-urban watersheds. It provides step-by-step guidelines and R-scripts to analyze hydro-climatic parameters, evaluate hazards like droughts and floods, and assess trends in extreme weather events. The tool utilises open-source data to empower local authorities with data-driven decision-making capabilities, identify vulnerabilities, and implement proactive measures.

What?	This tool provides a step-by-step guideline for conducting a comprehensive assessment of watershed/urban hydrological processes. It offers an overview of the **hydroclimatic parameters** such as precipitation, evapotranspiration and temperature within the watershed that encompasses the urban study area, followed by an **evaluation of hydro-climatic hazards** such as **droughts and floods**, as well **as trends in extreme weather occurrences**.
Why? / Purpose	**Permitting data-driven decision-making:** Empowering local authorities to make informed decisions based on open data (without significant costs) **Identification of vulnerabilities and implementing proactive measures:** by assessing hydroclimatic hazards (droughts, floods, extreme precipitation) **Providing a comprehensive assessment of water management practices:** in the context of increasing urbanization and climatic variability, and as the study areas are transiting from rural to urban.

Field of Application (Scale of Application)	The tool can be applied at **multiple scales**, primarily focusing on **urban and peri-urban areas** within **broader watershed contexts**. The application of the can help for the **formulation of a detailed water-sensitive development plan** for secondary and tertiary cities.
End users	• Urban planners • Environmental scientists • Community organizations (NGOs) • Educational Institutions
Background	The tool was adapted to emphasize: • **Reanalysis Data Utilization:** Ensuring accessibility for municipalities with limited resources. • **Stakeholder Engagement:** Incorporating visual tools and guidelines that facilitate communication among various stakeholders involved in urban water management. • **Regional Relevance:** Tailoring methodologies to reflect local hydrological conditions and socio-economic contexts within Southeast Asia
Description	The tool is designed to facilitate a comprehensive assessment of watershed hydrological processes, specifically tailored for urban contexts. • It provides a structured framework and ready-to-use R-scripts for users to conduct a hydrometeorological baseline assessment • It enables the assessment various drought types—meteorological, hydrological, and agricultural • It incorporates a flood frequency analysis to evaluate flood risks. • It calculates precipitation extreme indices and analyses trends in extreme weather occurrences, all utilizing open-source data. This integrated approach equips municipalities with critical insights for effective urban water management and planning.

Strengths and Limitations	**Strengths:** Utilization of Open-Source Data, simplified and Step-by-Step Guidelines, permits an enhanced risk management **Limitations:** data quality dependency, and enhanced technical skills requirements.
Requirements (Instruments used)	• Information on required resources such as time, skills, software, costs • Software: GIS software, • Skills: proficiency in a programming language (e.g., R).
Keywords	Hydrometeorological Baseline Assessment, Reanalysis Data, Drought hazards indices, SPI, SPEI, VHI, VCI, TCI, Aridity Index (AI), Extreme Precipitation Events Indices, Flood Frequency Analysis

Tool Manual

The "Insights for urban water management using open-source data" tool consists of four components, all of which rely on open-source data. These components can be used sequentially or individually, allowing end-users to focus on specific aspects of interest. Each component includes its own set of steps

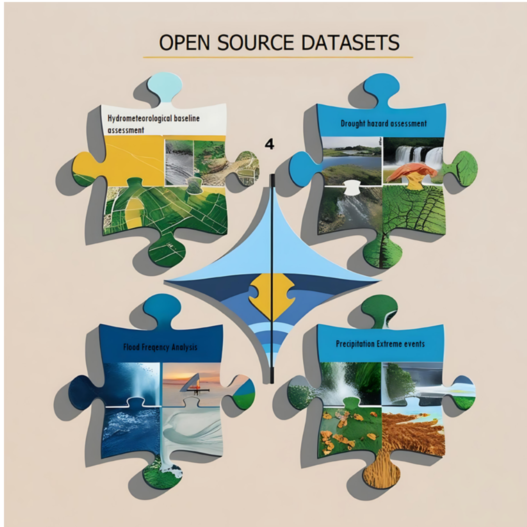
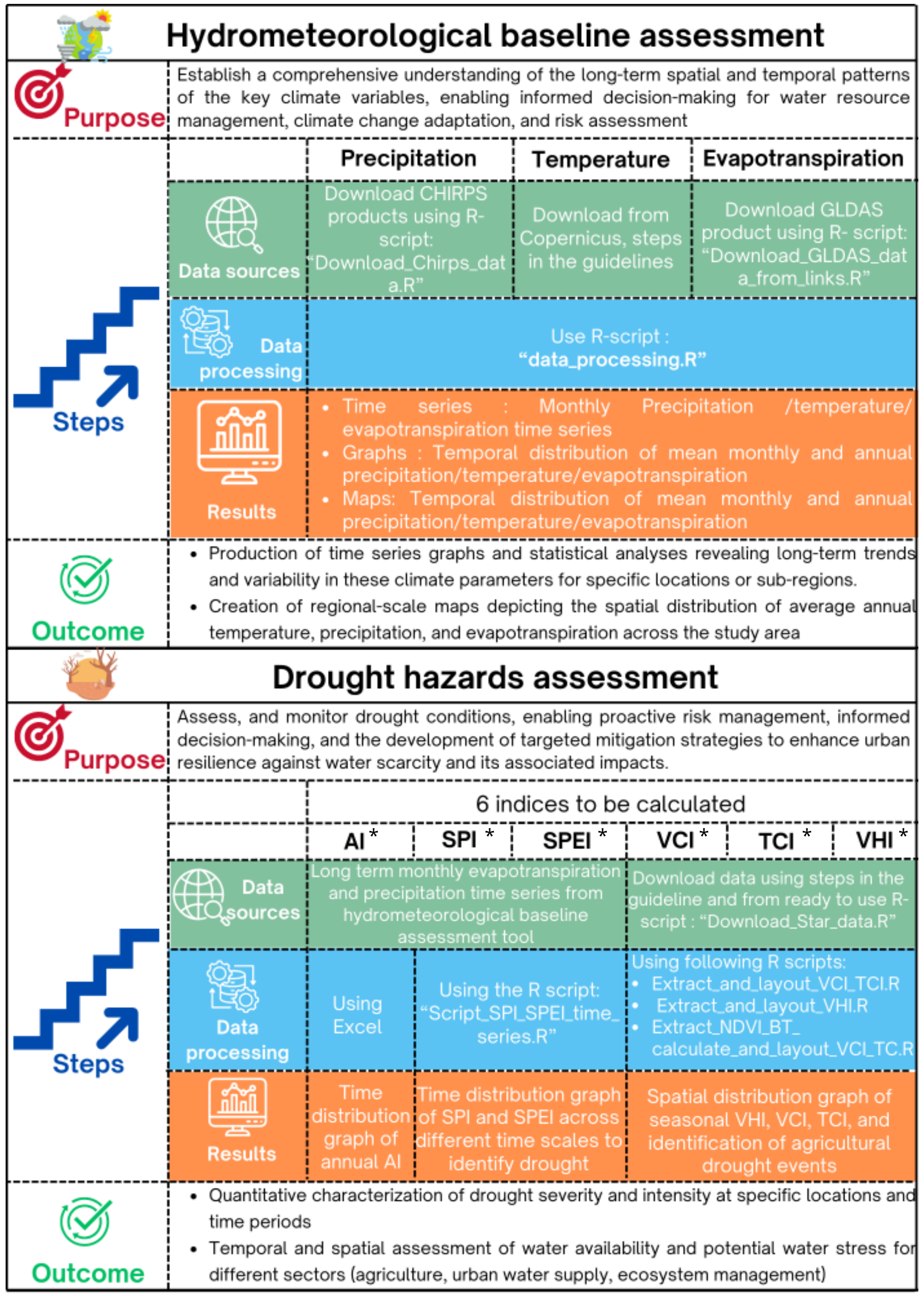
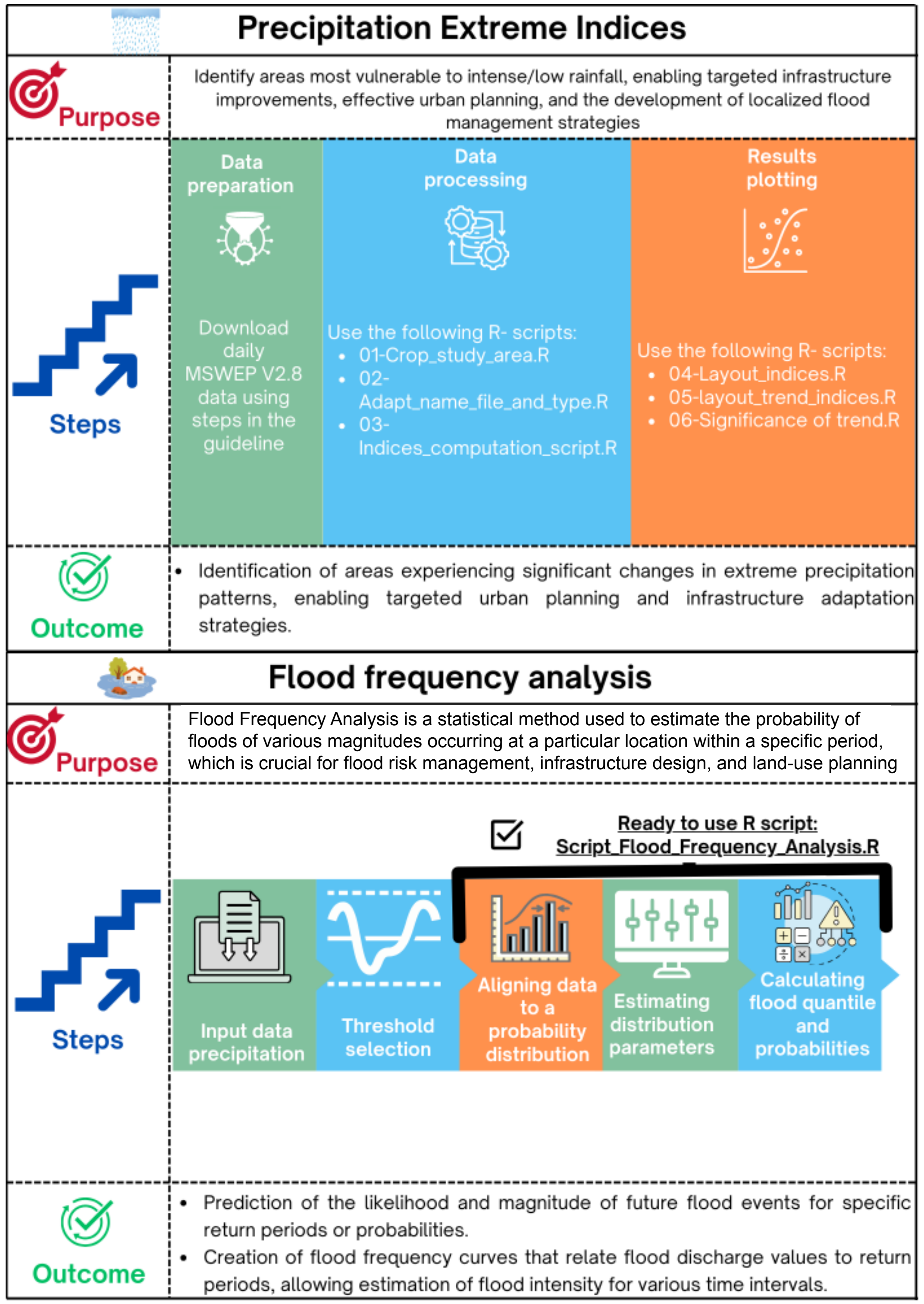


Figure 17:
Four key components that constitutes the "Insights for urban water management using open-source data" tool.

The overall characteristics and steps of these four components are explained below:



* **AI:** Aridity Index, ***SPI:** Standardized Precipitation Index, ***SPEI:** Standardized Precipitation Evapotranspiration Index, ***VCI:** Vegetation Condition Index, ***TCI:** Temperature Condition Index, ***VHI:** Vegetation Health Index



Tool overview

Advantages	Limitations
Utilizes open-source data, making it accessible for municipalities with limited resources	Dependency on data quality of open-source datasets
Provides step-by-step guidelines for comprehensive watershed assessment	Requires a minimum of technical skills, including proficiency in programming (e.g., R)
Enables data-driven decision making for local authorities	Does not provide access to all types of open-source data
Helps identify vulnerabilities and implement proactive measures	May require significant time investment to conduct full assessment
Applicable at multiple scales (urban and peri-urban areas)	Potential limitations in regional applicability
Incorporates visual tools to facilitate stakeholder communication	Results may be limited by the resolution and coverage of available open data

Study case

The Prek Te watershed and Kratie village serve as the case study where the four components of 'Insights for Urban Water Management using Open-Source Data' were applied.

Hydrometeorological baseline assessment

In this section, we showcase examples of the outputs generated by the provided R scripts.

a)

b)

Figure 18:
Examples of generated maps illustrating the multi-annual mean of precipitation (a), and temperature and evapotranspiration (b).

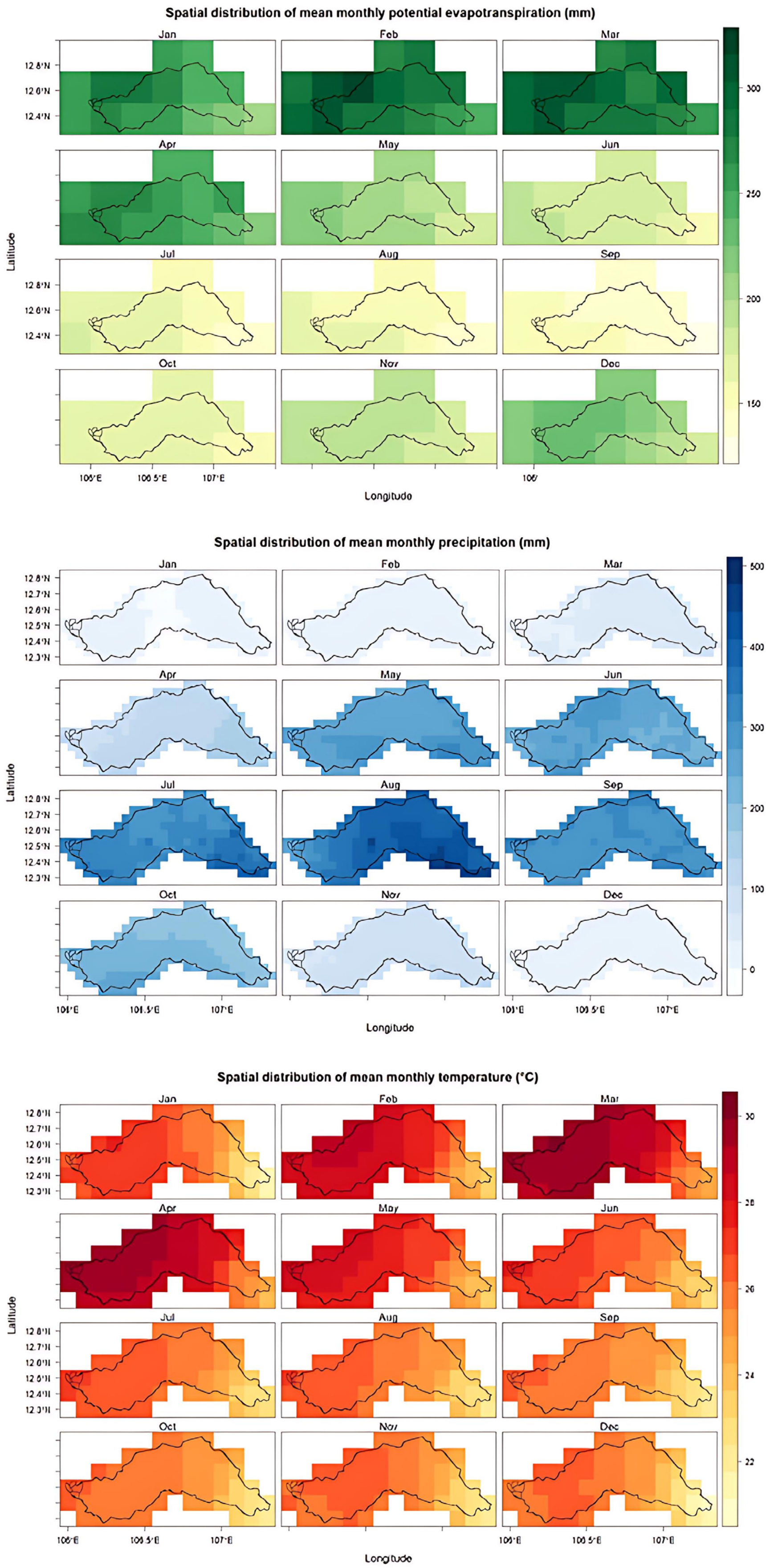


Figure 19:
Spatial distribution of long-term mean monthly precipitation, temperature and potential evapotranspiration

Drought hazards assessment

1. For Aridity Index (AI)

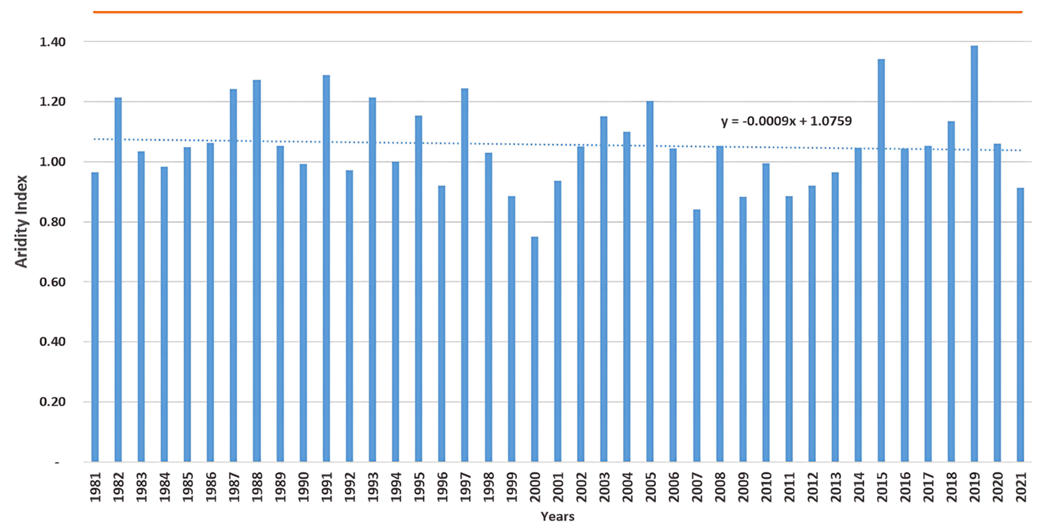
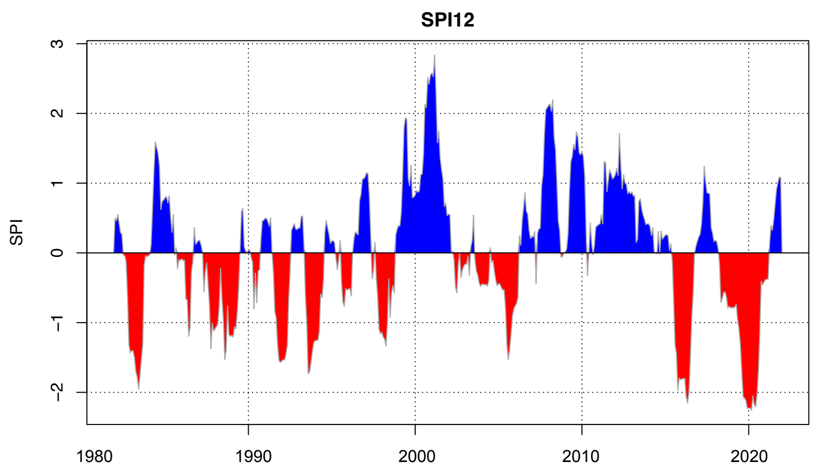


Figure 20:
Temporal distribution of yearly Aridity Index in Prek Te watershed. The orange line represents the limit of humid climate values above this threshold means a dry-sub humid climate. The dashed blue line is the linear trend of the annual change in the aridity index.

2. For Standardized Precipitation Index (SPI) and Standardized Precipitation and Evapotranspiration Index (SPEI)

The provided R script permits to calculate the SPI and SPEI over different time scales (1, 3, 6, 9, 12, 24 months) and to identify drought periods.



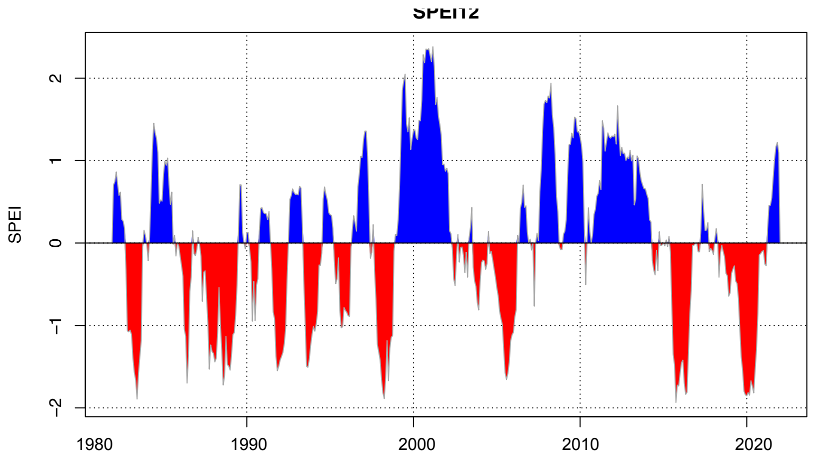


Figure 21:
Results of SPI and SPEI calculation using 12 months' time scale. Red areas indicate drought periods.

3. For Vegetation Health Index (VHI)

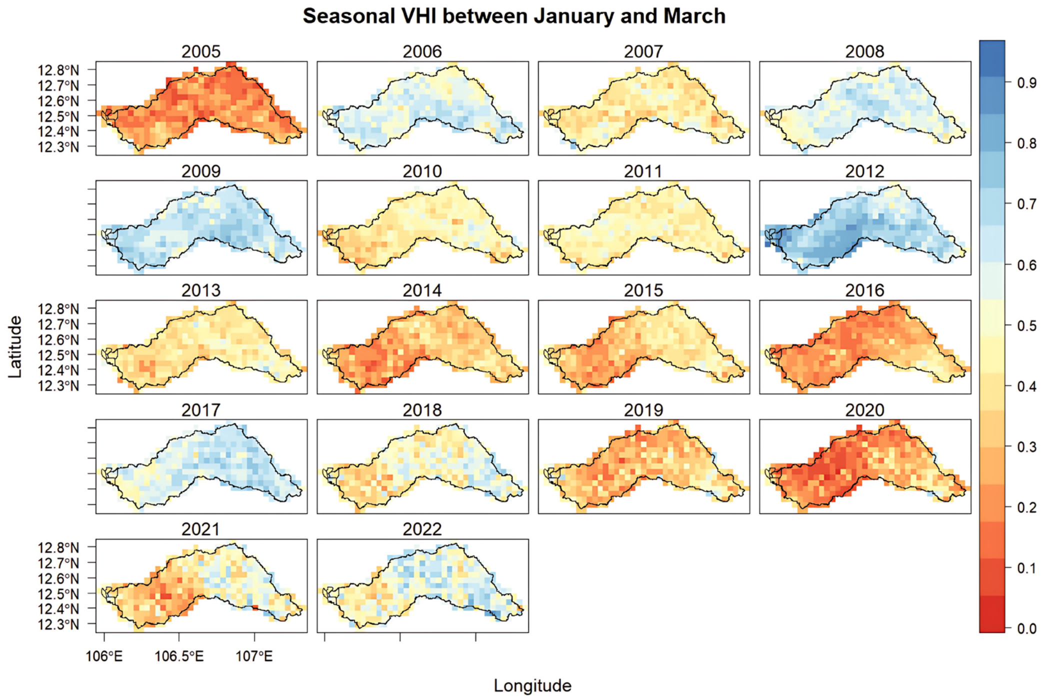


Figure 22:
Temporal distribution of VHI during the first quarter of the year between 2005-2022. Years with red coverage indicate agricultural drought periods.

Based on the results illustrated in Figure 16, the Prek Te watershed (and Kratie village) experienced during the first quarter of the year in 2005, 2019, and 2020 drought conditions.

Evaluating trends in precipitation extremes

In this section, we focus solely on R10 mm, one of the 13 calculated EPE indices, which showed a significant trend compared to the other indices in the Prek Te Watershed in Cambodia.

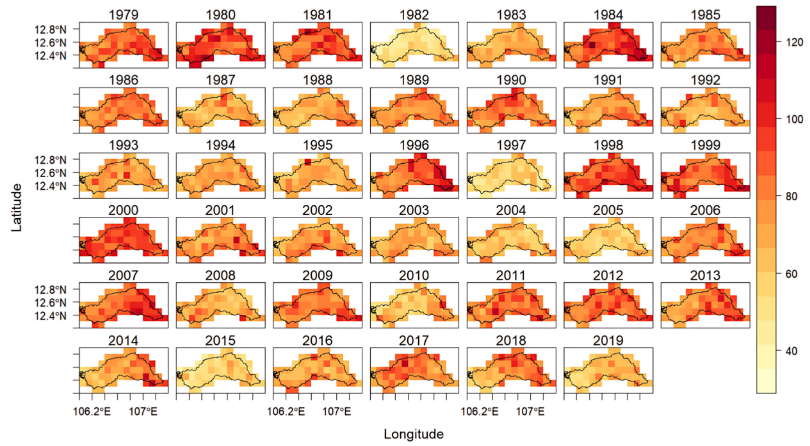


Figure 23:
Temporal variation of R10 mm in Prek Te watershed in Cambodia between 1979-2024. Years with darker colors had higher number of days where daily precipitation exceeded 10mm

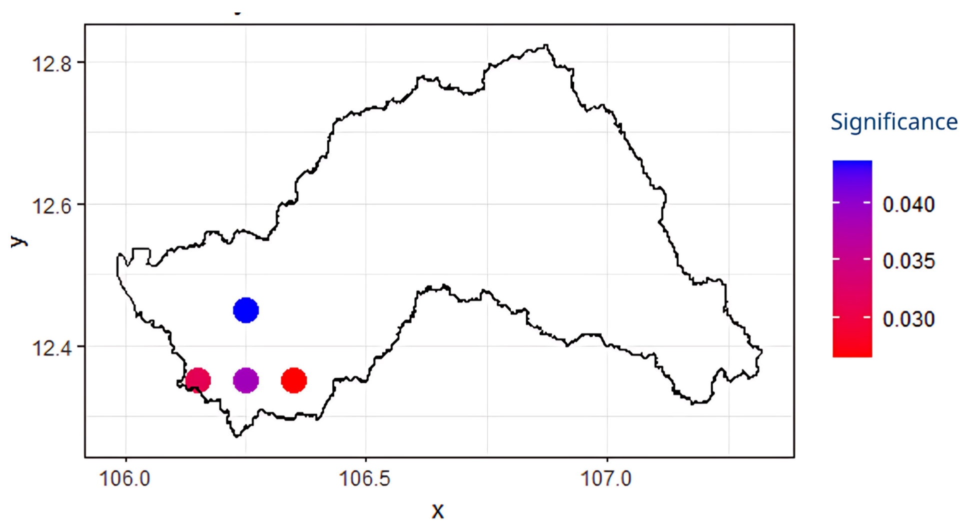


Figure 24:
Regions within the Prek Te watershed that show a significant trend in R10mm. A trend is considered significant if the p-value is below 0.05.

Flood Frequency analysis

The Table 7 summarizes the expected flood magnitudes (in meters) for various return periods (in years); and Figure 25presents the flood frequency curve for the Kratie station showing the alignement between the selected distribution and the recorded data.

Table 7: Return Periods and Associated Flood Heights.

Return_Period (Years)	Flood_Magnitude (m)
2	21.11
5	22.26
10	22.82
25	23.35
50	23.65
100	23.88

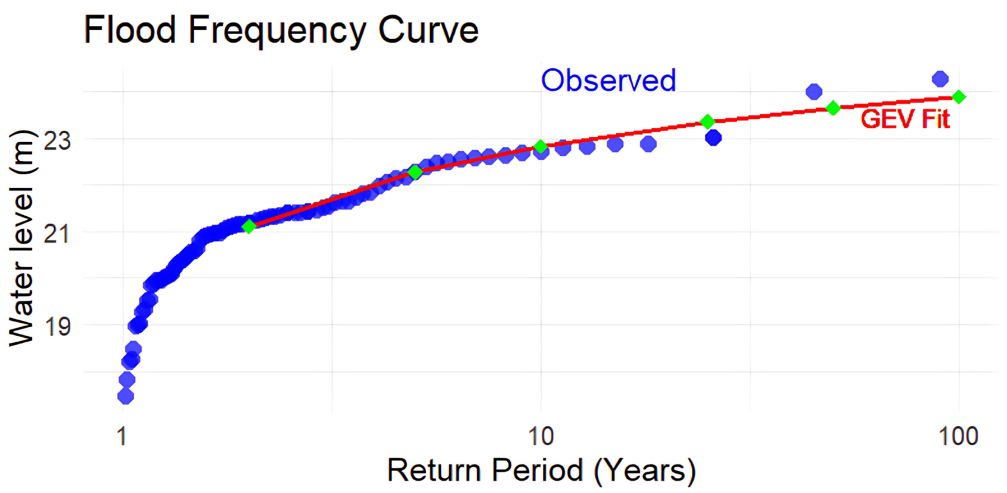


Figure 25: *Flood frequency curve of the Kratie station*

Analysis of Flood Frequency Analysis Results

The data indicates a clear trend in flood magnitudes as the return period increases. Notably:

- The flood magnitude for a 2-year return period is estimated at 21.11 meters, while the magnitude for a 100-year return period rises to 23.88 meters. This increase highlights the growing risk associated with less frequent, more severe flooding events.
- The increments in flood magnitude between shorter return periods (e.g., from 2 to 5 years) are more pronounced, suggesting that even slight increases in frequency can lead to significant changes in expected water levels.
- As the return period extends, the increments in flood magnitude become smaller, indicating a diminishing rate of change for more extreme events

Access to the tool

https://th-koeln.sciebo.de/s/pZGEHvJRJXlAleo

Further readings

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Tool 6: Drone Survey

Author: Frederic Hebbeker

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: Case specific • Activity Duration: 5 days	• Open • Close	• Basic • Medium • Advanced

The tool provides guidance to the application of multi-copter drones for scientific surveys, including site scoping, flight planning, flight implementation and post processing. The design addresses specifically technical staff from the urban planning & water resources sector tasked with the high-resolution analysis of land use, vegetation and topography to provide information for comprehensive water-sensitive urban planning.

What?	Drone surveys involve the use of UAVs (unmanned aerial vehicles) equipped with cameras and sensors to map out land surface to produce high resolution imagery of usable for analysis in urban planning. It provides cost-effective and flexible means for up to date data collection, compared to ground-surveys and satellite imagery, ideal for localized analysis.
Why? / Purpose	The tool provides guidance for entry-level application for new technical users to help navigate the diverse field of drone applications and select an appropriate workflow for the needs at hand to provide information about urban environments, in the absence of ground survey information. Complementary value exists specifically for satellite-based assessment on a small scale in suitable weather conditions.

Field of Application (Scale of Application)	Especially useful for building & neighbourhood scale, with relevance to water, land and infrastructure monitoring to identify buildings, vegetation corridors, topographic information and infrastructure. Provides valuable addition for urban planning and was tested in all focus areas of the three living labs in the PolyUrbanWaters project.
End users	Technical staff of urban planning and water resources management, Academia
Background	Drones are quickly becoming a state-of-the-art technology for the application in urban planning and monitoring throughout the industry. The quick development also led to a wide variety of options that can make it difficult for new users to navigate. During the PolyUrbanWaters project, partners and stakeholder have shown great interest in the application of drone surveys. This tool documents the simple recommendations and workflows for new users, based on the experience of the project.
Description	The tool describes the different stage of a drone survey, from initial scoping and definition of suitable objectives to flight planning, -implementation and post processing. This involves the use of satellite information, photogrammetry and GIS software to generate spatial information and spectral indicators important for localized urban planning information. In conjunction with the different steps are recommendations for applications involving minimal financial & skill levels to achieve basic objectives, while also introducing relevant information for safe operation & maintenance of drones.
Strengths and Limitations	**Strengths:** High resolution outputs, up to date information, flexible application **Limitations:** Weather dependency, applicable objectives tied to financial resources and existing skill level, complex to apply for larger areas

Requirements (Instruments used)	**Time:** Moderate to extensive, depending on implementation skill level and survey scale **Skills:** Understanding of operation & safety procedures, acquisition of local permits **Equipment:** Computer for scoping and post processing, drone of choice **Costs:** Moderate to high, depending on the objective
Keywords	Photogrammetry, Point Cloud, Digital Terrain Model, Digital Surface Model, Spectral indices

Tool Manual

This tool provides guiding workflow and recommendations for diverse technical and financial contexts, helping new users navigate the complexities of drone applications. It also emphasizes safe operation and maintenance, compliance with local regulations, and the acquisition of necessary permissions. With its focus on practical implementation, the tool serves as a bridge for entry-level applications in academia and professional sectors.

1. Objectives

- **Provide Comprehensive Workflow Guidance:**

Deliver step-by-step instructions for all stages of drone surveys, including site scoping, flight planning, execution, and data post-processing, depending on existing skill level & objectives.

- **Enable High-Resolution Spatial Analysis:**

Equip users with knowledge to generate precise information on land use, vegetation, and topography at the local scale, supporting water-sensitive urban planning efforts.

- **Promote Safe and Accessible Drone Usage:**

Offer practical advice on safe operation, maintenance, and compliance with local regulations, ensuring that drone technology is used effectively and responsibly.

2. Steps

The drone survey tool follows six general steps, with a variety of different sub-steps, depending on the skill level, available resources and chosen objective of the user. The elaborate version of the following description is documented in the Tool Manual.

Step 1: Scoping

During the scoping process, the user identifies an area of interest to conduct a drone survey in and gets familiar with the characteristics of the site. This includes administrative boundaries, land cover, topography, seasonal and permanent water bodies and the presence of any restrictive elements such as airports, military sites, religious sites, etc. Throughout the scoping process, a combination of satellite-based information as well as local inquiries are needed. As an outcome of the scoping process, the drone survey tool user should narrow down the general area of interest to a more specific location, with relevance to water-sensitive urban development, based on stakeholders' interest and relevance to the urban water cycle. Additionally, any limitations present at the site of interest are identified, and the foundation for the definition of the objective provided. It is important to note that the size of the survey area will largely influence the complexity of the tool application, as the amount of time spend on data collection and amount of data can grow very quickly, making post-processing and analysis time and/or resource-intensive. Therefore, especially for new users, it is crucial to determine the smallest area possible, recommendable not more than 75Ha per survey cycle.

Step 2: Definition of objective

There are several results that can be derived from a drone survey, depending on the available hardware (drone & computer) or skill level. The tool user may choose what is suitable for the intended purpose. It is important to note that in case any restricting elements were identified in the study site, flying may not be allowed at all, given local regulations. The following describes different outputs and the necessary resources for flight implementation and post-processing.

The most basic achievable result is commonly known aerial images, e.g. pictures, panoramas and videos taken by a drone. This can already be useful to show a site, non-scientific documentation or reporting, requiring only very minimal financial resources and skill level (safe operation).

Secondarily are the generation of orthomosaics, a high-resolution map of the survey site, that contains geographic referenced images (RGB) and can also be used to identify vegetation corridors or buildings with basic spectral indicators.

This can be useful for concrete mapping and provides measurable inputs to decisionmakers. It does require small financial resources (50-100€) for flight planning and post processing, while the required skill level is minimal (safe operation, basic understanding of mapping parameters).

Thirdly, in combination with the before mentioned are **advanced spectral & spatial analysis**, to f.e. determine vegetation health, generate digital surface and/or terrain models. This is especially useful for planning, modelling and monitoring of concrete measures in urban development, while however requiring more specialized drones and medium skill level (medium understanding of mapping parameters & basic post processing knowledge), while financial resources for flight planning and post-processing can be kept small (50-100€).

Lastly, a complex result that is addressed in the drone survey tool is **3D Analysis**. This can be turned into digital models of the study site, f.e. the generation of digital twins. It does however require a high skill level (high understanding of consecutive mapping & medium post processing knowledge). The required financial resources can range from small to medium.

The final definition of the objective for the drone survey is closely related to the conclusion of the scoping process, considering local needs, physical characteristics or restricting elements to determine the survey site (Where?). In the definition of objective (What?), the previous derived information should be combined with information about existing skill level and resources (Monetary & Time), to decide what the most useful result of the survey should be.

It is essential to discuss with decision makers how the derived output will be used in the planning process, to maximize efficient implementation. Generally speaking, if skill levels and resources are very small, aerial images or orthomosaics should be prioritized, as they can already yield results with this survey tool and a drone. With pre-existing skill levels and more resources, advanced analysis, recommendable in only small areas are feasible, f.e. to test the potential of drone surveys and integration into local planning processes.

With more advancing skills and already regular implementation of drone surveys, required resources will increase. These can be useful, especially for regular technical project planning and infrastructure monitoring, when the use of 3D Analysis becomes realistic. Ultimately, the user of this tool should inquire whether or not drone based information is already used in the urban area of interest, and together with the applicants own skill level, apply the most basic objective first and increase the complexity of the objective over time.

Step 3: Flight planning

Planning a drone flight involves the final identification of the survey site and creating respective boundaries with additional buffer for improved quality of the results. The boundary relates to the identified objective and can be designed based on administrative outlines, elevation features or interest in a specific ecosystem. Most objectives for drone survey involve flying a drone in automated mode, where the mission pattern will be planned before the field trip. Post-processing requirements, already need to be considered during the planning, as this involves mapping software with relevance to flight height, speed and image overlap to be programmed in an automatic flight software. Additional consideration should be given to the weather to avoid equipment overheating, rain or strong winds which are unsuitable conditions for flying a drone. Access points to start the survey mission must be defined, which should provide a clear view of the survey area and are best located as close as possible to the site. It is imperative that only ca. 65% of the available flight time per battery is planned for safe operation. To follow local requirements, it is further necessary to check legal requirements of operating a drone and obtain a permit or at least inform local authorities.

Safe operation and maintenance

General drone operation covers the controls described in Figure 26

Control	Effect
PITCH	Forward/reverse flight, tilting the copter about the **lateral axis.**
ROLL	Sideways flight, tilting the copter sideways around the **longitudinal axis.**
YAW	Speed change of the co-rotating motors, movement or rotation around the **vertical axis**
THROTTLE	Speed change of all motors, **altitude change, vertical movement / Speed**

Figure 26:
Control options for multi-copter drones.

For safe operation it is important the batteries are handled with care to circumvent the risk of explosion and provide longevity by avoiding extreme temperature, physical damage and moisture. Furthermore, a pilot should be positioned on the windward side of the drone, inspect an area before flying and maintain constant line of site. As a general guideline flying above 120m should be avoided, as well as flying over uninvolved persons, especially crowds. For safe operation software should be regularly updated, the compass calibrated, and pre-flight checklists followed.

Step 4: Flight implementation

The quality and difficulty of the flight itself is largely determined by the level of detail in previous flight planning. Generally, for mapping a flight height of 80m, with a 75-80% image overlap is recommendable, as well as a flight speed of 5m/s to avoid blurry images. It is important to guarantee constant internet connection between the drone and controller and ensure that the drone recognises the starting location as “Home”, as in case of unforeseen circumstances the drone will return to this location. Paying attention to the described safety measure is essential. Furthermore, the communication with uninvolved person passing the area, pre-flight checklist and equipment inspection is elaborated, together with important Dos and Don’ts during the flight, as well as data-transfer

Step 5: Post- processing

Post-processing involves the “stitching” of the individual collected images during the survey, based on common points between images and the generation of a “Point-cloud”. For general purposes, default options in the respective software should be sufficient, while more advanced analysis will require an adaptation of parameters, depending on the survey site characteristics.

The complexity varies with the chosen objective and size of survey area. If only aerial imagery was collected, no post-processing is necessary. Results can be exported in Raster format or JPEG format if no GIS integration is intended.

Photogrammetry

Depending on the intended outcome/result of the drone survey and skill levels of the user, different software solutions can be recommended. For users with non or very small resources/ experience, the simplest solutions are provided by GEONADIR (n.d), as this platform essentially handles the process without the need of the user to get involved. However, it should be noted that with a free of charge plan, the output will be publicly available. For users with already basic understanding and small resources, OpenDroneMap (Toffanin et al., 2023) provides an open source processing software, which can be run on a local computer (depending on available hardware). Or if large amounts of images need to be processed, it is very recommendable to use their cloud-based processing platform WebODM (Toffanin et al., 2023), if a good internet connection exists. Rather than generating all possible outputs, a selection in conjunction with the objective is recommendable. Generally, the default options for processing should yield sufficient results for orthomosaics, however, quality can be increased by raising minimum feature and pc quality parameters.

Cloud manipulation

Optionally allows post-processing if required and can be done using commercia-, but also open-source software. This is optional and can be applied for the improvement of Digital 2D or 3D Models. This is a general addition to the drone survey process, only recommended for users with experience, particularly when more complex 3D Analysis is the intended objective. Commercial software will provide good results for users that are new to this work, as generated point cloud can be directly edited within the software, targeted to the intended end use (f.e. removing of unwanted points). This is feasible if more resources, for software licensing exist. However, for users with more time available or skill level, open source software provides a suitable alternative, as there is large amount of education materials for self-learning available. The user can view and edit 3D Models, as well as conduct measurements or analyse features. Typical processes for cloud manipulation in post processing involve Cloud Filtering to improve Digital Terrain Models, point classification, Point-cloud comparison with many more depending on the users need. A wide variety of data formats can be used to produce mesh layers for the use in digital twins or visualizations, benefiting water sensitive urban planning.

Step 6: GIS integration and Data sharing

Results from post processing typically include exportable raster files, f.e. as orthomosaics, Digital Surface Models (DSM), Digital Terrain Models (DTM), as well as simple and advanced vegetation layers. These can be used in GIS Software for further analysis or map preparation, easily sharable, as it is the least data intensive. The benefits of Drone based DSM is that it caprovide high-resolution differences between individual structures, such as trees or buildings, as indicated in Figure 27.

- **Digital surface Model:** Captures both the environments natural and artificial features and can indicate, the remaining retention area, tree hights and structures in the surveyed area
- **Digital Terrain Model:** Captures the Ground surface of the surveyed area, without vegetation or structures. This can be useful especially for non-developed area to determine the natural flow of water and identify f.e. sites that are exposed to flood hazards within the survey area.

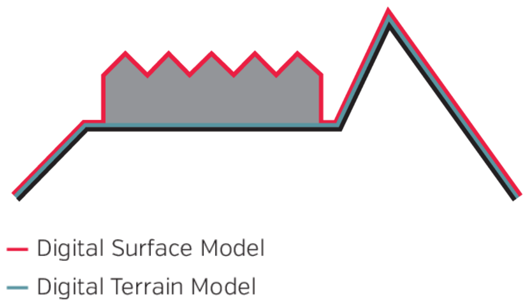

Figure 27:
Difference Digital Surface - and Terrain Model Source: (Marwaha & Duffy 2021)

Spectral vegetation Indices depend largely on the used sensors, data analysis is based on the individual bands of the raster file that correlate to the red-green-blue or more if additional sensors are used. For users with existing GIS experience, these can be done f.e. in QGIS, using the Raster calculator, or editing by masking, merging or other analysis to create results important for water sensitive urban planning. The interpretation links the output of the drone survey to a useful conclusion to be used in water-sensitive urban planning (What does the information mean?) and provide necessary context to the collected data, including related watersheds, local climate, soil or hazards. The communication & sharing of the analysis results is traditionally done in written documentation, such as reports & maps, but can also happen in different formats, such as videos, posters and more. Furthermore, cloud based processing based on WebODM can also share 2D and 3D results in an interactive form with links that allow each user of the information to investigate the results further on their own. Generally speaking, it should be checked which of the involved stakeholders have interest in what type of data, and shared accordingly, ranging from raw images, to post processing results or prepared maps and analysis.

Study case: Kratié - Cambodia

Step 1: Scoping

General areas of interest in Kratié were identified as the urban extension areas north and west of the adjoining lake , as well as the important water channel that runs through the town which can be identified based on the topographic and land cover baseline displayed in Figure 28. Additionally, ecosystems of high value east of the lake provide important water regulating functions. Season floods can be identified with Sentinel 1 satellite images, periodically over the past decade, specifically in the year 2018, with complex flood dynamics (see Figure 29) . Restricting elements were not identified.

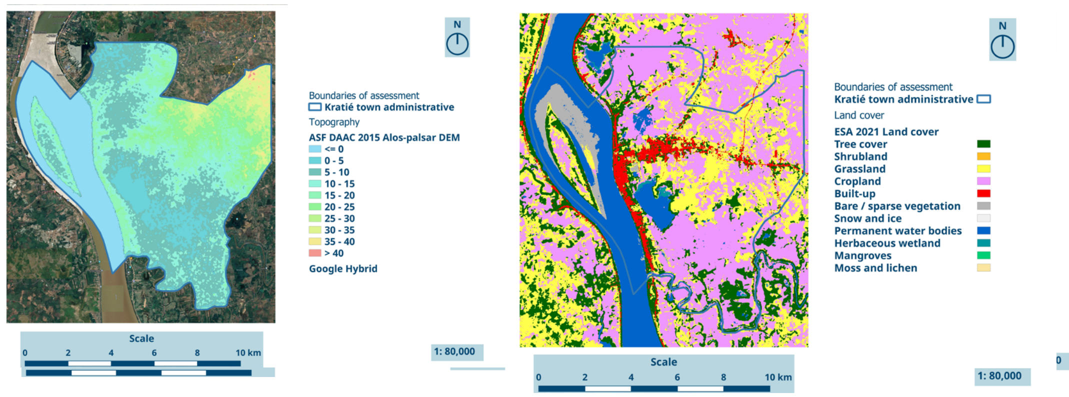

Figure 28:
Topography (left) & Landcover (right) in the riverine landscape around Kratié (own elaboration based on ASF DAAC 2015 and Zanaga et al., 2022)

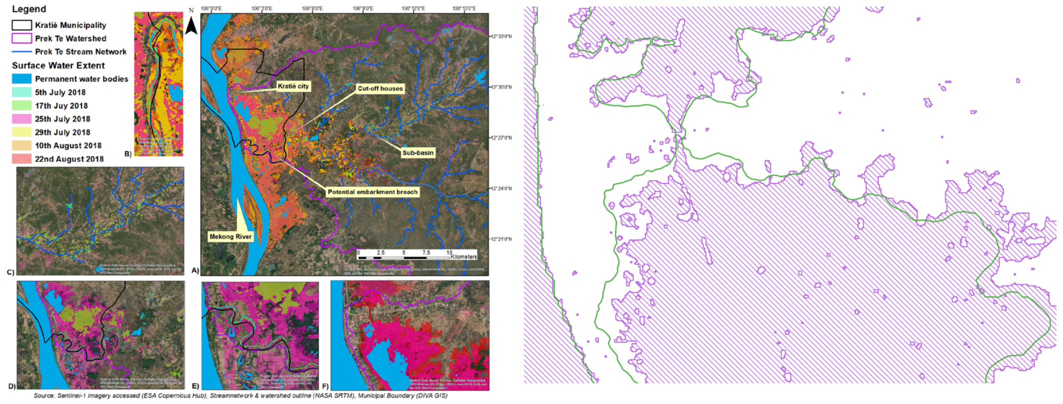

Figure 29:
Inundated area in the riverine landscape around Kratié and Comparison of an HQ 10 event with water level at the Mekong of 22.69m and an elevation contour line of 20m. Source: Own élaboration and Hebbeker et al, 2022

Step 2: Definition of objective

The identified Objective for Kratié are aerial imagery to inform specifically about areas difficult to access or oversee due to low topography. In addition, orthomosaics and simple vegetation indicators for the documentation of land use and flooding are feasible outputs of this work, using a combination of different drones.

Step 3: Flight planning

Flight planning consisted of two sets of survey missions during the dry and wet season to allow a comparison between land use and flooded areas. Due to the large area of interest, around 30 individual flight mission were planned (see Figure 30), using Drone harmony, as well as DJI flight mission planning software, in a lawn-mower pattern.

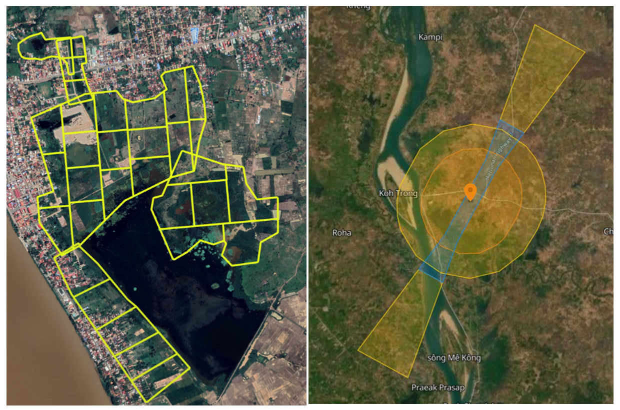

Figure 30:
Flight planning areas around Spen Sor, as well as north, west and east of Lake Mleach(left) and investigation of DJI Geozones(right)

All mapping areas of interest are subject to Warning zones (yellow) and Enhanced warning zones (orange) as there is an old airport in Kratié, however after consultation with local partners from ESC BORDA who provide the contact to the local authorities, this airport is no longer in use, but the zoning from DJI remains, but causes no flight restriction (see Figure 30). Parts are situated in an authorized zone (blue) need to be unlocked in advance through the DJI app or the Fly Safe portal from DJI.

Drone Regulation in Cambodia

On first inspections there are many websites & blogs informing about the usage of drones in Cambodia, however, firsthand information from the Cambodian government is not identifiable:

- No drone laws in Cambodia, exceptions are drone bans in Phnom Penh, Angkor Park and around historic temples, note of cautions (assume authorities will oppose), recommend contacting civil aviation authority, general rules of flight should be followed
- Allowed drone use, general rules of flight should be applied
- No codified drone use regulation, general rules of flight should be followed, implementation of international recommendations, permit for research flights
- Inter-ministerial working group push towards a sub-decree on Drone Management, regulating the registration, production and use of all drones, a formulation of sub-decree for the Ministry of Interior was drafted.

Outcome of review:

It can be concluded that with permission from local authorities and implementation of general drone flight rules, the fieldwork in Kratié can be conducted.

Acquisition of permit for drone flight in Kratié

Through the local Cambodian partners of the PolyUrbanWaters project ESC – BORDA, a written mission letter (prepared by ESC BORDA) with an attached schedule in khmer was submitted to the Deputy provincial governor. The plan was then approved and a permit issued by the Municipal Governor of Kratié town and responsibility assigned to the Department of Water resources and Meteorology. An introduction with the deputy director took place. This permission allows independent flight conduction and also publication. To allow for explanations during the field work, an activity letter from ESC-BORDA was provided and in case necessary, staff assigned for problem solving and explanation.

Step 4: Flight implementation

Flights were implemented in March and October 2023, informing local stakeholders, and a translated general permit sharing dates, intent and pilot, without additional support during the survey. It should be noted that Cambodia did not have any regulation regarding drones at the time. The collected images provided a detailed spatial outline of ecosystems within the extension area , such as Trees, ponds and wetlands within patches of subsistence agriculture & aquaculture (see Figure 31). The comparative flight in the wet season revealed detailed outlines of the floodplain relevance for a regular event, covering large parts of the areas to be developed, where as existing buildings were mostly outside of the water (see Figure 32).

Figure 31:
Aerial images from the flight during the dry season in March 2023

Figure 32:
Examples of aerial images from the wet season 2023

Step 5: Post- processing

WebODM was used to process the results, producing the following outputs for the two individual surveys:

1. **Dry season(march):** 12 fast orthomosaics, 5 orthophotos & point clouds; 5 DSM, 5 Green Leaf Indicator - no point cloud manipulation
2. **Wet season (October):** 11 Orthomosaic & point clouds; 7 DSM; 9 Green Leaf indicator, - no point cloud manipulation

Step 6: GIS integration and Data sharing

Generated data was used to identify areas of development as well as potential evaluation, using Simple vegetation indicators. Aerial imagery and Panoramas were made available, the results were shared with the partner organizations, in addition to raw imagery of the first flight during March 2023 with the responsible department, however, no interest was mentioned during the second survey. The following images represent the baseline as of early March 2023 and can be used for further environmental monitoring, important water body buffer zones, land use planning or urban planning.

Results from the post processing of flight 1 march 2023:

Figure 33:
Hydrological important channel „White bridge" Spen Sor

This area was chosen for drone mapping due to its important function, linking natural retention basins in Kratié north and south (see Figure 28). Identifiable are reduced flow capacities due to land filling activities both west and east of the channel can be observed, as well as individual ponds and wetland vegetation (see Figure 33).

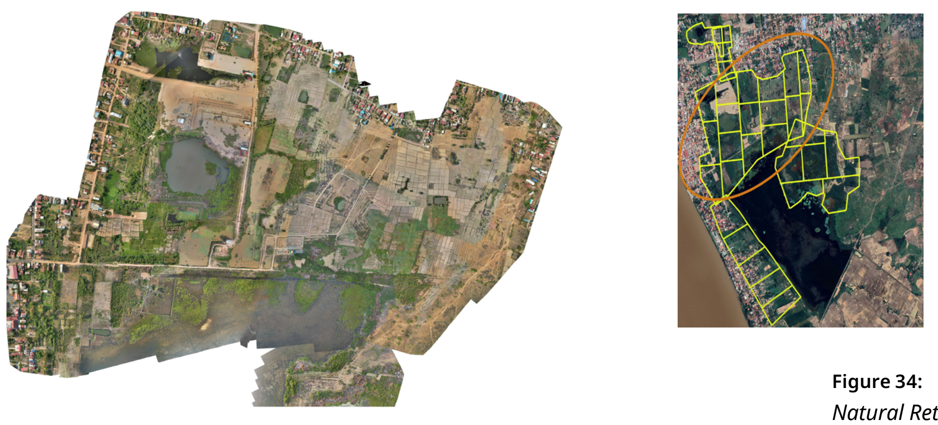

Figure 34:
Natural Retention area north of Lake Mleach

North of Lake Mleach was chosen for drone mapping due to its important function to act as natural retention area during flooding and the active urban development dynamics that are changing the land use rapidly. The imagery document urban development activities and the continuous reduction of water retention capacities, especially in western part of this area, while in the east agricultural land use dominates. Along the lake shore, wetland ecosystems can be identified (see Figure 34).

Figure 35:
Ecological valuable area (Wetland)

The area east of the lake was chosen for drone mapping due the presence of dense wetland vegetation that has multiple important ecological functions. Based on the imagery, the use of this area through local people and loss of vegetation through burning, animal grazing and other activities can be observed, framing the active use of this ecosystms by locals, while encroaching on this vital ecosystem (see Figure 35).

Figure 36:
Flood prone lakefront

The western lakeshore was chosen for drone mapping with potential development interests within natural retention boundaries of the Lake and a current settlement dynamic of poorer households. Based on the imagery, the area especially between the houses and the lakefront are used by local people for subsistence agriculture or grazing. But also a few cases of development (constructions) can be observed. As part of these processes, loss of vegetation and natural retention space can be identified, however, more green spaces are intertwined in the settlement (see Figure 36), in contrast to the central town.

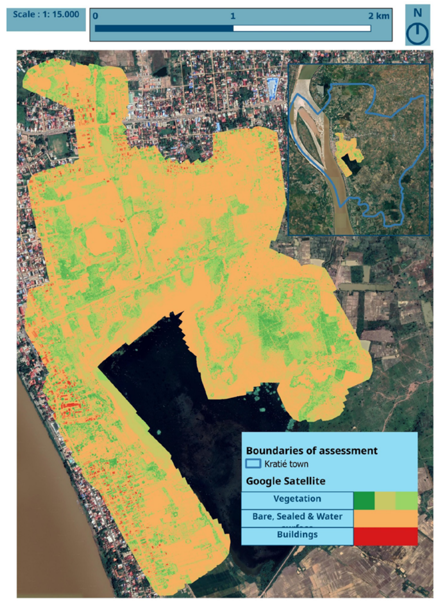

Figure 37:
GLI spectral indicator showing existing vegetation corridors in the survey area.

Figure 38:
Results from the flight in the wet season October 2023

The drone surveys around the important Lake Mleach document a number of important vegetation corridors by using a simple spectral indicator (see Figure 37), combining wetlands, trees and shrubs which are important elements to include into water sensitive development, as they are seasonally flooded and provide important buffers, which however are threatened by land reclamation (between 2 and 5 meters) as part of semi urban settlement dynamics (see Figure 38). Furthermore, a lot of area is under use for animal husbandry (Grass and Shrublands), small scale agricultural activities (Rice fields, Gardens, Plantations) and aquaculture (Ponds & Lake itself) during the dry season, providing important water storage. Existing vegetation corridors, ponds and pockets of wetland provide an opportunity for sustainable development, however these valuable ecosystems around the lake are encroached by cultivated land, wetlands being cleared systematically. This reduction of flood retention and water storage capacity, also decreases cooling effects, water purification potential, biodiversity, and attractiveness, while increasing the speed of the lake's degradation and loss of its natural benefits to the people of Kratié. This type of development is common in southeast Asia when urban development occurs within Floodplains and has been document in particular in Phnom Penh. The western part of lake Mleach exemplifies opportunities where gardens and plantations mix very heterogenous with semi-urban settlement, which provides a great opportunity if preserved. In the upcoming development in Kratié a decisive question will be how green, and blue spaces will be integrated into the urbanizing areas. Raw as well as processed data and aerial images were shared with the respective stakeholders to support further vision building processes.

Access to the tool

https://th-koeln.sciebo.de/s/Y7WjZmtZpOqgHIC

Further readings

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GEONADIR (n.d) Turn drone mapping data into insights - Create insights on the environments and sites that matter to you. https://geonadir.com/

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3. *Vision Building Tools*

ITT Institute for Natural Resources Technology and Management

Faculty of Spatial Development and Infrastructure Systems

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POLYURBAN WATERS

Tool 1: Compendium of Nature-based Solutions for Water Resources Management: Urban and Peri-urban Areas of Southeast Asia

Authors: Xhesika Hoxha, Zahraa Salem Aswad Alobaidy, Juan David Mercado Leal, Bisma Setyadi

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 2 hours • Activity Duration: 4–6 hours	• Open • Close	• Basic • Medium • Advanced

The tool identifies a set of NbSs tailored for secondary and tertiary cities in the SEA region, enabling the stakeholders and decision-makers to make the best selection of suitable options based on specific criteria and challenges.

What?	A collection of 36 NbS especially designed for Secondary and Tertiary Cities in the SEA Region, combined by a framework outlining the suitable procedure for the selection of measures based on several criteria.
Why? / Purpose	This tool supports the identification of suitable locations and the determination of appropriate implementation scales based on context-specific challenges for Nature-based Solutions (NbS) in secondary and tertiary cities within the Southeast Asia (SEA) region. It aims to optimise the spatial distribution of NbS to maximise benefits and minimise potential maladaptation.
Field of Application (Scale of Application)	**Scale of application:** Secondary and tertiary cities in the SEA Region. **Examples:** Identifying suitable areas for urban green spaces.
End users	Academics, NGOs, Urban planners, local stakeholders.

Background	Developed in response to the increasing emphasis on targeted and effective implementation of NbS. Adapted for the SEA region by working with local people, considering regional environmental challenges, scale and type of actions, and incorporating lessons learned from previous baseline assessment tools.
Description	The compendium is organized into four sections. Starting from the conceptualization, challenges& solutions identifications, NbS catalogue structure and ending with the list of NbSs with two distinctive profiles (Descriptive & Visual).
Strengths and Limitations	**Strengths:** Adapted solutions, well contextual fit solutions, address the trade-offs **Limitations:** Language barrier, potential conflicts with existing infrastructure, and different community preferences.
Requirements (Instruments used)	**Time:** Varies according to project size. **Skills:** Graphical and visual literacy. **Equipment:** Computer/ Tablets to access the digital compendium.
Keywords	Nature-based solutions (NbS), Ecosystem Services (ESs), Secondary and Tertiary Cities, Type of Action, Conservation, Restoration, Installation

Tool Manual

This tool is composed of three components, each targeting a distinct yet complementary aspect of Nature-based Solutions (NbS) to promote an informative and engaging approach (Hoxha et al,. 2025):

1. **First component 'Compendium':** This component provides detailed summaries and a collection of enriched, quantifiable metrics. It delivers comprehensive data that facilitates an in-depth understanding of NbS.

2. **Second Component 'Stricker symbology '**: Acting in a supporting role, this component focuses on knowledge conveyance through symbology. Key aspects of NbS are represented visually with symbols, making complex information more accessible and intuitive.

3. **Third Component 'Cards':** Taking an interactive approach, this component combines the symbols from the second component with the data from the first component to create hand-held cards. These cards gamify the process of raising awareness and familiarizing stakeholders with various solutions tailored to different challenges.

Component One: The Compendium

The Compendium serves as a comprehensive compendium of Nature-based Solutions (NbS) that are vital for enhancing water-sensitive structures and combating environmental changes. It provides a framework to address a spectrum of social, economic, and environmental challenges by offering essential ecosystem services. The compendium defines categories and features to better describe problems, propose solutions (NbS), and outline how these solutions will achieve their targets through ecosystem services. This method streamlines information flow, enabling the selection of optimal solutions for specific problems.

To present this information concisely, the compendium employs an integrated approach, combining visual, mathematical, and textual methods. Each NbS may have distinct information that others do not, making an unstructured combination of data neither practical nor reader friendly. To address this, the compendium organizes information by listing NbS and evaluating their capabilities against various challenges and ecosystem services. This approach introduces a quantifiable assessment of each NbS strengths and limitations, supplemented by standardized evaluation data on how the NbS delivers its ecosystem services.

In this context, the Compendium offers visual representations, such as radar charts, to assess the implementation and performance phases of each NbS. These charts allow readers to easily evaluate how well a particular NbS performs across different criteria, facilitating comparisons and aiding in the selection of the most suitable solution(s). However, recognizing that the selection process may not always be definitive, the compendium includes three visual similarity matrices. These matrices quantify the similarities between NbSs based on shared ecosystem services, scales of action, and addressed challenges. This allows readers to explore alternative NbSs if a clear decision cannot be made using the radar charts.

Once suitable NbS are identified, the Compendium provides concise, templated textual descriptions of each solution, complemented by visual illustrations and real-life photographs. These elements ensure that all aspects of the NbS are covered.

Overall, the Compendium provides comprehensive information on challenges, ecosystem services, and global standards relevant to NbS while maintaining comparability using both conventional metrics and novel calculated metrics presented in visual and tabular formats.

This compendium is designed for two primary audiences, positioned at opposite ends of the spectrum. The first group includes readers and academics seeking to familiarize themselves with the concept of NbSs or delve deeper into the details of assessment and recommendations as subject matter experts. The second group comprises stakeholders directly or indirectly affected by climate-related issues, who play an influential role in decision-making for NbS projects.

Component Two: Sticker symbology

Different symbols were used in the shape of stickers for a better understanding of the current challenges and make it more attractive and engaging. Stickers help also make complex information more accessible and intuitive. The used symbols are shown below

Type of Action

Type of Scale

Challenges

Ecosystem Services

Component Three: The Cards

The other component of this tool is the set of cards, which draw their information from the compendium. These cards can also serve as a resource during capacity-building sessions, particularly for supporting gamification activities.

The front side of the card includes the name of the NbS and a corresponding photograph, as illustrated in Figure 39. The back side of the card presents the type of action and NbS category. Below, a detailed schematic is provided to illustrate the specific aspects of the NbS. Additionally, the challenges tackled by the NbS and the type of scale are presented. Furthermore, a concise description is also included to provide an overview of the NbS. This page also contains other aspects such as the required budget to implement the NbS, required maintenance, and the effective time until the NbS positive effect on the ecosystem is realized. An example layout of the second page of the card is illustrated in Figure 40.

Figure 39:
Front side of a card

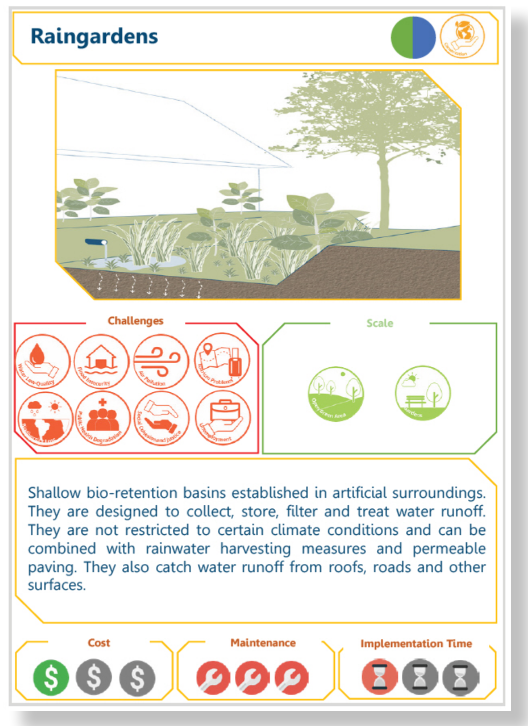

Figure 40:
Back side of a card

Study case

In June 2022, the Compendium 'Nature-based Solutions for Water Resources Management: Urban and Peri-urban Areas of Southeast Asia' was used for the first time in a multi-stakeholder workshop in Sariharjo to develop the water-sensitive scenario. The process began with a "Business as Usual Scenario" session to identify critical issues such as urban development trends, economic opportunities, and challenges in water management. This was followed by a "Water-Sensitive Scenario" session, where participants from 16 sub-villages collaborated to design visions for their areas using features like trees, permeable surfaces, and riparian buffers. These discussions emphasized the interconnected nature of interventions and highlighted the need for a systemic approach.

Figure 41:
Multi-stakeholders Interactive Workshop in Sariharjo, Indonesia. Source: TUB and THK 2022

With anticipated population growth and land changes, participants suggested measures like rainwater harvesting, porous paving, infiltration wells, and urban forests to address flooding, manage water runoff, and improve air quality. Given spatial constraints, they adopted solutions such as terracing and infiltration techniques suited to peri-urban areas. Additional ideas included installing rain gardens in residential complexes and forming partnerships with investors to collect rainwater, thereby reducing dependence on groundwater. Together, these strategies showcase a comprehensive and collaborative effort toward sustainable urban water management.

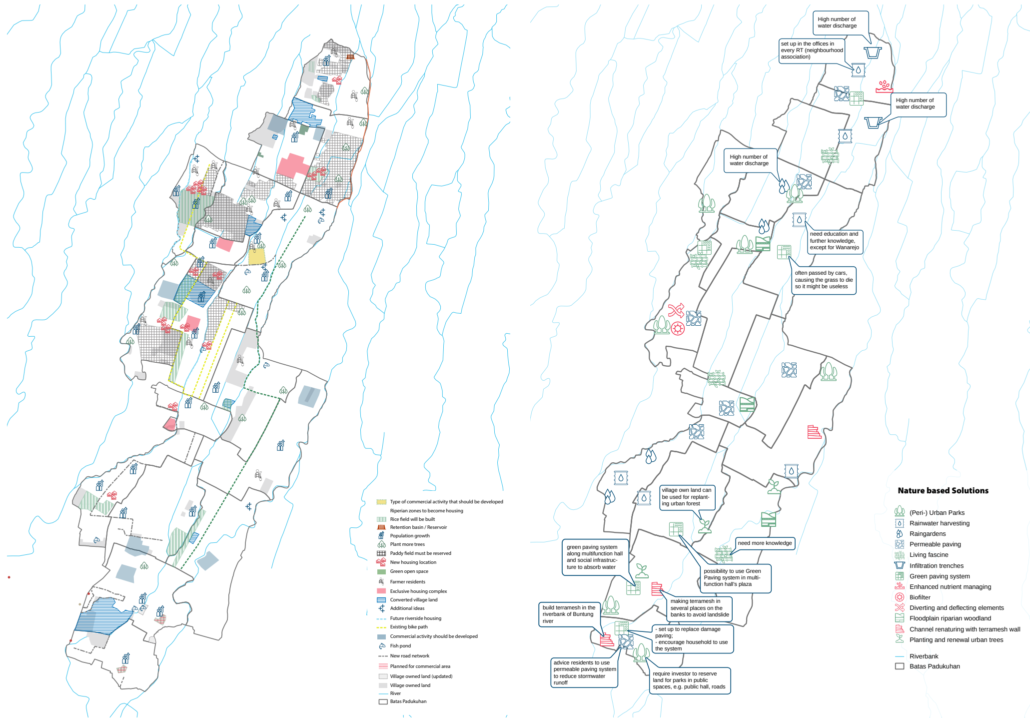

Figure 42:
Digitalized outcomes from manual mapping of 'business as usual' and 'water-sensitive' scenarios in Sariharjo, Indonesia. Source: HU-TUB and F12-THK, 2022

Access to the tool

https://epb.bibl.th-koeln.de/frontdoor/index/index/docId/2997

Further readings

Croeser, T., Garrard, G., Sharma, R., Ossola, A., & Bekessy, S. (2021). Choosing the right nature-based solutions to meet diverse urban challenges. Urban Forestry & Urban Greening, 65, 127337. https://doi.org/10.1016/j.ufug.2021.127337

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World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. Washington, D.C. World Bank Group

Tool 2: Selection and Assessment of Potential Nature-based Solutions (NbS)

Authors: Xhesika Hoxha, Zahraa Salem Aswad Alobaidy, Juan David Mercado Leal

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• **Urban Management** • **Water Management**	• **National** • **Regional** • **Municipal**	• Preparation Time: **1–2 hours** • Activity Duration: **2–4 hours**	• **Open** • Close	• Basic • **Medium** • **Advanced**

Description: This tool helps decision makers to optimise the choice of NbS based on criteria and needs. It is designed to provide a unified visual sketch that illustrates the rating of several aspects of each NbS, allowing for comparisons and benchmarks according to users' requirements.

What?	Selection and Assessment of Potential NbS for Secondary and Tertiary Cities in the SEA Region
Why? / Purpose	This tool is designed to assist decision-makers in selecting and assessing potential nature-based solutions (NbS) for implementation in secondary and tertiary cities in the SEA region. It aims to optimise the choice of NbS based on local conditions and needs.
Field of Application (Scale of Application)	**Scale of application:** Secondary and Tertiary cities in the SEA Region. **Examples:** Identifying suitable areas for urban green spaces.
End users	Academics, NGOs, Urban planners

Background	Developed in response to the growing need for sustainable urban development in SEA cities, influenced by global trends in NbS. The tools is adapted for the SEA region by working with local and indigenous people, taking into account local and regional environmental challenges, social particularities, and Economics needs.
Description	The tool involves a systematic approach to select NbS sites and determine the appropriate scale. It considers factors such as land use, hydrology and social dynamics to identify optimal locations. The aim is to ensure that NbS integration enhances urban resilience and sustainability.
Strengths and Limitations	**Strengths:** A straightforward process, saving time, and ability to compare different options (NbSs) in one frame. **Weaknesses:** unable to add more NbSs into the tool.
Requirements (Instruments used)	**Time:** Dependent on the complexity of the assessment. **Skills:** Graphical and visual literacy. **Equipment:** Computers/Tablets for making selection by the Excel sheets
Keywords	Nature-based solutions (NbS), Ecosystem Services (ESs), Secondary and Tertiary Cities, Type of Action, Conservation, Restoration, Installation

Tool Manual

NbS Selection Tool

This tool is built based on the NbS compendium, where it holds the NbS addressed challenges and scale of Action. Thus, from this data, the versatility, scalability, and Major Challenges categories are derived. However, this mixture of tabular and visual data will clutter the tool. Thus, the tabs are coloured into dark green, green, and yellow, where dark green represents the interactive tool, green represents the tabular data, and the yellow represents the references and metadata.

The structure of the tool will be as follows:

Step 1: Interactive Section

This section will hold the interactive tool where the user can nominate one or many suitable NbS based on his selection criterion. The instructions on how to operate the tool are elaborated below.

The selection can be done bi-directionally to navigate through different scenarios while opting for the best NbS(s) for a certain challenge/ type of scale.

However, to reset the selections for both NbS to scale mapping and NbS to challenge mapping, the funnel symbol above each column can be used to delete all the selections and start the process over again.

- **NbS to Scale Mapping**

When we have a predefined scale of a new project, and we want to know which NbS follows those predefined criteria:

1. Choose the NbS type and/or scale à will filter the NbS which are connected with the chosen NbS type and/or scale and remove some unavailable items from the list, as shown in Figure 43 (first scenario).
2. The step in section A can be applied in the opposite direction (second scenario). For example, it is possible to start from NbS list to investigate the type of scale where this NbS can be applied in, in addition to the NbS type, as shown in Figure 44.

Figure 43:
NbS Mapping according to the type of scale (first scenario)

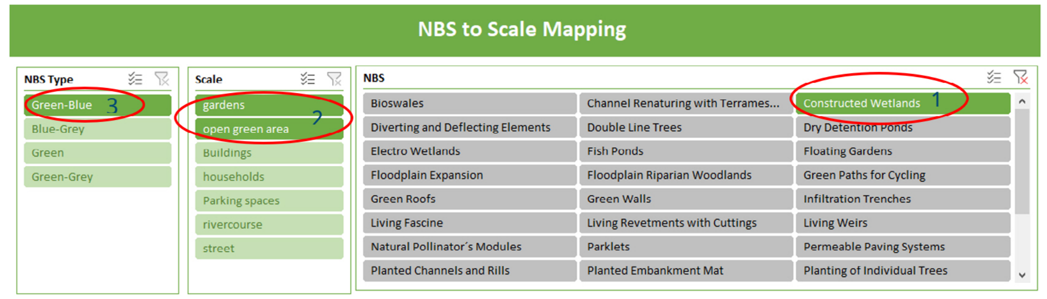

Figure 44 :
NbS Mapping according to the type of scale (second scenario)

- **NbS to Challenge Mapping**

When we have a predefined challenge of a new project, and we want to know which NbS follows those predefined criteria:

1. Choose the **challenge** and/or sub-**challenge** → will filter the NbS that are connected with the chosen **Challenge** and/or **sub-challenge** and remove some unavailable items from the list, as shown in Figure 45 (first scenario).
2. The step in section A can be applied in the opposite direction (second scenario). For example, it is possible to start from NbS lists to investigate the sub-challenge where this NbS can tackle, in addition to the challenge (Economic, environmental, or social), as shown in Figure 46.

Figure 45

NbS mapping according to challenges (first scenario)

Figure 46

NbS mapping according to challenges (second scenario)

Step 2: Tabular Sections

This section holds the tabular information that is powering the interactive tool that is also used in the NbS compendium. It is recommended not to add/delete any element from the tables.

- **Selection of Challenges**

This sheet consists of different columns which are illustrated in Figure 47. The sheet also holds the binary data, where 1 is replaced by a green-filled circle indicating to the ability of NbS to tackle a challenge, and 0 is replaced by a red-filled circle, indicating to inability of NbS to tackle the challenge, as shown in Figure 47.

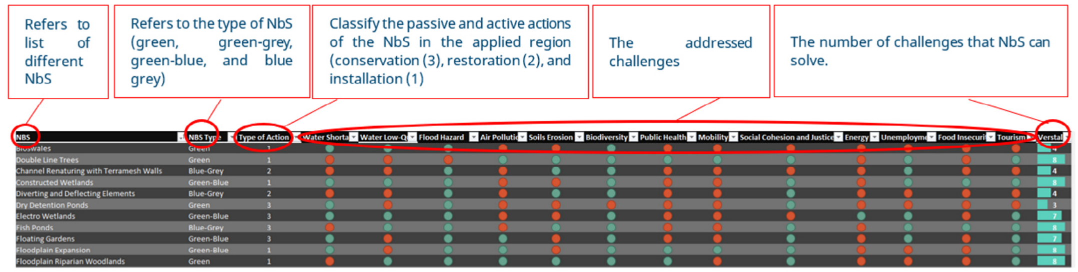

Figure 47

NbS addressed challenge matrix

- **Selection of Type of Scale**

This sheet consists of different columns which are illustrated in Figure 48. The sheet also holds the binary data, where 1 is replaced by a green-filled circle indicating to the applicability of NbS to be implemented in a specific scale, and 0 is replaced by a red-filled circle, indicating to inapplicability of NbS to be implemented in a specific scale, as shown in Figure 48.

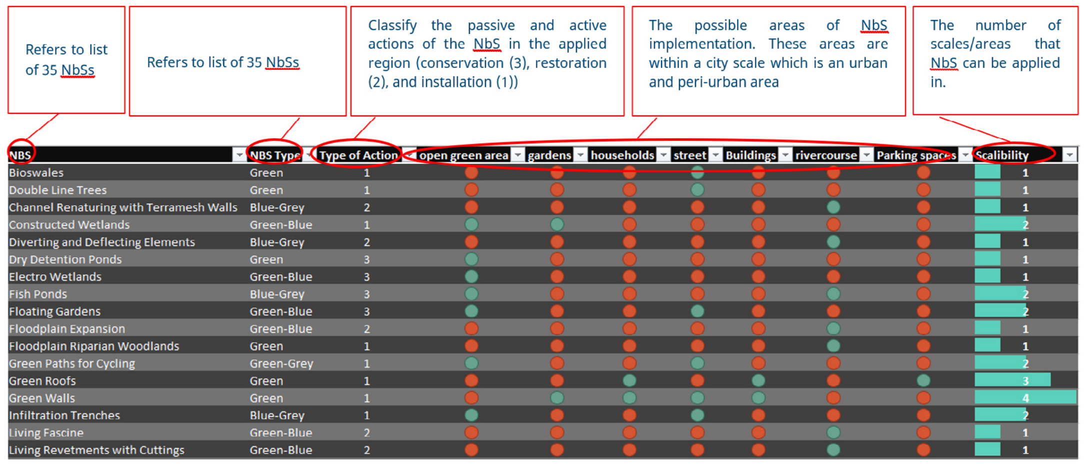

Figure 48:

NbS addressed type of scale matrix

Step 3: Reference Section

This section holds the metadata and descriptive information about the usage of the tool and definitions of the terminology used.

- **A.2 NbS Assessment Tool**

This tool gives the reader the ability to access the raw and calculated data that were used to generate the radar charts for each NbS, with the ability to multi-select NbS for a quick comparison. The tool is also partitioned into two tabs, where the green tab represents the interactive radar charts dashboard with a selection filter that allows multi-select. While the red tab holds the raw assessment data.

In the dashboard tab, one filter selection filter is used to give the user the ability to select one or many NbS to showcase the selected NbS performance and Implementation power, as shown in Figure 49. The radar chart has three values (1, 2, and 3), and in both charts and for all the KPIs used, 1 represents a bad rating, while 3 represents a perfect rating. Additionally, the rating is discrete where no fractions were used. These design choices were made to ensure interpretability, and relativity to other NbS & KPIs and context.

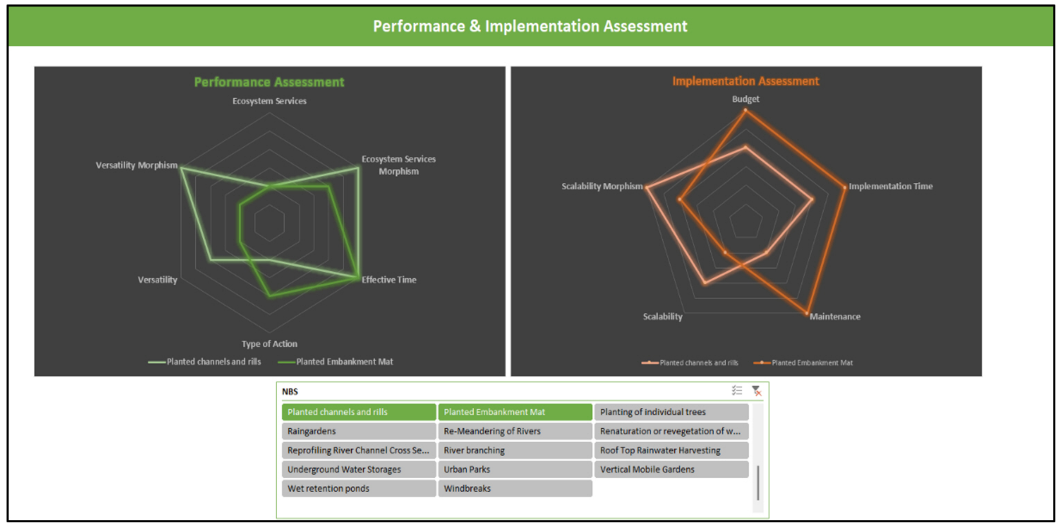

Figure 49:
Performance & implementation assessment for a selected subset of NbSs

Study case

For our first pilot case, we engaged with stakeholders in the Sleman area of Indonesia. The stakeholders were facing a water shortage challenge and expressed a preference for implementing a solution at the household level, specifically using blue-gray NbS. Using the tool 'Selection and Assessment of Potential Nature-based Solutions' with these preferences, the recommended NbS was identified as "Rooftop Rainwater Harvesting" as shown in Figure 50.

To further support the stakeholders, we presented the key performance and implementation metrics visually through radar charts generated using the same tool. This approach effectively conveyed the expected outcomes of implementing the selected NbS, ensuring clarity and informed decision-making.

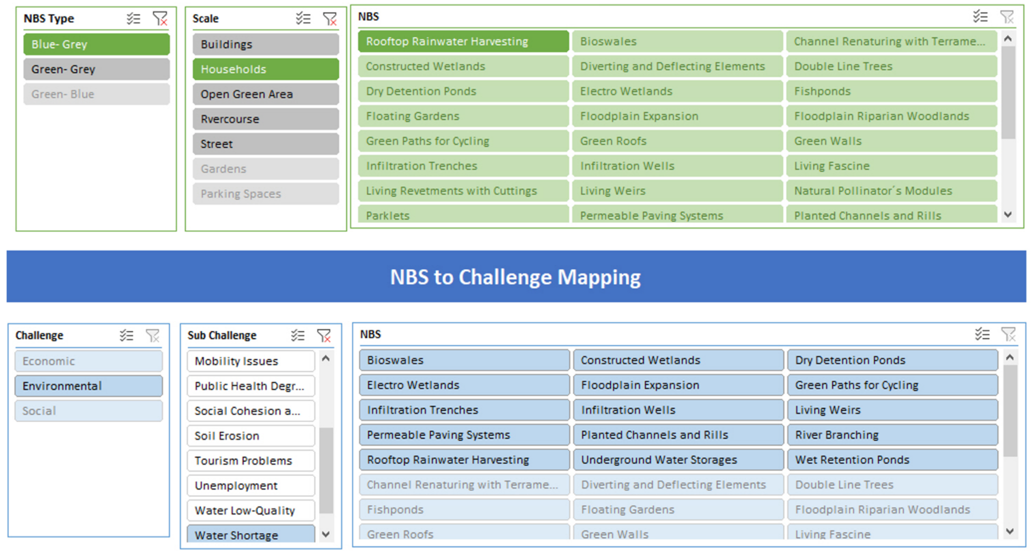

Figure 50:
Selection of NbS according to the stakeholders' preference

Access to the tool

https://th-koeln.sciebo.de/s/eeKMILZLCkXuKuv

Further readings

Voskamp, I. M., de Luca, C., Polo-Ballinas, M. B., Hulsman, H., & Brolsma, R. (2021). Nature-Based Solutions Tools for Planning Urban Climate Adaptation: State of the Art. Sustainability, 13(11), 6381. https://doi.org/10.3390/su13116381

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Brom, P., Engemann, K., Breed, C., Pasgaard, M., Onaolapo, T., & Svenning, J. -C. (2023). A Decision Support Tool for Green Infrastructure Planning in the Face of Rapid Urbanization. Land, 12(2), 415. https://doi.org/10.3390/land12020415

Croeser, T., Garrard, G., Sharma, R., Ossola, A., & Bekessy, S. (2021). Choosing the right nature-based solutions to meet diverse urban challenges. Urban Forestry & Urban Greening, 65, 127337. https://doi.org/10.1016/j.ufug.2021.127337

Nesticò, A., Passaro, R., Maselli, G., Somma, P. (2022). Multi-criteria methods for the optimal localization of urban green areas. Journal of Cleaner Production 374.

Tool 3: Assessment of Impact and Effectiveness of Selected NbS

Authors: Juan David Mercado Leal, Xhesika Hoxha

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• **Urban Management** • **Water Management**	• **National** • **Regional** • **Municipal**	• Preparation Time: **2 hours** • Activity Duration: **8 hours**	• **Open** • Close	• Basic • Medium • **Advanced**

This framework serves as a valuable resource for practitioners, policymakers, and researchers involved in the planning, implementation, and evaluation of NbS in urban areas, aiming to enhance urban resilience, sustainability, and quality of life through informed decision-making and strategic NbS implementation. The framework includes the principles guiding NbS performance, the process of developing a monitoring and evaluation strategy, the indicators used to measure NbS performance and impact, and the data requirements for a comprehensive assessment.

What?	Framework for assessing the impact of Nature-Based Solutions (NBS) on (peri)-urban environments.
Why? / Purpose	The purpose of this framework is to provide a systematic approach to evaluate the effectiveness of NBS interventions in enhancing urban sustainability, resilience, and quality of life. It aims to guide practitioners, policymakers, and researchers in measuring the outcomes of NBS projects, thereby facilitating informed decision-making and policy development.

Field of Application (Scale of Application)	The framework is applicable at various scales, ranging from neighbourhood or district levels to city-wide implementations. It is designed to assess the impact of NBS across diverse urban contexts, including green space management, biodiversity enhancement, social justice, economic development, health and well-being.
Historical Overview	The framework it is grounded in the growing recognition that integrating nature into urban planning and development is important. This approach has gained momentum as cities seek sustainable solutions to address environmental challenges, improve public health, and enhance social cohesion.
Description	Data collection methods vary across indicators and include both quantitative and qualitative approaches such as surveys, interviews, participant observation, and spatial analysis using Geographic Information Systems (GIS). The document outlines specific procedures for measuring each indicator, including the scale of measurement, data sources, and frequency of data collection.
Strengths and Limitations	**Strengths:** Comprehensive and multidisciplinary approach to evaluate NBS, applicability across different urban contexts, and potential to inform policy and practice. **Limitations:** Need for extensive data collection, the complexity of measuring certain indicators, and the requirement for expertise in various fields.
Requirements (Instruments used)	Various instruments and tools for data collection, including scale inventories, questionnaires, GIS software, besides tools to measure physical activity
Keywords	Nature-based solutions (NbS), Indicators, Theory of Change, Monitoring and Evaluation.

Tool Manual

The systematic iterative framework provides essential standards for creating effective monitoring and evaluation plans for Nature-Based Solutions. It utilizes a four-step methodology that starts with theory of change development and moves through the design of results chains and selecting questions, evaluation definitions and indicators, followed by the determination of data collection method to facilitate optimal NbS initiative planning and tracking. The Figure 51 demonstrates the iterative method of Theory of Change construction as well as the interrelation between outcomes definition and impact specification.

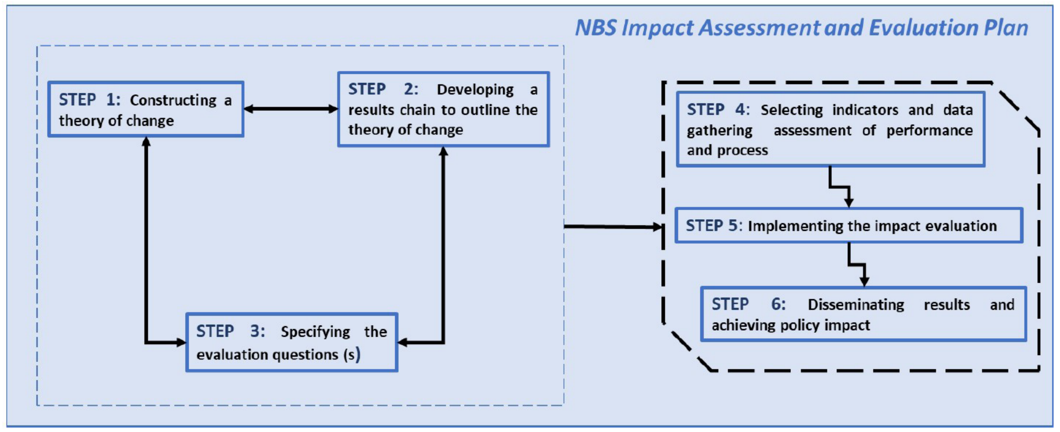

Figure 51.
Summary of steps for developing NbS impacts and evaluation plan
Source: Modified from (European Commission, 2021)

Step 1: Constructing the Theory of Change

Any local area should start with a Theory of Change development for matching urban challenges to NbS interventions and city specific strategic goals. The first step is to establish a proper baseline of the area, where key challenges need to be defined based on rigorous assessments - especially those referenced in the “Compendium of Nature-based Solutions for Water Resources Management: Urban and Peri-urban Areas of Southeast Asia”. Planners should use system-based challenge identification (such as flooding and water pollution together with green space deficiencies) to establish clear goals and their required implementation steps. This process clarifies how planned interventions will address the identified problems and what outcomes can be expected in the short and long term:

Structured Reflection on Context Challenges and Objectives

- Align baseline assessments and local challenges (e.g., frequent urban flooding) with the specific goals to adress.
- Define objectives (e.g., reduce flood frequency by 30% within five years) and clarify which challenges require policy or design interventions.
- Translate these objectives into concrete NbS actions, ensuring that the scope and scale of each intervention match local realities.

Linking Strategic Goals to NbS Outcomes

- Connect urban development plans or broader frameworks (e.g., SDGs) to the proposed NbS.
- Show the direct correlation between the selected NBS and how it contributes to local water security,environmental quality, or socio-economic benefits.
- Use stakeholder input to confirm that the chosen actions are technically feasible and socially acceptable.

Involvement of Stakeholders

- Include municipal authorities, technical experts, and community groups early in the planning process.
- Foster trust by incorporating different perspectives, ensuring shared ownership of challenges and solutions.
- Refine objectives and planned actions through multiple feedback loops with stakeholders.

Regular Engagement and Iterative Process

- Host recurring review sessions or workshops to assess whether the Theory of Change remains valid.
- Adjust proposed objectives and actions as new data or community priorities emerge.

Role of Technical Experts

- Consult engineers, ecologists, and social scientists to verify the plausibility of proposed outcomes and measurement methods.
- Collaborate with local teams to embed technical rigor and data-collection expertise in the Theory of Change

Step 2: Developing a results chain to outline the theory of change

Creating a results chain for nature-based solutions (NBS) requires several basic elements. NbS implementation requires a precise definition of objectives, together with clearly identified actions that describe local problems in detail, followed by selected performance targets and concrete steps for implementation. The method requires a visual representation of NbS action-impact relationships to predict planned outcomes and identify potential gaps, while planning adjustments to maximize operational effectiveness.

The desired outcomes of NbS implementation, such as reduced flood frequency, improved ecosystem services, increased physical activity, improved mental well-being, etc., are defined at this stage, along with the selection of visible intervention approaches to achieve these goals.

It is essential to consider both expected and unexpected impacts, as well as synergies and trade-offs, along the entire pathway. The evaluation process depends on a full understanding of these impacts in order to establish cause and effect. Developing a results chain requires a complex analysis that links NbS actions to expected impacts, while identifying both intended and unintended effects, how local conditions affect these outcomes, and how different outputs relate to each other. By using systematic steps, researchers gain insights into predicting constraints that enhance the success of NbS implementation.

Step 3: Specifying the evaluation questions

The specification of evaluation questions for NbS serves a fundamental purpose: specific evaluation questions help to determine the precise effects of NbS implementations in addressing targeted problems and achieving pre-determined goals. Impact evaluation arises from questions that address complex causal questions about the role of interventions such as retention ponds in reducing flooding or urban forestry in improving biodiversity. This evaluation seeks to determine the performance of NbS initiatives, compared to settings without interventions and other solutions that do not rely on NbS approaches.

The questioning process seeks precision to add contextual depth to the theory of change, while selecting indicators that meet its requirements. The evaluation requires researchers to recognise external elements that affect the assessment of outcomes during specific time periods in target regions. Advanced knowledge of unpredictable influencing elements facilitates the correct attribution of causes to NbS-related interventions.

The methodology combines specific impact analysis of NbS initiatives with identification of relevant factors and causal linkages to correctly attribute results. The approach provides a contextual account that supports indicator selection and identifies the direct impact of NbS in solving problems and achieving goal.

Step 4: Selecting indicators and data gathering

Select appropriate Indicators

The main reason for the selection of indicators and the implementation of the data collection method is to assess the performance of the NbS and its consistency with the intended theoretical framework. The selection of indicators follows a step-by-step approach using SMART criteria, which stands for Specific, Measurable, Attributable, Realistic and Time-bound. The evaluation system uses outcome statistics that measure societal problems and process statistics that measure methods to deliver NBS benefits.

The selection of indicators needs to achieve consistency, while taking into account evidence of synergies and trade-offs from the theory of change. Stakeholder prioritisation is essential in distinguishing between core outcome assessment indicators (critical to measuring key NbS impacts) and ancillary indicators (desirable but not essential measures). A logical starting point should focus on core indicators, but future expansion should be in line with available resources and active policy objectives.

Development of Local Monitoring and Data Collection Plan

A robust local monitoring and data collection plan requires stakeholders to implement specific actions that form a cohesive data collection strategy. The system assigns precise functional roles to monitoring stakeholders who make operational decisions, lead research activities, conduct field assessments and provide logistical support. The selected indicators require specific monitoring equipment and methods, which are followed by a predetermined measurement schedule.

The data collection plan consists of four main components, describing both the specifics of data collection and analysis approaches, together with data storage requirements, followed by presentation approaches for policy and decision making. The development of risk anticipation strategies for data collection activities becomes important due to potential time delays, limited response and unexpected costs. This leads to the creation of planned mitigation strategies before delays and unforeseen circumstances occur.

Step 5: Implementing the impact evaluation

The analysis of the data collected during the implementation of the Impact Monitoring and Evaluation Plan aims to assess the performance of the NbS in relation to the defined objectives. The analysis evaluates positive and negative impacts, examining the synthesis between different challenges through multi-criteria analysis to include multiple stakeholder perspectives. Data results need to be evaluated against the original theory of change requirements to verify whether implemented NbS activities are achieving the expected outcomes or producing unanticipated side effects.

Time element analysis is critical because impacts have different durations to emerge, therefore, continuous monitoring of changes that occur over time are needed. Through its core processes, evaluation requires a long-term view, which cautions against making early judgments about the effectiveness of NbS, as it has to be assessed how these initiatives evolve over time. The full assessment requires benchmarking of indicators against scientific standards to properly interpret changes that occur over time.

Step 6: Disseminating results and achieving policy impact

The final phase of this process focuses on disseminating the results of NbS impact assessments to ensure that they provide widespread benefit to citizens, businesses, scientists and local authorities. Organisations need to present full sets of results, showing both positive and negative outcomes, so they can learn from mistakes and avoid repeating unsuccessful approaches. Both outcome and process reporting generate valuable evidence that supports all stakeholders involved in NBS initiatives. Dissemination of locally developed knowledge facilitates NbS implementation through the establishment of city councils as standard models for future projects. Successful dissemination requires academic articles combined with reports and presentations and visual mapping of impact results.

Access to the tool

https://th-koeln.sciebo.de/s/lCZenziuvVbhLSQ

Further readings

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European Commission. (2021a). Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners. https://doi.org/10.2777/244577

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4. *Transformation Pathways Tools*

ITT
Institute for Natural Resources Technology and Management

Faculty of Spatial Development and Infrastructure Systems

Technology Arts Sciences TH Köln

POLYURBAN WATERS

Tool 1: Rooftop Rainwater Harvesting Calculator

Authors: Samuel Edward Hume

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 1 day • Activity Duration: 3–6 hours	• Open • Close	• Basic • Medium • Advanced

This tool allows for the calculation of the Rainwater Harvesting (RWH) potential of different rooftop catchments. This refers to how much water can be collected by a rooftop or groups of rooftops. The tool uses average monthly precipitation and the rooftop surface area and material. A tank size to store excess water is suggested if water demand data is available.

What?

The tool calculates the amount of rainwater that can be harvested from rooftop catchments using the parameters for the rooftop catchment and precipitation data. It also estimates a tank size based on the scenario.
Outputs:
- Monthly and Annual Rainwater Harvesting Potential
- Supply to Demand Surplus or Deficit
- Approximate Tank Size

Why? / Purpose

To evaluate whether implementing rooftop rainwater harvesting systems is beneficial in case studies.
The tool effectively calculates rainwater harvesting potential from rooftop catchments and can be used quickly and easily to quantify the potential supply and compare it to the demand.

Field of Application (Scale of Application)

The tool can be applied to any building or set of buildings. The scale can be from individual buildings to medium-sized urban districts. The context of tool use is urban areas with a need of a supplementary water supply or improved runoff storage.

End users

- Practitioners in the field of water engineers and urban planning. As well as governors from local and regional level
- Bachelor's and master's students of Engineering, Resource Management, Environmental Studies or related studies

Background

The idea developed through the interest in calculating how much water could be harvested from the rooftops considered in the water-sensitive park area in Sam Neua case study to support the Concept Note. It was decided to develop the tool concurrently so that these calculations could be easily done for other case studies. Tank sizing was then implemented so that there is a suggestion for the system as a whole.

Description

Data Requirements: Average Precipitation Data (Monthly or Annual), Water Demand (Monthly, per building), Rooftop Material, Rooftop Catchment Area
Outputs:
- Monthly and Annual Rainwater Harvesting Potential:
  The amount of water that can be harvested each month, and total over the year.
- Supply to Demand Surplus or Deficit
  Takes the total RWH potential from the above calculation and the total yearly demand and calculates the difference
- Approximate Tank Size
  Calculates tank size based on volume of water would be used. Calculation depends on whether the RWH potential is greater or smaller than the total demand.

Strengths and Limitations

Strengths: Easy to use, simple data requirements, clear estimation of RWH potential, easy to compare different catchments and easy to switch between scenarios
Limitations: Requires specific demand data to properly inform about the potential benefits of a RRWH system. The tank sizing calculations don't consider any economic aspects.

Requirements (Instruments used)	**Time:** Short, analysis for small groups of building can be done within a day **Skills:** Basic knowledge of GIS and Excel. Moderate data processing skills for monthly precipitation data. **Equipment:** Computers for spreadsheet access/data handling, images of the study area for rooftop characteristics, GIS to calculate areas. **Costs:** Low. Potential site visits, data collection.
Keywords	Rainwater Harvesting, Rainwater Harvesting Potential, Runoff Coefficient, Hydrological Year

Tool Manual

Overview

The tool allows the user to be able to calculate rainwater harvesting (RWH) potential for a given rooftop catchment based on the average monthly precipitation and rooftop material. The tool also suggests a tank size based on demand.

The main application is to calculate the rainwater harvesting potential (VR). This refers to the volume of water that can be collected from the rooftop over a period of time. The equation for this is as follows (Adugna et al., 2018; Hari et al., 2018; Villar-Navascués et al., 2020):

$$V_R = A * P * C_r$$

Where: VR=Rainwater harvesting Potential (m3); A = Catchment area (m2); P=Precipitation (m); Cr = Runoff coefficient

The catchment area (A) refers to the rooftop area that will be used in the calculation. Depending on the scale and purpose of the use case, this area can reflect individual buildings or groups of buildings. The runoff coefficient (Cr) is the proportion of precipitation that becomes surface runoff. In other words, it is the fraction of rainfall that will be able to be stored. Each rooftop will have a slightly different Cr. It depends on the material and slope.

The tool also provides estimates for tank size based on the RWH potential and demand. The calculation depends on whether the RWH potential is greater or less than the demand. If the RWH potential is greater, then the tank size is one month's demand plus the cumulative volume of the difference between RWH potential and demand in the months where demand is greater than RWH supply.

Step 1: Data Inputs

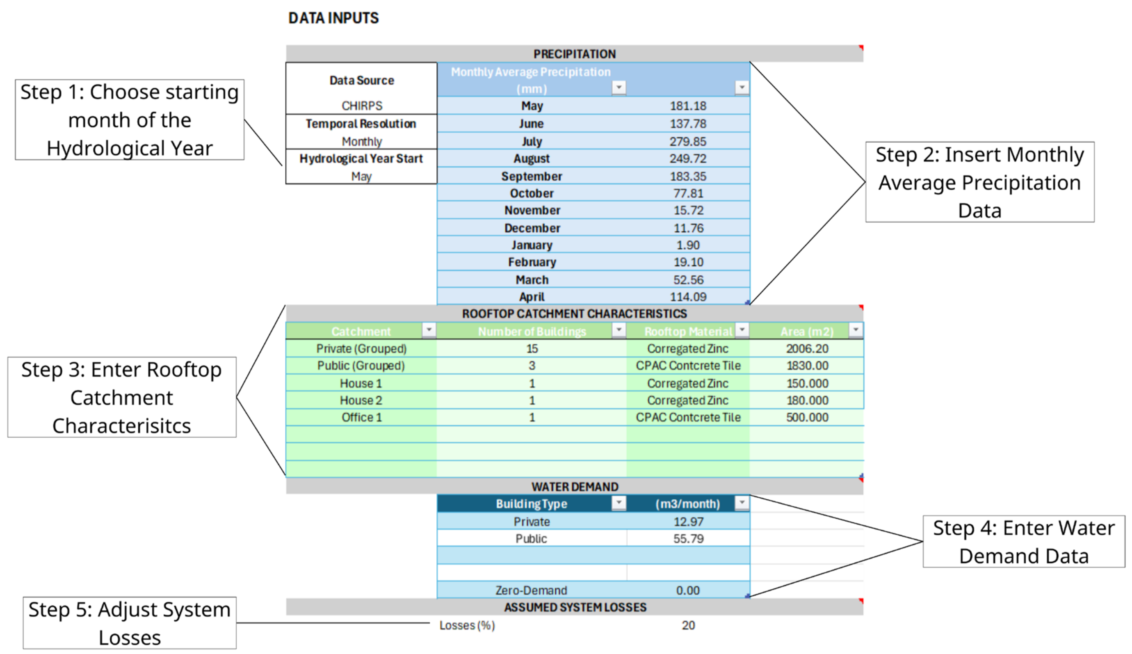

Figure 52:
Data input steps for RRWH tool.
Source: F12-THK, 2024

- **Add Precipitation Data**

Add precipitation data in average monthly format. It is recommended to use the Climate Engine app (https://app.climateengine.org/climateEngine, Huntington et al., 2017) to download data from CHIRPS (C. Funk et al., 2015) if rainfall gauge data is unavailable. The data source can be indicated in the box. The month in which the hydrological year starts can be selected from a drop-down menu.

- **Add Rooftop Catchment Data**

The rooftop catchment data is formed of 4 components. First is the identifier of the catchment or catchment name. This should be easily identifiable and different from the other catchments being used in the analysis. The number of buildings within the catchment is then required. This allows for diverse applications of the tool and individual buildings or groups of different sizes.
The rooftop material is taken from a table on the "Rooftop Material Types" sheet within the tool. Certain materials are already listed, however roof materials not included must be added to this table. The table requires the runoff coefficient of the material. This can usually be found in journal articles for common rooftop material types. Once a material is added on the "Rooftop Material Types" sheet, it will appear within the "Rooftop Material" column in the "Data Inputs" section.
The Area refers to the total area of the catchment. Therefore, if multiple rooftops are being considered, this area should reflect the combined areas of all rooftops within the catchment. The area of rooftops can be determined using satellite imagery and GIS by drawing polygons. Additionally, Google Research provides a dataset "Open Buildings" that identifies buildings in the Global South: https://developers.google.com/earth-engine/datasets/catalog/GOOGLE_Research_open-buildings_v3_polygons#citation (Sirko et al., 2021).

- **Add Demand Data**

Demand data reflects how much water will be used. It is optional, as it difficult to quantify due to the water from RRWH being only suitable for certain uses but should be added if available. The quantity for different uses can be estimated in some cases. When available, the data allows for the visualisation of the relationship between the water able to be supplied from the system and the demand. Also, whether the supply can meet the demand. It also helps to refine the tank sizing process and discussed in Section 1.

- **Add Assumed Losses**

Assumed losses account for inefficiencies within the system, losses from evaporation and small rainfall events that produce no runoff. The default value is 20%, however it can be refined if extra information is available.

Step 2: Select Outputs

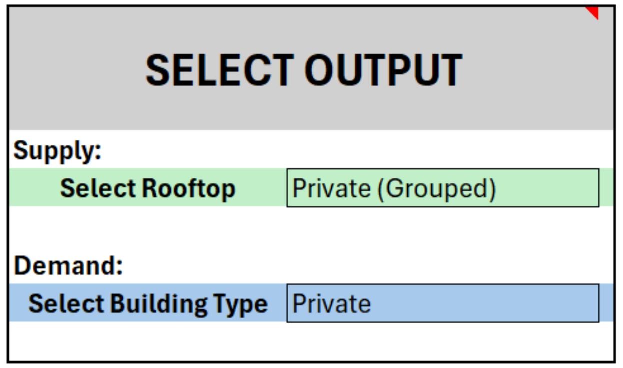

Figure 53:
Output selection box from RRWH tool.
Source: F12-THK, 2024

The selection interface (Figure 53) allows to select a rooftop catchment and demand from the data input tables. As multiple catchments and demands can be stored in the data inputs, switching between different combinations is simple and allows for comparisons to be made more easily.

Step 3: Visualising and Interpreting Results

Results are found on the "Outputs" sheet. It is composed of tables and graphs. The table (Figure 54) displays the monthly RWH potential, cumulative monthly RWH potential and cumulative monthly demand. Additionally, the Annual total is displayed along with the annual volume collected per square meter. This value allows for easy estimations of rooftops with similar characteristics that weren't considered in the analysis.

Rooftop Catchment Area	Demand Type
200	Demand 2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Rainwater Harvesting Potential (m3)	1.44	1.44	4.32	10.08	23.04	25.92	27.36	23.04	17.28	7.20	4.32	2.88
Cumulative Rainwater Harvesting Potential (m3)	1.44	2.88	7.20	17.28	40.32	66.24	93.60	116.64	133.92	141.12	145.44	148.32
Cumulative Demand	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00	110.00	120.00

Annual Total (m3)	Annual (m3/m2)
148.32	0.74

	Value	Unit
Annual Supply Surplus/Defecit	28.32	m3
Calculated Tank Size Per Building	48.40	m3
Suggested Tank Size Per Building	50.00	m3

Figure 54:
Results Table, RRWH Tool.
Source: F12-THK, 2024

The annual surplus/deficit is displayed and is coloured coded depending on if it is negative or positive. It reflects whether the supply can meet the demand. A tank size is recommended based on the calculations described in Section 1, the suggested tank size rounds the calculated size to a regular tank size.

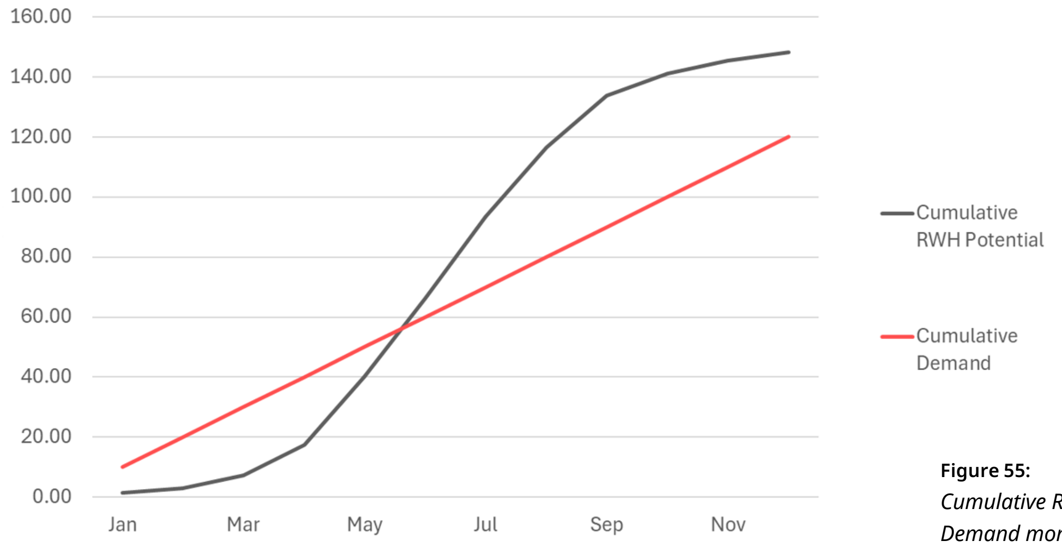

Figure 55:
Cumulative RWH Potential and Demand monthly time series, RRWH Tool.
Source: F12-THK, 2024

The graph allows for a visualisation of the trend between RWH potential and demand. It is useful for seeing deficits in dry season or the reverse in wet season. The final endpoint of each line shows whether the potential exceeds the demand over the course of the year or not.

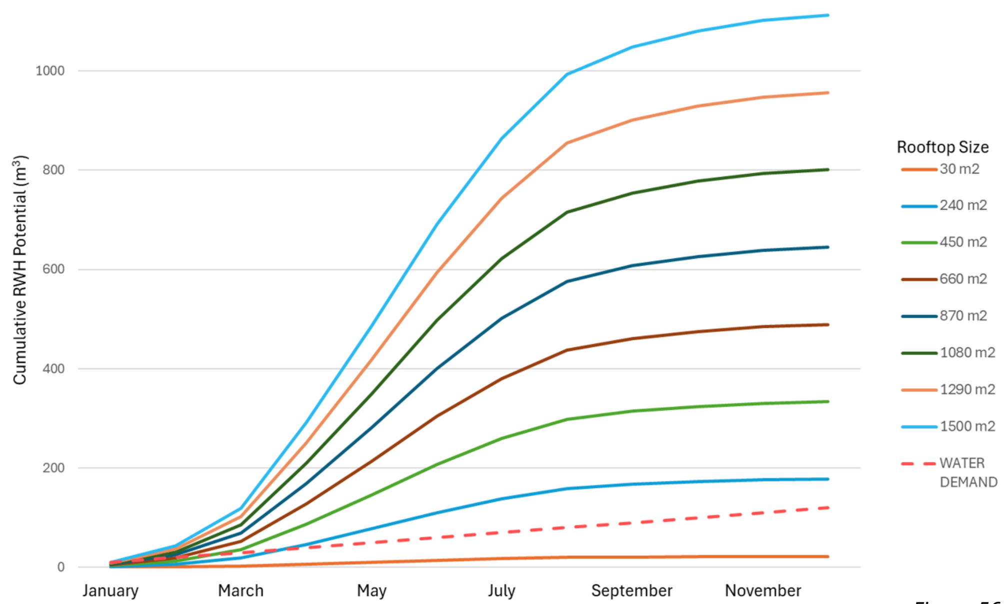

Figure 56: Results Table, RRWH Tool.
Source: F12-THK, 2024

Figure 56 is an output graph that shows the RWH potential of different rooftop areas. The range of sizes is determined from the areas already entered into the "Rooftop Catchment Characteristics".

Study case

The tool was used to assess the potential of Rooftop Rainwater Harvesting (RRWH) in Sam Neua, Laos, as part of the town's Multi-functional Park development. The area comprises of 15 residential and 3 public buildings as pilot sites.

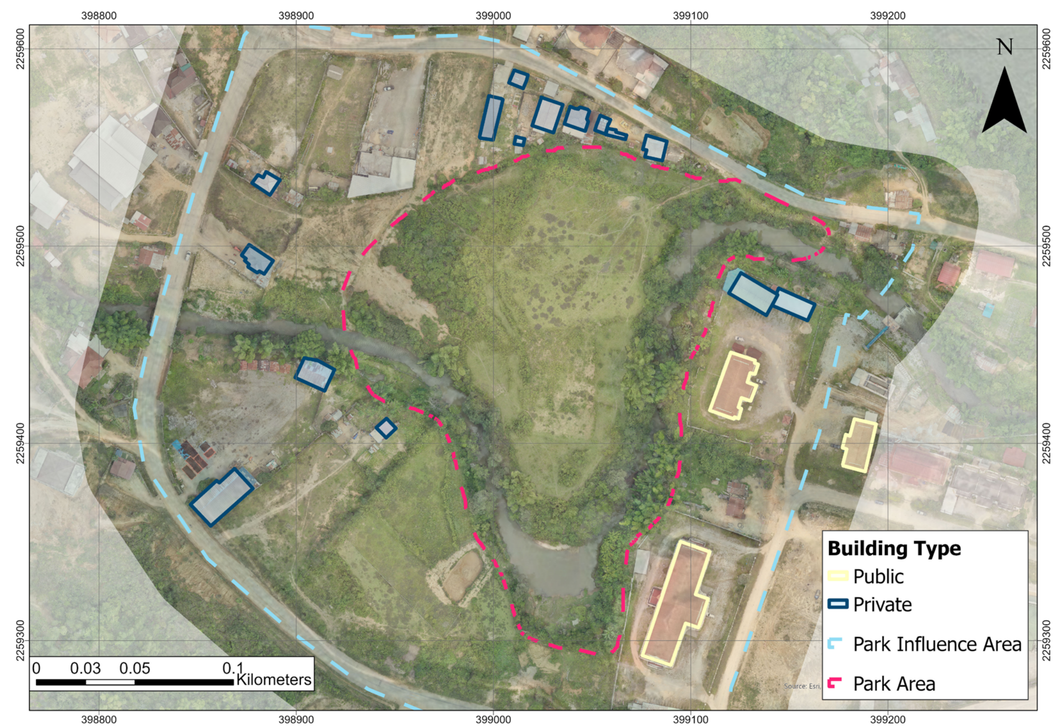

Figure 57:
Map of the Park area and buildings selected for RRWH implementation.
Source: F12-THK, 2024

The area has a temperate dry winter-hot summer climate (Cwa) (Kottek et al., 2006). This gives the region distinct dry and wet seasons and an annual average precipitation of 1324.87mm.

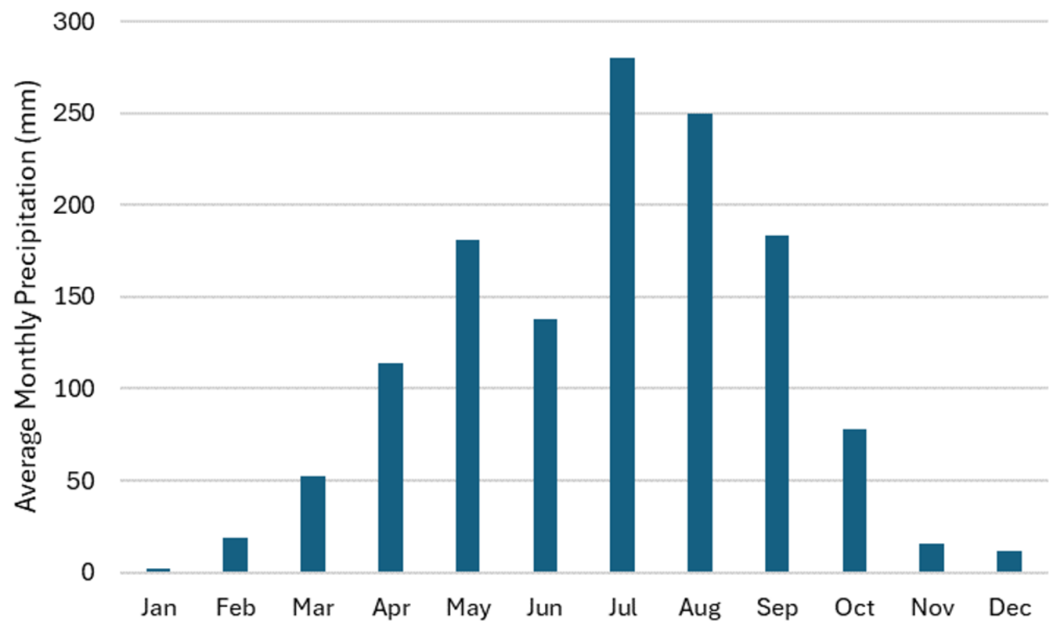

Figure 58:
Average Monthly Precipitation in Sam Neua Park, Laos.
Source: Funk et al.(2014)

The total rainwater that could be harvested for the buildings is large, with nearly one cubic meter of water being collected per 1m2 of rooftop. In the case of Sam Neua, RRWH shows great promise. For the public buildings, it shows that over the course of the year, 1745.59m3 of water could be harvested overall to supplement water supply. The amount of water that can be supplied is lower than the demand of the buildings. Therefore, tank sizing is determined by calculating the amount of excess water that can be harvested over the wet season whilst considering monthly abstractions to meet demand. For the public buildings, the potential supply also doesn't meet to the total demand. There is an overall deficit of -262.7m3 yearly. The suggested tank size is 200m3 from a calculated potential storage volume of 192.87m3 per building. There is a large amount of water that can be potentially supplied. The tank sizing is a concern as the calculated volume is very large. Private buildings can theoretically collect 1913.66m3 of water per year overall. With 15 buildings, the individual calculated storage volume considering constant water abstraction for each household would be 35.37 m3 meaning a suggested tank size of 40m2. This would provide a significant amount of water for each household. However, it is likely the costs of providing these tanks would also be too great.

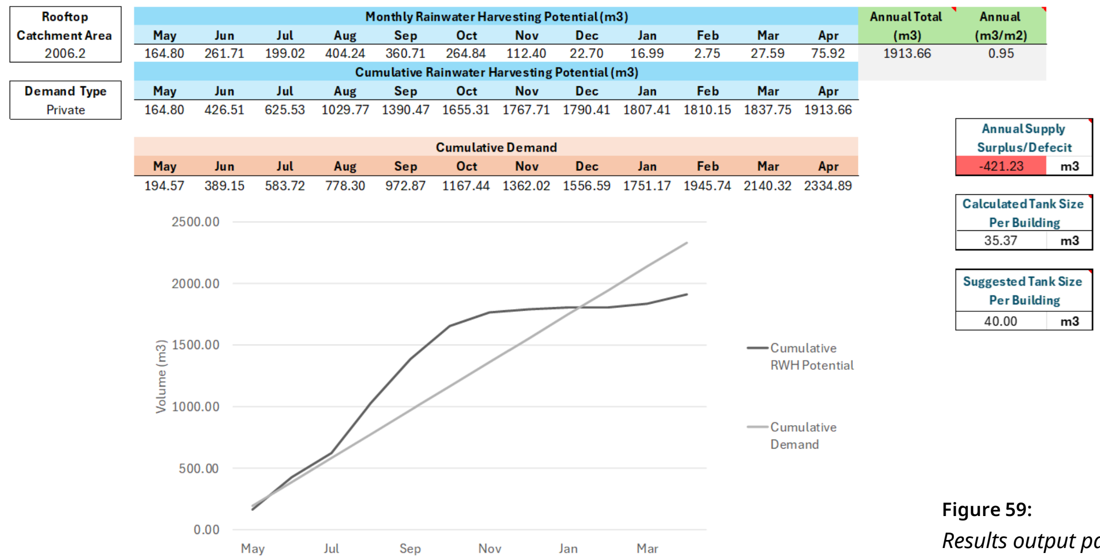

Figure 59:
Results output page for Private buildings.
Source: Rooftop RWH Tool, F12-THK, 2024

The results show that over the course of the year that the RWH potential was less than the total demand (Figure 59). However, the demand used was an estimation of total household demand. The amount of water supplied would likely cover the uses that harvested rainwater is suitable for. Due to the pronounced seasonality, the suggested tank size is large.

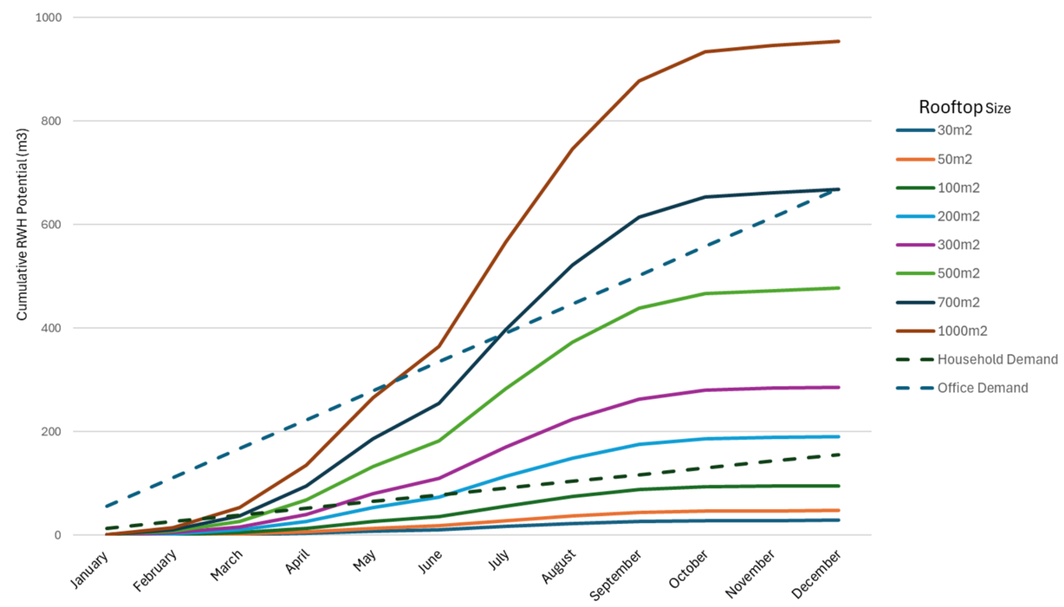

Figure 60:
RRWH potential and demand curves plotted cumulatively for different roof sizes, using CPAC concrete tiling as the roof material.
Source: Rooftop RWH Tool, F12-THK, 2024

The rooftop size necessary to meet the demand for both private and public buildings are realistic sizes met by multiple buildings within the study area. It is shown that to meet the average household demand, a roof size of approximately 180m3 is needed (Figure 60). A few of the households meet this requirement. For the Government office demand, a roof size of 700m3 would be needed.

Access to the tool

https://th-koeln.sciebo.de/s/7OsT6OvK8MXWC1x

Further readings

Abdulla, F. (2020). Rainwater harvesting in Jordan: potential water saving, optimal tank sizing and economic analysis. Urban Water Journal, 17(5), 446–456. https://doi.org/10.1080/1573062X.2019.1648530

Siddiqui, R., & Siddiqui, S. (2018). Assessing the Rooftop Rainwater Harvesting Potential in Urban Residential Areas of Pakistan: A Case Study of Model Town, Lahore, Pakistan. Int.J.Econ.Environ.Geol, 9(2), 11–19. https://www.researchgate.net/publication/343139795

Villar-Navascués, R., Pérez-Morales, A., & Gil-Guirado, S. (2020). Assessment of rainwater harvesting potential from roof catchments through clustering analysis. Water (Switzerland), 12(9). https://doi.org/10.3390/W12092623

Adugna, D., Jensen, M. B., Lemma, B., & Gebrie, G. S. (2018). Assessing the potential for rooftop rainwater harvesting from large public institutions. International Journal of Environmental Research and Public Health, 15(2). https://doi.org/10.3390/ijerph15020336

Tool 2: Hydrological and Hydraulic Modelling

Authors: Samuel Edward Hume, Lina Rocio Pérez Corredor, Juan Miguel Viquez, Frederic Hebbeker, Yagana Yusufi

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 5 days • Activity Duration: 1 day	• Open • Close	• Basic • Medium • Advanced

Hydrological and Hydraulic modelling tool provide many opportunities to investigate problems and solutions to water management issues. This tool applies methodologies to existing modelling software to produce results that can be used in designing and improving water sensitive urban design in secondary and tertiary cities in SEA. The first methodology uses HEC-RAS to provide a hydrodynamic model of an urban area using a detailed elevation model from drone imagery (see Drone Survey) combined with infiltration maps and precipitation data. The main output is a runoff map that helps to identify areas of accumulation during storm events, highlighting areas that would benefit most from NbS implementation. The second methodology uses SWMM to assess rainfall-runoff dynamics and evaluate the performance of urban drainage systems under various design storm events with different return periods. The analysis aims to identify flood-prone areas by assessing the capacity of the drainage infrastructure, pinpointing potential inundation zones, and determining the extent and severity of flooding using LULC, soil and elevation data. The method highlights critical areas that require improvements or redesign to enhance flood mitigation.

What?	The tool comprises two widely-used, open-access software applications—SWMM (Stormwater Management Model) and HEC-RAS (River Analysis System)—designed for hydrological and hydraulic modelling in urban and river basin environments. These tools simulate pluvial flooding on an urban scale, essential for understanding flood risks and runoff management. Main Characteristics: • **HEC-RAS:** Conducts 1D and 2D hydraulic modelling of river systems, enabling the simulation of river hydraulics, surface flow dynamics, and runoff impacts. • **SWMM:** Models the rainfall-runoff process in urban environments, simulating stormwater management and assessing how urban drainage systems respond to precipitation events, including both runoff and water quality.
Why? / Purpose	The purpose of this tool is to support decision-making for water-sensitive urban planning by providing precise simulations of water flows. It helps identify flood-prone areas, evaluate the effectiveness of Nature-based Solutions (NbS), and design sustainable infrastructure systems.
Field of Application (Scale of Application)	The methodologies are best suited to a municipality-level scale, small-medium sized urban areas. Larger areas are possible but have greater computational requirements.
End users	Urban planners and municipal water managers. Environmental and hydrological consultants, policymakers and local governments in secondary and tertiary cities, academics and researchers.
Background	These tools are globally adapted for hydrological challenges. These tools have been adapted in the (PUW) project for Southeast Asian (SEA) cities, incorporating regional hydrological data, localized flooding challenges, and participatory planning approaches.

Description	**HEC-RAS:** A detailed surface elevation model is used as the base terrain for the model. Within the model, infiltration data derived from soil type and land-use cover is overlayed onto the terrain. Design storm events are then integrated into the model which then provides the surface runoff and flow direction, allowing for the visualisation of runoff accumulations and potential flood risk zones. **SWMM:** Simulates urban runoff using sub catchment data, drainage networks, and rainfall inputs, incorporating NbS interventions and evaluating system performance under storm events.
Strengths and Limitations	**Strengths:** Integrates hydrological and hydraulic modelling for detailed, scenario-based assessments. Helps develop an understanding of the hydrology of the area. Visualizes outputs to effectively communicate results to stakeholders. Versatile application across urban and river basin contexts. **Limitations:** • Relies on accurate and high-resolution DSM/DTM data, difficult to calibrate, requires experience with the respective software. • Requires extensive input data (e.g., precipitation, elevation) which may not always be available. High technical expertise needed for model setup, calibration, and interpretation. Computationally intensive for large-scale applications.
Requirements (Instruments used)	**Time:** Moderate to long (for data preparation, calibration, and scenario analysis). **Skills:** Hydrological and hydraulic modelling expertise, GIS knowledge. **Software:** HEC-HMS, HEC-RAS, SWMM, GIS tools. **Costs:** Moderate (primarily for training and data acquisition).
Keywords	Hydrological Modelling, Hydraulic Modelling, Land Use – Land Cover, Surface Runoff, Pluvial Flooding, Fluvial Flooding.

Tool Manual

Introduction:
Hydrological and hydraulic modelling is a valuable tool in urban water management. It can serve multiple applications, including determining flood extent, designing dams and analysing drain networks. Within the project, models were identified as a useful tool to gain insights into the hydrology of the pilot areas. Specifically, the models were designed to determine the runoff from urban areas and identify where it accumulates. This allows for the identification of risk zones for urban flooding and also helps highlight areas that would benefit most from the implementation of NbS. Drone data was collected to for the base of the models, and these were used in combination with open-source datasets to produce the models.

Objectives:
- Identify areas prone to high surface runoff and runoff accumulation
- Identify flood-prone areas, evaluate drainage capacity, highlight critical areas for improvement.

HEC-RAS Method:

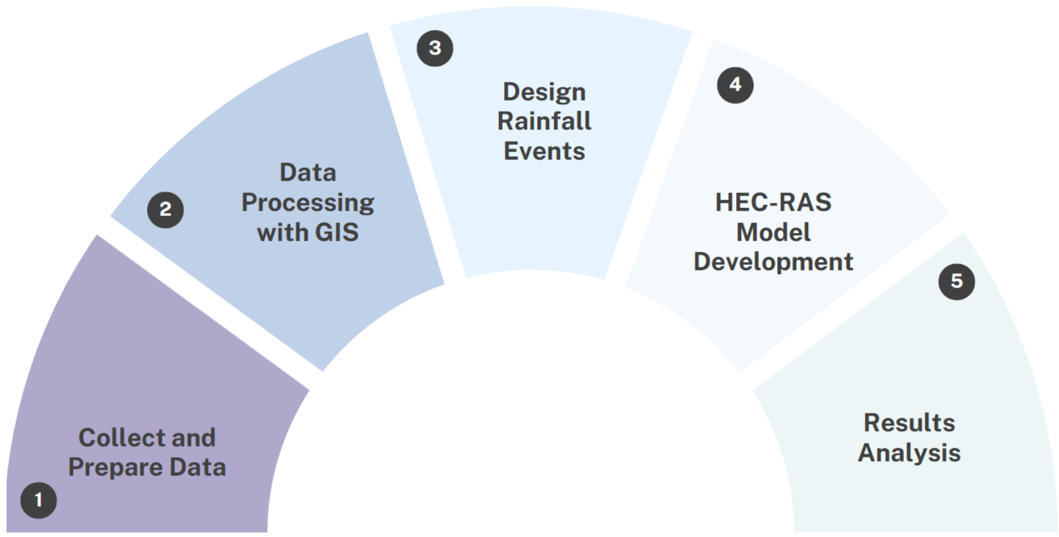

Figure 61:
Flow chart of HEC-RAS methodology
Source: F12-THK, 2024

Step 1: Prepare Data

1. **Precipitation Data:** Use a long-term historical precipitation dataset. If rain gauge data or higher temporal resolution data is unavailable, the MSWEP V2.8 3-hourly historical precipitation dataset is recommended. Extraction of timeseries of this data can be accomplished using the Insight for Urban Water Management Using Open-Source Data tool. If rain gauge data or similar is available, it is preferred over MSWEP data.
2. **Terrain Model:** A digital terrain model (DTM) is used. It can be derived through photogrammetry with adapted SMRF (simple morphological filter) parameters (see Drone Survey tool). In order to best represent the surfaces that impact runoff, houses should be included from the DSM, based on open building data, corrected with a high resolution orthomosaic. The DTM is resampled to a resolution of 0.5 meters, balancing computational efficiency and terrain representation accuracy. It is added as a Terrain layer in RAS Mapper as a .tif file.
3. **Study Area:** Add a shapefile of the study area as a polygon in RAS Mapper.
4. **Land Use and Land Cover (LULC):** Collect Land Use/Land Cover (LULC) data and Hydrological Soil Group (HSG) data for the study area. Global LULC datasets, such as the GLC Share Database (FAO) or Worldcover (ESA), are usually sufficient for the model. Photogrammetry from drones can be used to improve classifications (see Drone Survey tool); Each LULC classification also needs a Mannings coefficient. The SWMM User's Manual Version 5.2 Table A.6 (Rossman & Simon, 2022) can be used for approximating this value.
5. **Soil Data:** Obtain soil data to determine the HSG of the study area. A global dataset for HSG is available at the ORNL DAAC website (Ross et al., 2018).

Step 2: Data Processing in ArcGIS

1. Process spatial datasets, including precipitation, terrain, LULC, and soil data, using ArcGIS or equivalent GIS software.
2. `Ensure layers are pre-processed to align spatially and are in the same coordinate reference system.

Step 3: Design Rainfall Events

1. Use the Frequency Storm Method in HEC-HMS, relying on Depth-Duration-Frequency (DDF) data. The DDF durations are 3, 6, 9, 12, 24, and 48 hours, and return periods: 1, 2, 5, 10, 30, 50, and 100 years. Perform a DDF analysis using a

long-term historical precipitation dataset. Use a Python package developed by (Pichler, 2024) for DDF analysis. Generate a DDF table for the study area. Input precipitation values from the DDF table for each duration and return period. Generate a precipitation time series for the storm event using the Frequency Storm Meteorological Method in HEC-HMS.

Step 4: HEC-RAS Development

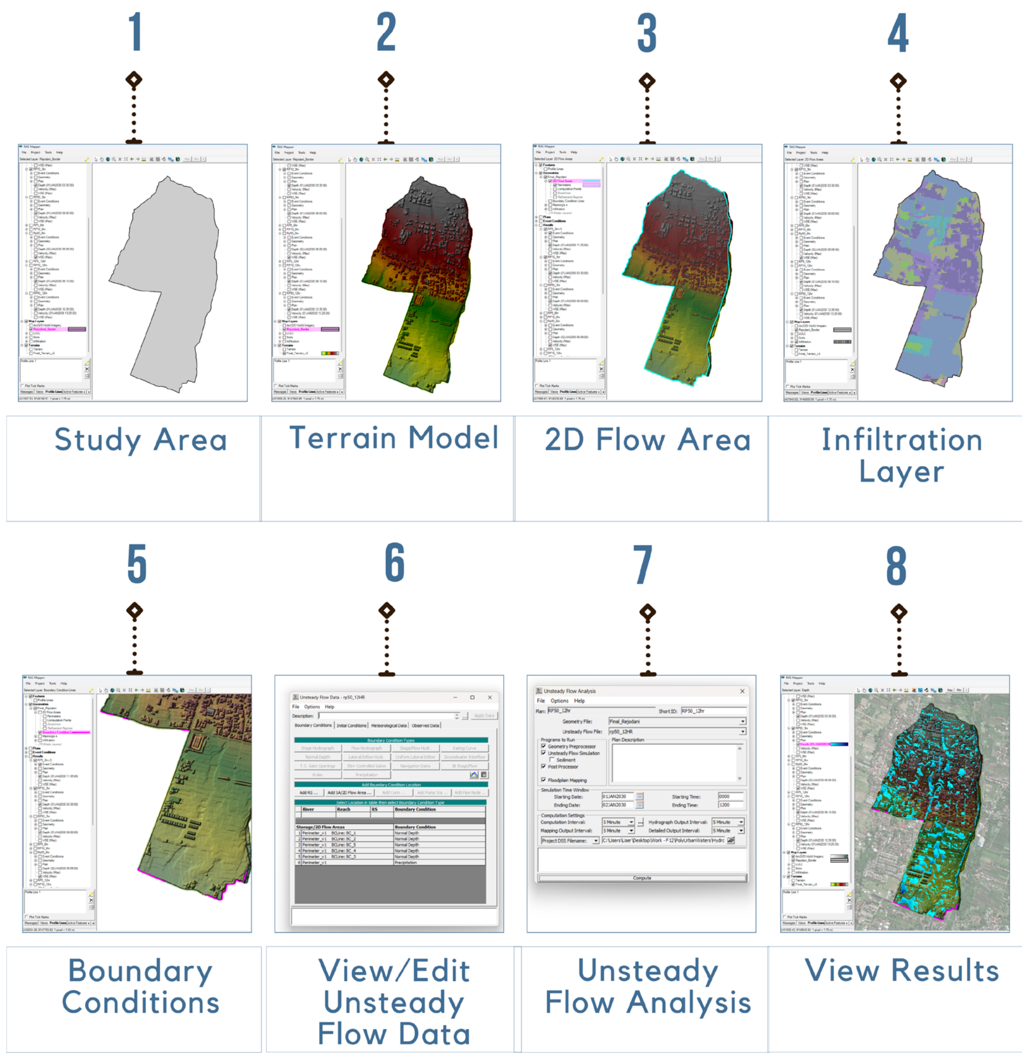

Figure 62:
Stages of the construction of the HEC-RAS model

1. **Study Area:** Add the study area shapefile as a reference layer in RAS Mapper.
2. **Terrain Model:** Import the DSM into RAS Mapper as a terrain layer.
3. **2D Flow Area:** Add a 2D Flow Area under "Geometries" in RAS Mapper. Draw the perimeter of the flow area around the study area but within the terrain's limits. Add computational points spaced according to the terrain resolution and calculate the computational grid.
4. **Infiltration layer:** Combine LULC data with HSG using RAS Mapper to create a new intersected polygon layer. Refer to Curve Number (CN) tables in the HEC-HMS Technical Reference Manual (USACE, 2024.) to assign CN values to the polygons. Initial Abstraction is assumed to be 0.1. Minimum infiltration rate is determined by the soil type, according to the HEC-RAS Technical Reference Manual.
5. **Boundary Conditions:** Add boundary conditions under "Geometries":

- Perimeter Boundary Condition: Define the perimeter of the 2D Flow Area.
- Normal Depth Boundary Condition: Set for water outflow at the model boundaries.

Input the appropriate hyetograph for the precipitation event at the 2D flow area boundary.

6. **View/edit Unsteady Flow Data:** The 2D flow area requires 2 boundary conditions. The boundary condition line uses normal depth to allow flow out of the 2D flow area. The second boundary condition is for the 2d flow area perimeter, which is how the precipitation event is defined. Here, the matching hyetograph from the chosen storm event is entered.
7. **Unsteady Flow Analysis:** The programs set to run are the Geometry Preprocessor, Unsteady Flow Simulation, Post Processor and Floodplain Mapping. The computation settings used are a computation interval of 5 minutes, with the hydrograph output, mapping output interval and detailed output interval are all set to 10 minutes.
8. **View Results:** The results can be views in RAS Mapper. The key output is the water depth throughout the event. This can be used to identify areas which see a high accumulation of runoff or high flow. Profile lines can be added to these areas of interest, which allows for the plotting of cross sections that show the water depth over the terrain using Water Surface Elevation (WSE) data.

SWMM Method:

Step 1: Data Required and processed

1. **Precipitation:** High-resolution precipitation data, preferably minute- or hourly-scale, are required for accurate modelling. Short intervals are ideal for small areas, while hourly data suffices for larger regions (Rossman, 2015). In the absence of local data, reanalysis datasets like MSWEP V2.8 (3-hour resolution) offer a viable alternative, combining satellite, ground, and model data for reliable simulations.

2. **Design Rainfall events:** Use the Frequency Storm Method in HEC-HMS, relying on Depth-Duration-Frequency (DDF) data. The DDF durations are 3, 6, 9, 12, 24, and 48 hours, and return periods: 1, 2, 5, 10, 30, 50, and 100 years. Perform a DDF analysis using a long-term historical precipitation dataset. Use a Python package developed by Pichler, M. (2024) for DDF analysis. Generate a DDF table for the study area. Input precipitation values from the DDF table for each duration and return period. Generate a precipitation time series for the storm event using the Frequency Storm Meteorological Method in HEC-HMS.

3. **Catchment parameters data:**

- **Topographic data:** The digital terrain model with the resolution of (0.5m) derived from Drone (Hebbeker, 2025) is used for delineating catchment boundaries and identifying drainage patterns and primarily used ArcGIS Pro for the delineation.
- **Land cover and soil data:** Collect Land Use/Land Cover (LULC) data and Hydrological Soil Group (HSG) data for the study area. Global LULC datasets, such as the GLC Share Database (FAO) or Worldcover (ESA), are usually sufficient for basin-scale models. Obtain soil data to determine the HSG of the study area. A global dataset for HSG is available at the ORNL DAAC website (Ross et al., 2018).
- **Infiltration method:** The Curve Number (CN) method is applied to model soil infiltration in sub catchment areas. This empirical method, based on the SCS Curve Number derived from the SWMM user manual (Rossman, 2015) table A4, based on land use and hydrologic soil groups, with adjustments for mixed land uses.
- **Catchment parameters:** The subcatchment area are calculated using ArcGIS Pro. Slope are determined by importing a Digital Terrain Model (DTM) into ArcGIS Pro, generating slope rasters, and calculating average slopes using the Zonal Statistics tool. Subcatchments widths are estimated using the Skew Factor formula, which adjusts the channel length based on the ratio of larger to total areas on either side of the drainage channel, ensuring accurate representation of irregular shapes (Rossman, 2016). Imperviousness is calculated using land cover,

soil, CN maps and predefined percentages from SCS TR-55 guidelines. Depression storage and Manning's n values were calculated as weighted averages based on land cover types, using SWMM guidelines (Rossman, 2015).

4. **Drainage system data:**

- **Junctions and conduits:** A single vector layer combining drainage and river networks was used to model conduits, with junctions and outfalls represented in separate layers for their distinct purposes. A Manning's n value, in line with SWMM recommendations, was applied to the conduits, ensuring consistency with standard flow modelling practices (Rossman, 2015).
- **Junctions and conduits configuration:** Conduits are defined by their inlet and outlet junctions to ensure proper flow direction, with flow moving from higher to lower elevations. Junctions were configured with invert elevations and maximum depths for correct flow modeling (Rossman, 2015). Conduit dimensions can be adapted based on studies from similar regions, when site-specific data is not available. Junction invert elevations are derived by extracting surface elevations from a Digital Terrain Model (DTM) using GIS tools, then subtracting the channel depth to accurately represent flow behaviour.

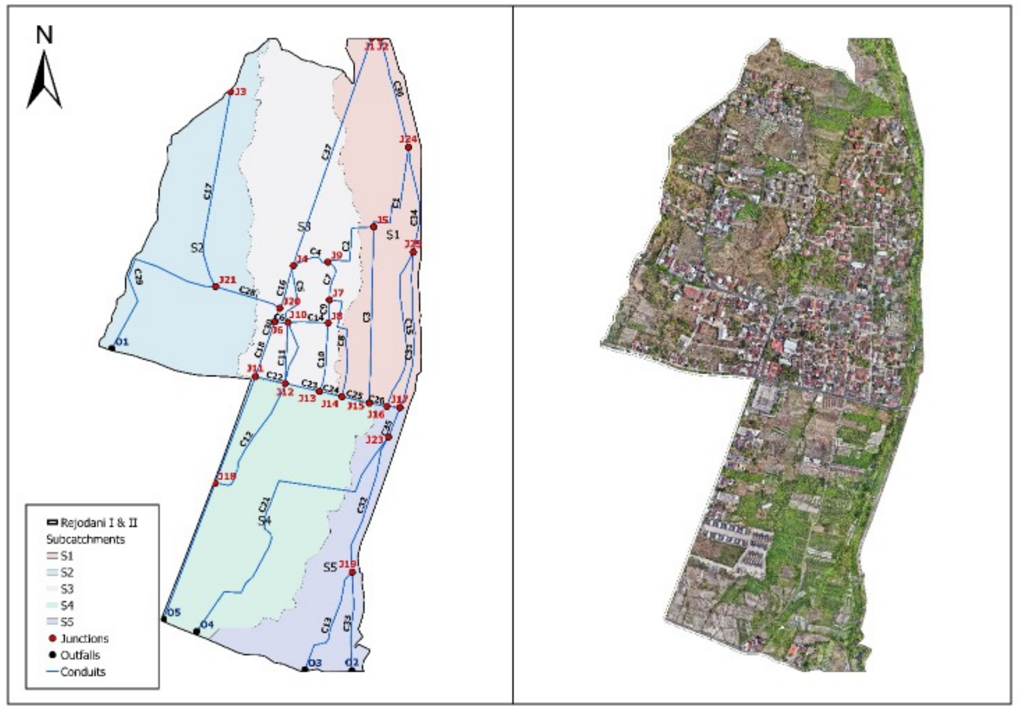

Figure 63.
Sub catchments division and representation of drainage system in Rejodani sub-villages I and II, Indonesia. Source: F12-THK, 2024

Step 2: Model construction and setup

Spatial features like sub-catchments, outfalls, junctions, and conduits are prepared as GIS shapefiles and then converted into the SWMM INP format for simulation. This is done using the "Generate SWMM INP" plugin in QGIS. The shapefile's attribute table must include required fields for the conversion to work, while optional fields can be left empty if not needed. After confirming the attribute tables are filled, the plugin creates the INP file, integrating the data into the SWMM simulation.

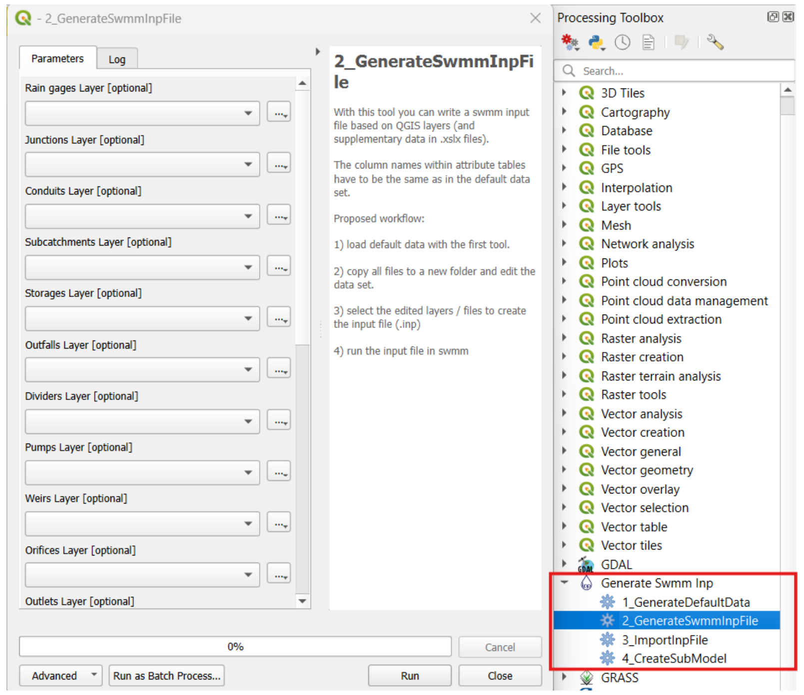

Figure 64.
QGIS format conversion to SWMM input
Source: F12-THK, 2024

In the model construction phase, several key steps are applied to run the models effectively. First, the rain gauge is set for each storm event duration (48H, 24H, 12H, 6H, and 3H) and their associated return periods (1Y, 2Y, 5Y, 10Y, 30Y, and 50Y). The parameters for sub-catchments, junctions, outfalls, and conduits, as outlined earlier, are carefully reviewed to minimize any errors in the model.

The SWMM simulation options are configured based on the storm's characteristics and the system's response to rainfall. By setting up these configurations, the model is run for each return period and duration.

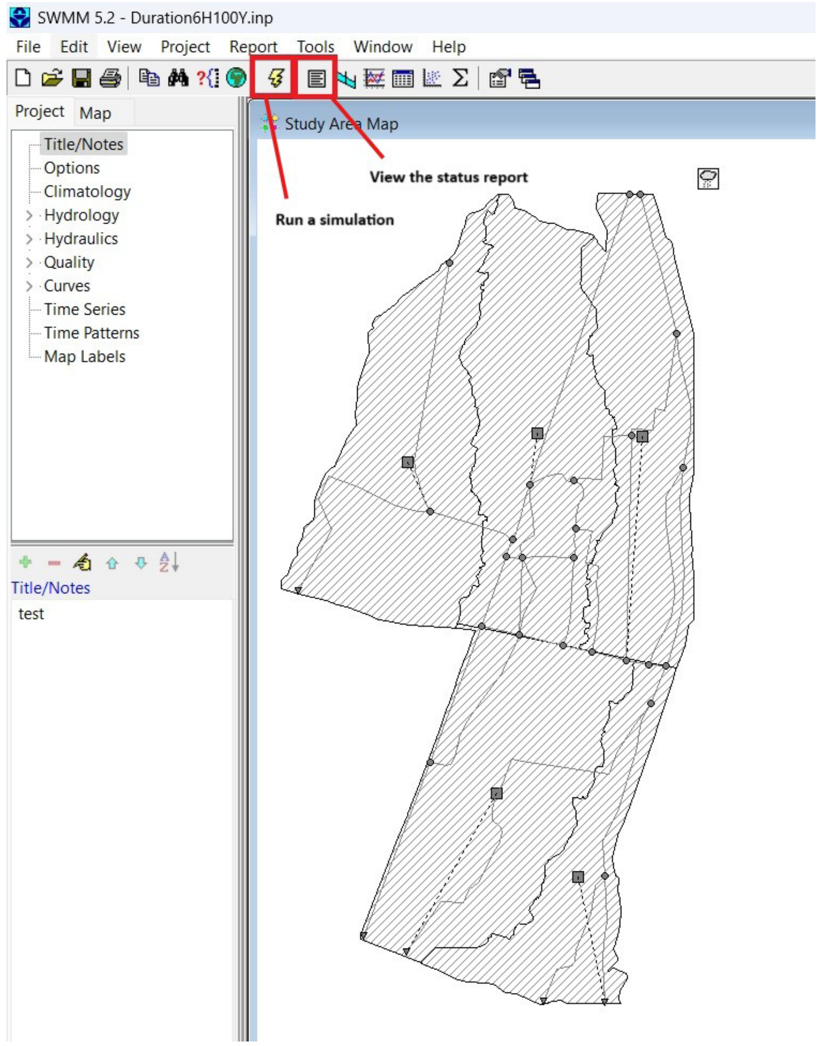

Figure 65:
SWMM sub-catchments division and representation of drainage system
Source: F12-THK, 2024

Study Case

HEC-RAS Method: Rejodani I +II, Indonesia

The HEC-RAS method was applied to the sub-villages Rejodani I + II in the pilot city of Sleman, Indonesia. The objective was to identify areas that may have a risk of flooding under extreme precipitation events.

Precipitation data was taken from MSWEP V2.8, which is a 3-hourly global precipitation reanalysis data product for the period 1979-2020 (Beck et al., 2019). Depth-duration-frequency (DDF) curves were derived using Python, with a package created by Pichler, M. (2024). HEC-HMS was used to apply the Frequency Storm method to derive storm event hyetographs (see Fig. 66).

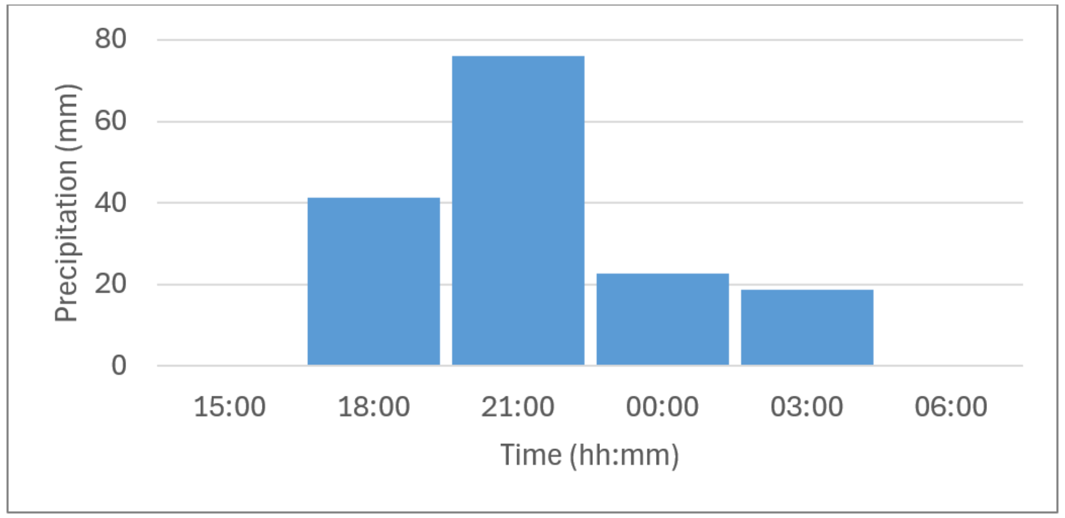

Figure 66.
Storm event hyetograph for a storm duration of 12 hours and return period of 50 years
Source: ITT 2024

A drone survey, conducted in October 2023 was used to derive DSM & DTM, adapting SMRF- parameters to increase the quality of Digital Terrain models, recommendable, especially in urban area (see Pingel et al., 2013). To enable not only the terrain runoff, but also runoff from houses, buildings footprints, based on Sirko et al., (2021), were adapted with the derived high resolution orthomosaic and used to clip them from the DSM and insert them into the DTM.

The LULC used was from the ESA Worldcover 2021 dataset (Zanaga et al., 2022) with some reclassifications performed using imagery from the drone survey to improve accuracy. This was intersected with hydrological soil group data from Ross et al.

(2018) using RAS Mapper. These were used to derive a CN map of the area. The CN of the study area ranges from 79 in forest areas to 95 in densely built-up areas. The high CN reflects the urbanised nature of the catchment and also the clayed soil type.

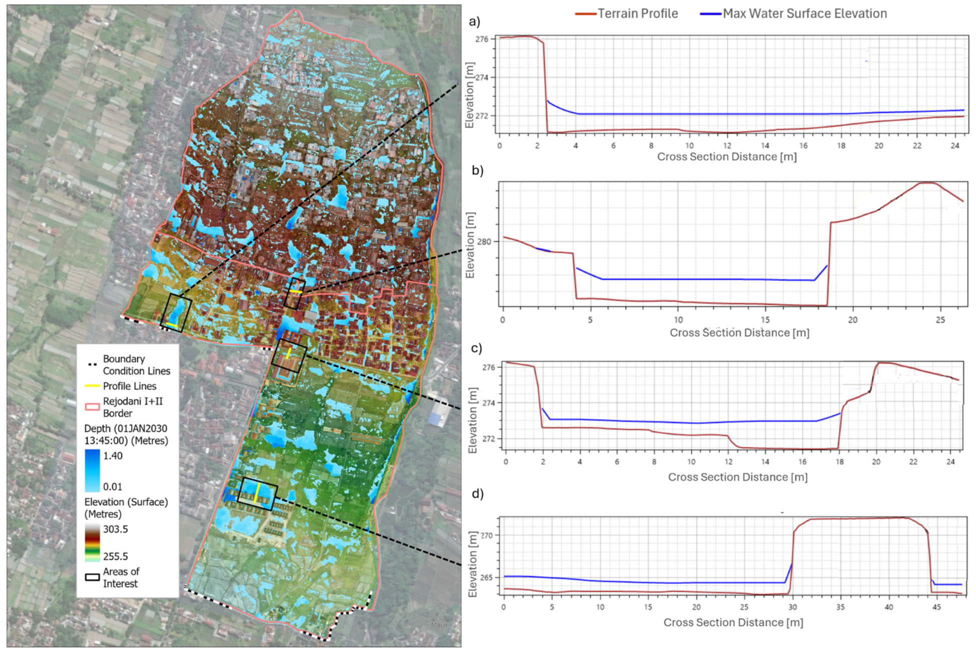

Figure 67.
Instantaneous flood depth map and maximum flood depth cross sections at selected Areas of Interest for a 12hr storm event with a 50-year return period. Water Surface Elevation shown for: a) "Outflow west side" b) "Main Street" c) "Commercial Centre" d) "Housing Estate"
Source: F12-THK, 2024

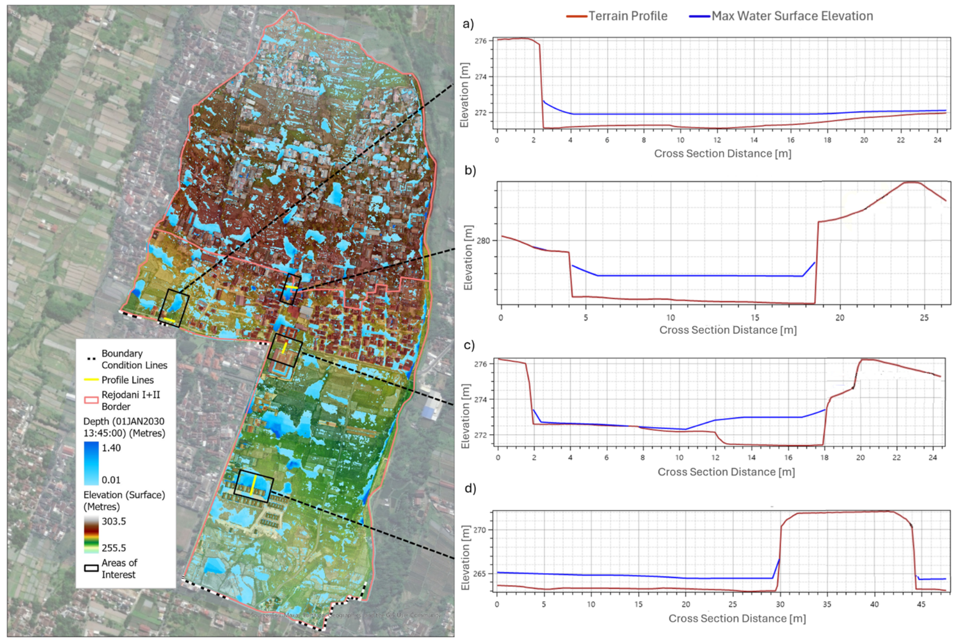

Figure 68.
Instantaneous flood depth map and maximum flood depth cross sections at selected Areas of Interest for a 12hr storm event with a 10-year return period. Water Surface Elevation shown for: a) "Outflow west side" b) "Main Street" c) "Commercial Centre" d) "Housing Estate"
Source: F12-THK, 2024

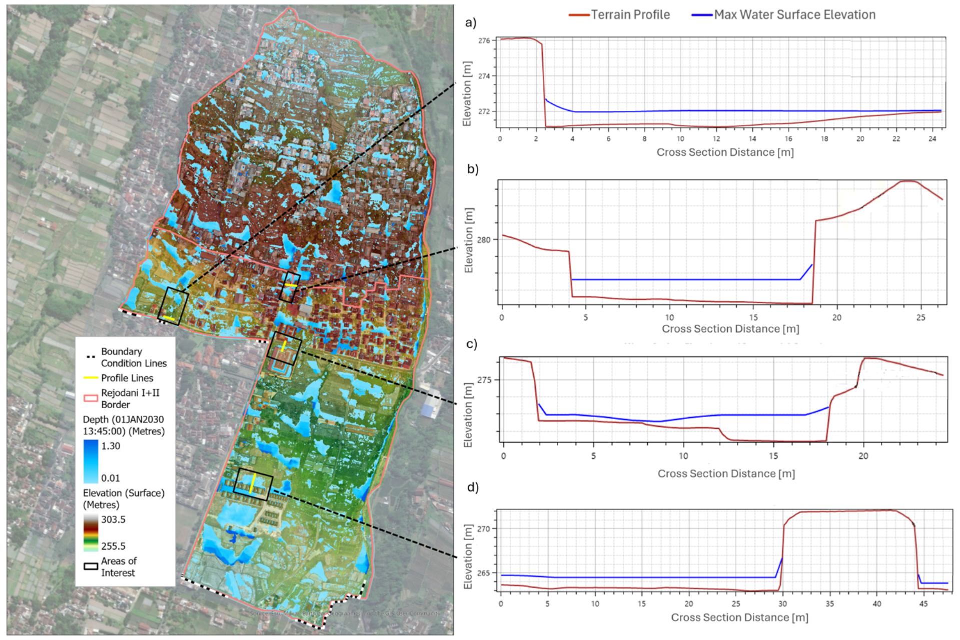

Figure 69.
Instantaneous flood depth map and maximum flood depth cross sections at selected Areas of Interest for a 12hr storm event with a 5-year return period. Water Surface Elevation shown for: a) "Outflow west side" b) "Main Street" c) "Commercial Centre" d) "Housing Estate"
Source: F12-THK, 2024

The results of the model highlighted several areas which have high water depths throughout the event. Of these, 4 were selected as Areas of Interest (AOI). For these areas, cross section showing the elevation and water surface elevation were taken for the highest flood depth at each point. Flood depths in most of the AOIs showed flood depths of over 1m in the events, which is a depth which could cause damage to buildings and infrastructure. Overall, the flood depths associated with more extreme flood events only showed minor increases in flood depth at the AOIs. The RP50 event had a max flood depth of around 20cm higher than the RP5 event. However, larger areas of the study area had water depths of over 0.5m during the RP50 event. A notable trend was that the AOIs typically saw multiple flood waves as runoff travelled down the catchment from different parts of the study area.

Additionally, photos of the AOIs were taken with the modelled flood depths for the different return periods marked (Fig. 70-71).

Figure 70.
Photo of "Main Street" area, a selected area of interest, with overlayed simulated flood levels for a 12hr storm for each event for return periods of 5-year to 50-year
Source: F12-THK, 2024

Figure 71.
Photo of "Commercial Centre" area, a selected area of interest, with overlayed simulated flood levels for a 12hr storm for each event for return periods of 5-year to 50-year
Source: F12-THK, 2024

SWMM Method: Rejodani I +II, Indonesia

The rainfall-runoff simulation results across various return periods (100 years to 1 year) and a 12-hour duration have highlighted significant vulnerabilities in the drainage system (Fig. 72). The higher return periods, such as 100 years, 50 years, and 30 years, pose significant flood risks, with certain junctions consistently reaching their full capacity during extreme events.

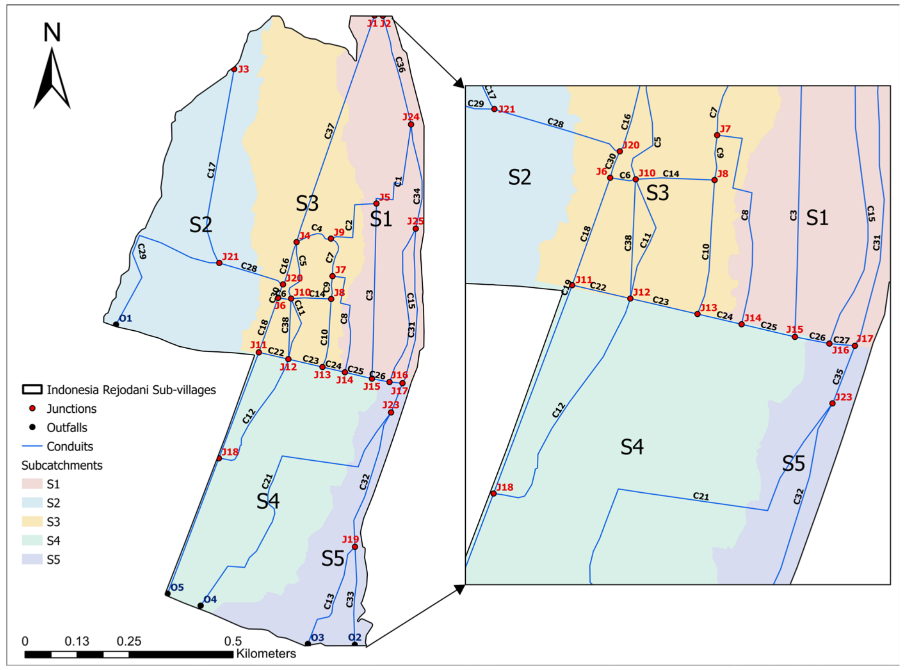

Figure 72.
Representation of Sub catchments and Drainage System
Source: F12-THK, 2024

For example, in the 100-year return period, junctions such as J12, J14, J15, J20, and J18 are particularly vulnerable, as they consistently reach full capacity, indicating a high risk of flooding during severe storms. Similarly, in the 50-year return period, junctions J12, J18, J14, and J20 are under significant stress, reaching full capacity and showing a clear potential for localized flooding. In the 30-year return period, J12, J18, and J20 remain at full capacity, signalling ongoing flood risks in these areas (Fig. 73). Junctions J6, J13, J21, J11, and O5 also show depths approaching critical levels, requiring attention (Fig. 74).

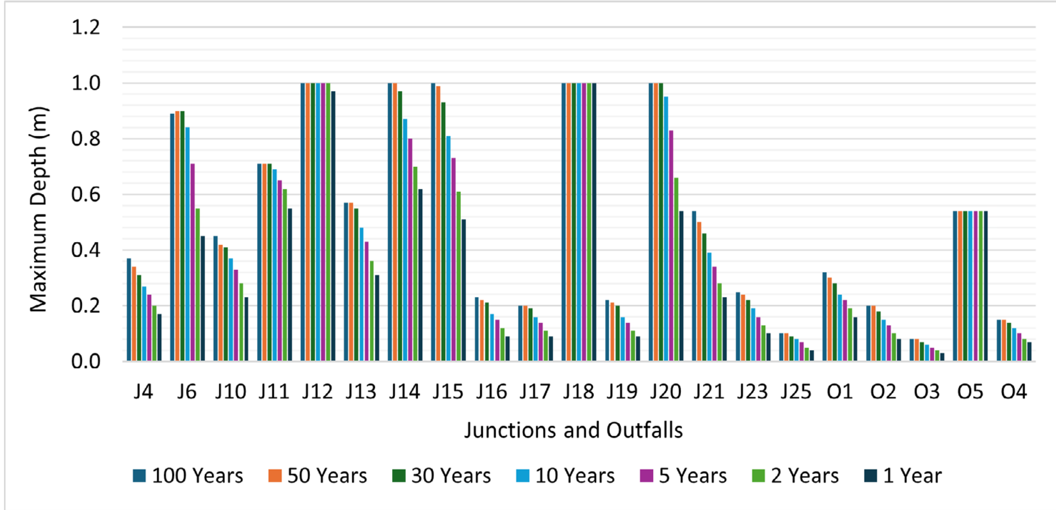

Figure 73.
Reported Maximum Depth (m) of Junctions and Outfalls for Duration 12 Hours.
Source: F12-THK, 2024

Similarly, conduits C12 and C25 demonstrate full depth ratios of 1.0 during extreme events of 100-year, indicating they are at full capacity, risking surcharging, while other several conduits such as C6, C11, C30, C38, C19, C22, C5, C18, and C23 approach critical levels (Fig. 74). These findings highlight key junctions and conduits under significant stress, requiring targeted mitigation measures to enhance system resilience.

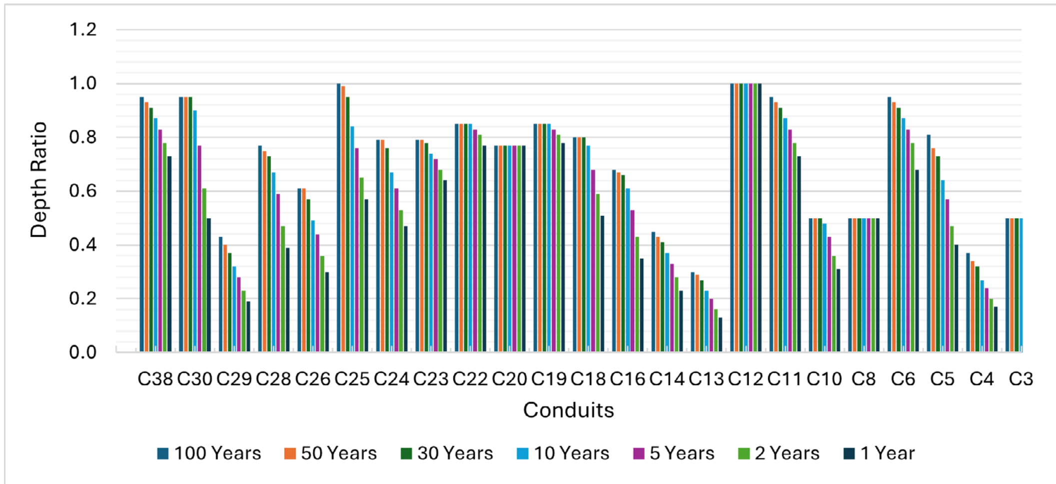

Figure 74.
Maximum Full Depth (m) of conduits for Duration 12 Hours.
Source: F12-THK, 2024

As return periods decrease (10 years, 5 years, 2 years, 1 year), flood risk becomes more localized, with fewer junctions impacted and lower depths across the system. For example, in the 10-year event, flooding is limited to J12 and J18, and conduit performance improves, with reduced full depth ratios. Subcatchment S3 exhibit the highest runoff and peak flows, representing critical flood risks, while S1's low infiltration exacerbates surface flooding potential. Conversely, S5's low runoff and high infiltration effectively mitigate risk. Overall, the results emphasize prioritizing flood mitigation at critical junctions, conduits, and subcatchments identified under higher return periods, ensuring adequate capacity to manage stormwater during extreme events.

Access to the tool

https://th-koeln.sciebo.de/s/TZgNdhBmV4AQLvX

Further Readings

Pichler, M. (2024). idf_analysis: Intensity duration frequency analysis with python based on KOSTRA (v0.2.4). Zenodo. https://doi.org/10.5281/zenodo.10559992

Natarajan, S., & Radhakrishnan, N. (2020). An Integrated Hydrologic and Hydraulic Flood Modeling Study for a Medium-Sized Ungauged Urban Catchment Area: A Case Study of Tiruchirappalli City Using HEC-HMS and HEC-RAS. In Journal of The Institution of Engineers (India): Series A (Vol. 101, Issue 2, pp. 381–398). Springer. https://doi.org/10.1007/s40030-019-00427-2

Khatooni, K., Hooshyaripor, F., MalekMohammadi, B., & Noori, R. (2025). A new approach for urban flood risk assessment using coupled SWMM–HEC-RAS-2D model. Journal of Environmental Management, 374. https://doi.org/10.1016/j.jenvman.2024.123849

Rossman, L. A., & Huber, W. C. (2016). Storm Water Management Model Reference Manual: Volume I – Hydrology (Revised) (EPA/600/R-15/162A). U.S. Environmental Protection Agency, Office of Research and Development.

Rossman, L. A. (2017). Storm Water Management Model Reference Manual: Volume II – Hydraulics (EPA/600/R-17/111). U.S. Environmental Protection Agency, Office of Research and Development.

Tool 3: Data Management and Visualization Support

Author: Juan Luis Ramirez Duval, Surendra Shiwakoti

Scope–Field of Application	Application Scale	The Duration	Users	Skill requirements
• Urban Management • Water Management	• National • Regional • Municipal	• Preparation Time: 15 days • Activity Duration: 15 days	• Open (with users rights) • Close	• Basic • Medium • Advanced

This tool provides an overview of using GeoNode for data management and visualization within the PUW framework. GeoNode is employed to facilitate the organization, sharing, and visualization of geospatial data to enhance cross-institutional collaboration, data-driven decision-making, and public engagement.

What?	GeoNode is an open-source platform designed for managing geospatial data and providing tools for visualization and sharing. It supports creating interactive maps, managing geospatial layers, and fostering collaborative efforts in spatial data handling. Its features enable stakeholders to analyze, store, and disseminate urban water management data efficiently.
Why? / Purpose	GeoNode supports evidence-based urban planning and integrated water resource management by making data accessible and visually interpretable. It bridges communication gaps between stakeholders and promotes informed decision-making.
Field of Application (Scale of Application)	GeoNode is applicable in various domains, including: • Cross-institutional data sharing • Urban water monitoring and management • Risk assessment and mitigation • Urban planning and infrastructure development

End users	End users include municipalities and government agencies, researchers and academic institutions, urban planners, environmental consultants, and civil society organizations. Management, Environmental Studies or related studies
Background	GeoNode originated as a solution for geospatial data management and collaboration. With advances in technology, it has become a powerful tool for organizations aiming to make data-driven decisions in water and urban resource management.
Description	GeoNode facilitates: • **Data Management:** Uploading, categorizing, and storing geospatial data layers in centralized repositories. • **Visualization:** Creating user-friendly dashboards, interactive maps, and visual analytics. • **Collaboration:** Allowing multiple stakeholders to access, annotate, and share data in real-time.
Strengths and Limitations	**Strengths:** Enhances accessibility and sharing of geospatial data, supports real-time collaboration, enables powerful visualization through customizable maps, and is open-source with community support. **Limitations:** Requires data literacy among users, depends on input data quality, and relies on stable IT infrastructure.
Requirements (Instruments used)	Instruments required include GeoNode software, training materials, IT infrastructure, and dedicated maintenance teams.
Keywords	GeoNode, Geospatial Data, Urban Water Management

Tool Manual

Step 1: Accessing the Platform

To begin utilizing GeoNode, follow these steps to access the platform:

- **User Registration:** If you are a new user, navigate to the GeoNode homepage and select the 'Register' option. Fill in the required details, such as username, email, and password, to create your account. Some GeoNode instances may require administrator approval for new accounts. Additionally, GeoNode supports integration with external authentication providers (e.g., LDAP, OAuth2), allowing users to log in using existing organizational credentials.
- **Logging In:** For existing users, click on the 'Login' button and enter your username and password. Upon successful authentication, you will be directed to your user dashboard.
- **User Dashboard:** The dashboard provides an overview of your activities, including uploaded datasets, created maps, and recent interactions. It also provides notifications about recent activities, such as comments on shared maps or datasets, facilitating better collaboration.
- **Navigation Menu:** GeoNode's interface includes a navigation menu with options such as 'Datasets,' 'Maps,' 'Documents,' and 'People.' These sections allow you to explore existing resources, create new ones, and interact with other users.

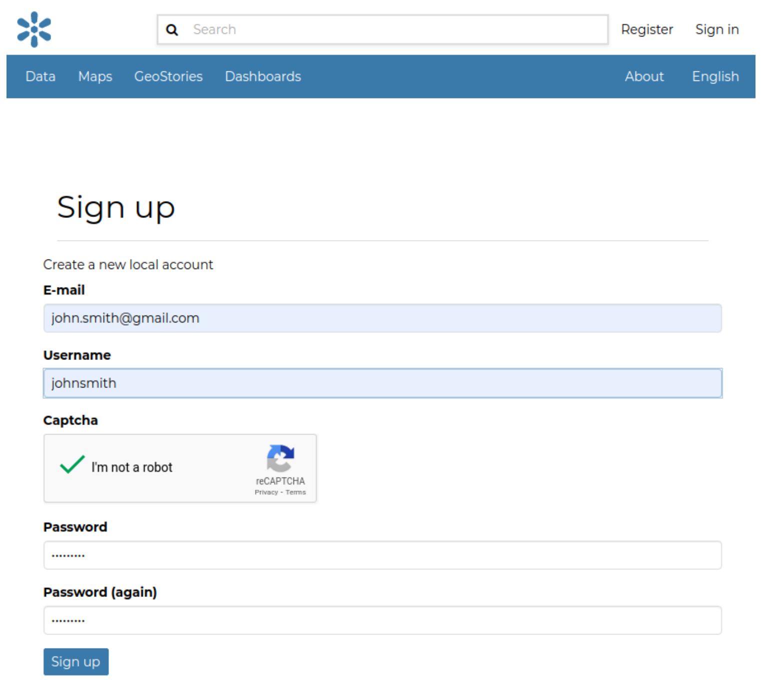

Figure 75:
Creating account/logging into GeoNode.

Step 2: Uploading Data

GeoNode supports the upload of various geospatial data formats, including vector and raster data. To upload data:

- **Access the Upload Page:** Click on the 'Data' menu in the navigation bar and select 'Upload Layer' Alternatively, from the 'Layers' page, click the 'Upload Layers' button.
- **Select Files:** Use the 'Choose Files' button to select the geospatial files from your local system. Ensure that all necessary files for the dataset (e.g., .shp, .shx, .dbf, and .prj for shapefiles) are included. GeoNode supports additional formats like GeoTIFF, KML, and GeoJSON, offering flexibility in the types of data you can upload.
- **Set Permissions:** Before uploading, you can define who will have access to the data by setting permissions. This includes specifying who can view, download, edit, or manage the layer.
- **Metadata Standards:** GeoNode adheres to international metadata standards (e.g., ISO 19115), ensuring that your data is well-documented and easily discoverable by others. Providing comprehensive metadata enhances data interoperability and reuse.
- **Upload Files:** After selecting the files and setting permissions, click the 'Upload files' button to initiate the process. A progress bar will indicate the upload status. Once completed, you can view the uploaded layer's information to verify its correctness.

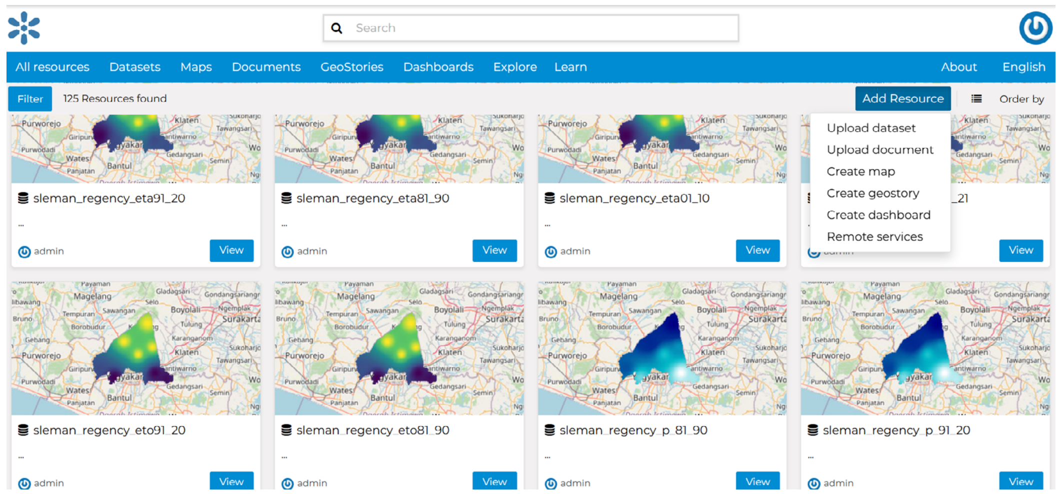

Figure 76.
Data catalogue in GeoNode

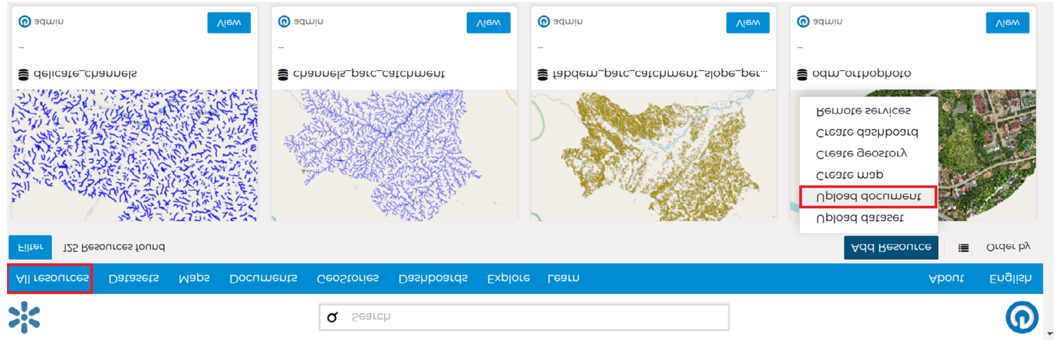

Figure 77.
Data Uploading using GeoNode User Interface

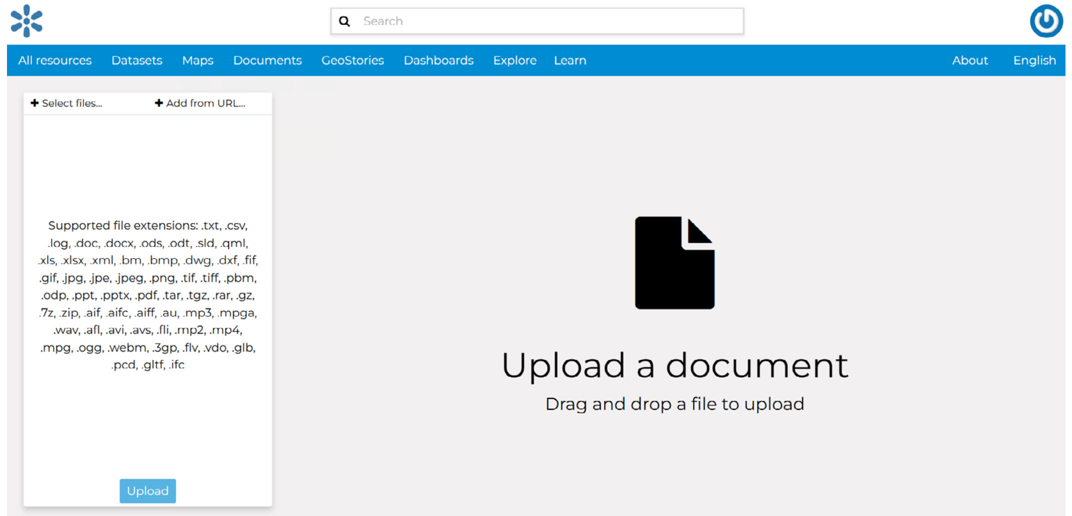

Figure 78.
Upload datasets in GeoNode

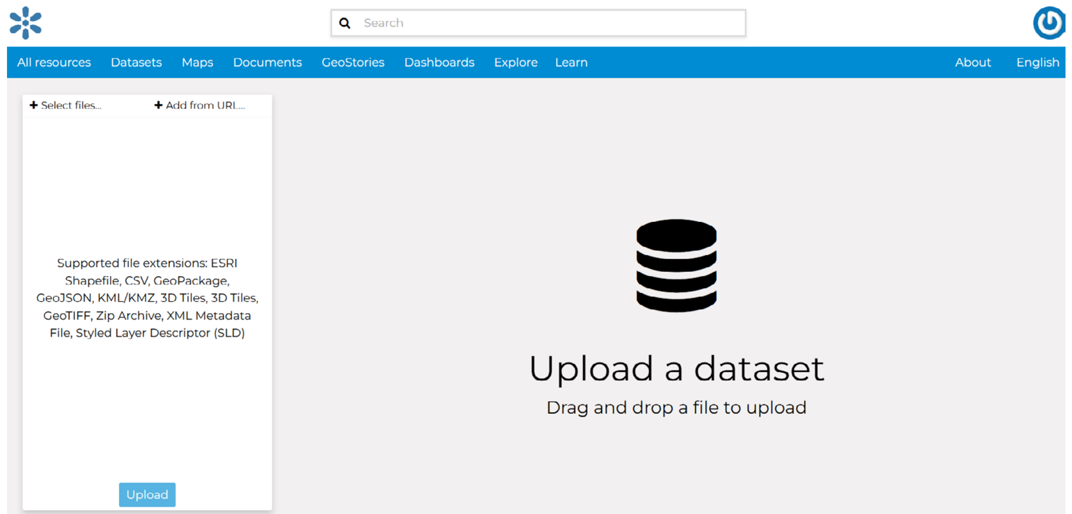

Figure 79.
Upload datasets in GeoNode

Step 3: Managing Layers

After uploading, managing layers involves organizing, editing, and styling your geo-spatial data:

- **Layer Information:** Access the 'Layer Info' page to view metadata, including the layer's title, abstract, keywords, and spatial extent. Ensure that this information is accurate to facilitate data discovery and usage.
- **Editing Metadata:** If updates are needed, use the 'Edit' option to modify the layer's metadata. This includes updating descriptions, adding keywords, and setting the appropriate coordinate reference system (CRS).
- **Styling Layers:** GeoNode integrates with MapStore, offering advanced styling capabilities, including the creation of complex symbols and the application of data-driven styles. Customize the visual representation of your data by accessing the 'Style' tab. Define symbology, such as colors, line styles, and labels, to enhance the map's readability.
- **Attribute Management:** Through the attribute table, users can explore, edit, and analyze individual data attributes for each layer.
- **Setting Permissions:** Adjust permissions at any time to control access to your data. This is crucial for collaborative projects where different team members may require varying levels of access.
- **Deleting Layers:** If a layer is no longer needed, you can delete it by selecting the 'Delete' option. Be cautious, as this action is irreversible and will remove the data from the platform.

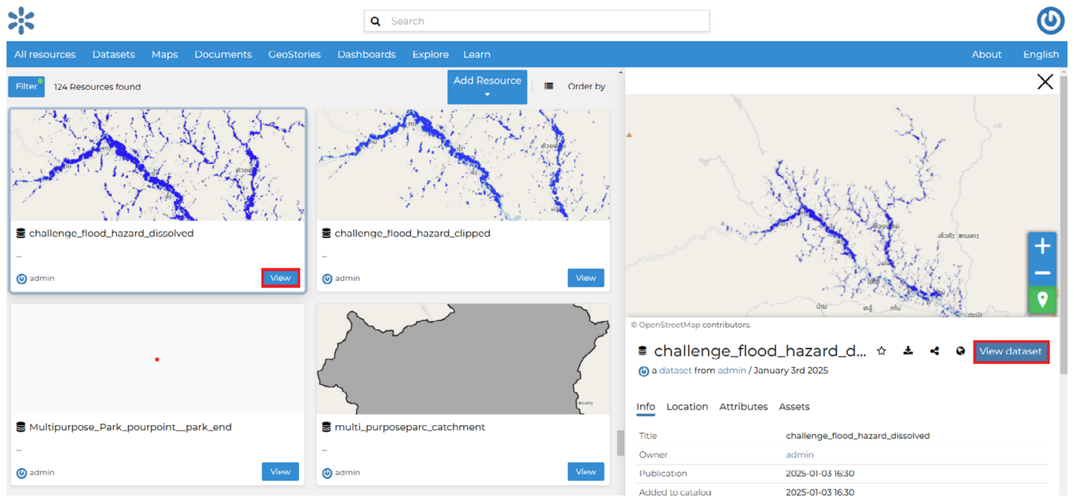

Figure 80.
Dataset browser in GeoNode user interface

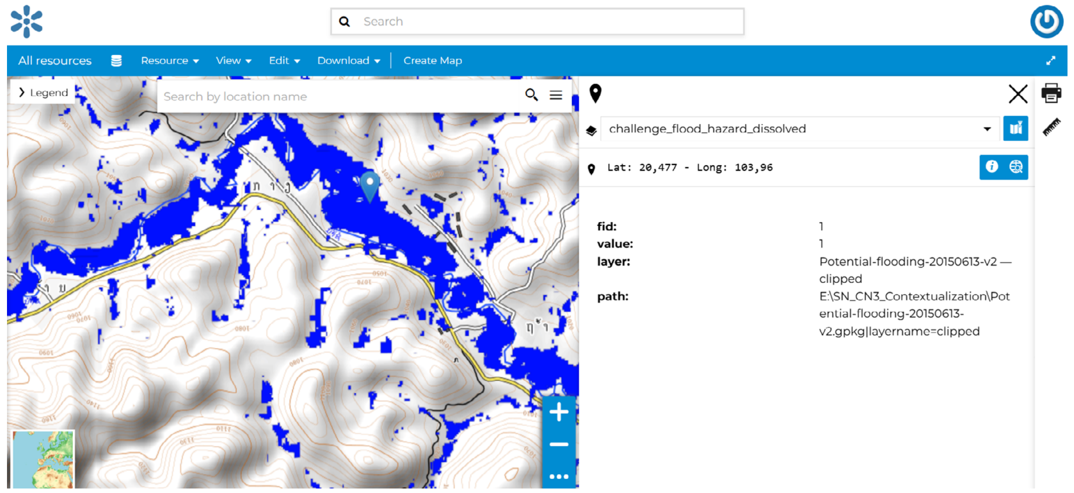

Figure 81.
Attribute viewer in GeoNode user interface

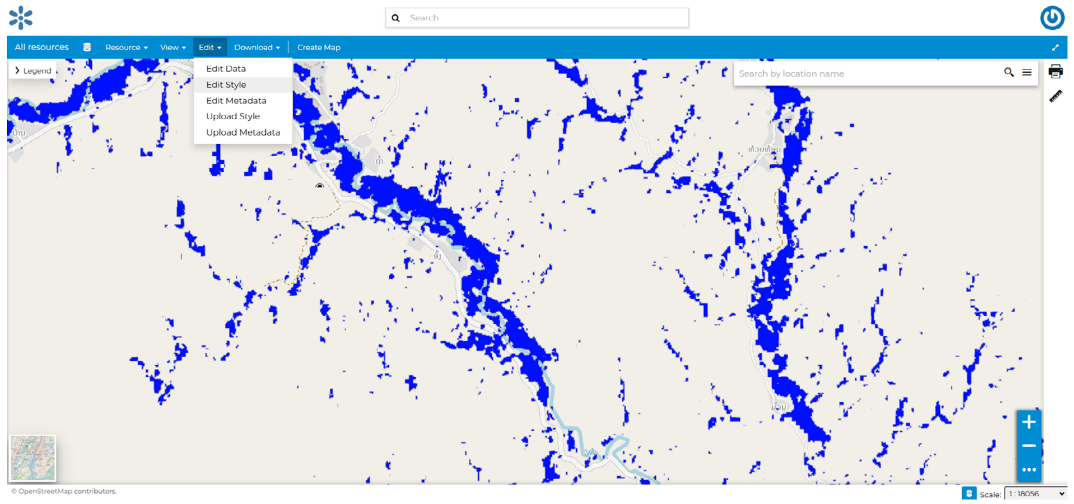

Figure 82.
Style customization in Geonode

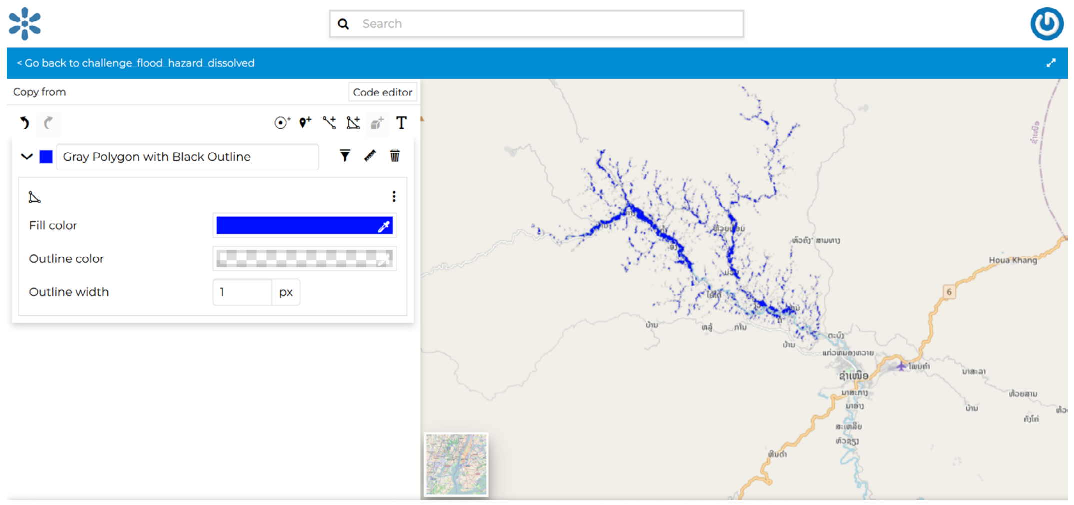

Figure 83.
Editing style of geospatial data in GeoNode

Step 4: Creating Maps

GeoNode allows you to create interactive maps by combining multiple layers:

- **Initiate Map Creation:** Navigate to the 'Maps' menu and select 'Create Map.' This opens the map viewer interface, where you can begin assembling your map.
- **Add Layers:** Use the 'Add Layers' function to search for and select the datasets you wish to include. You can add multiple layers, adjusting their order to control visibility and overlap.
- **Configure Layer Settings:** For each layer, you can adjust settings such as opacity, visibility, and display order. These controls help in creating a clear and informative map presentation.
- **Apply Styles:** If you have predefined styles, apply them to the respective layers to ensure consistent symbology. This enhances the map's aesthetic and functional quality.
- **Add Annotations:** Enhance your map by adding annotations, such as text labels, markers, and shapes, to highlight important features or provide additional context.
- **Save the Map:** Once satisfied with the composition, save your map by providing a title, abstract, and relevant tags. This metadata facilitates easy retrieval and sharing of the map.

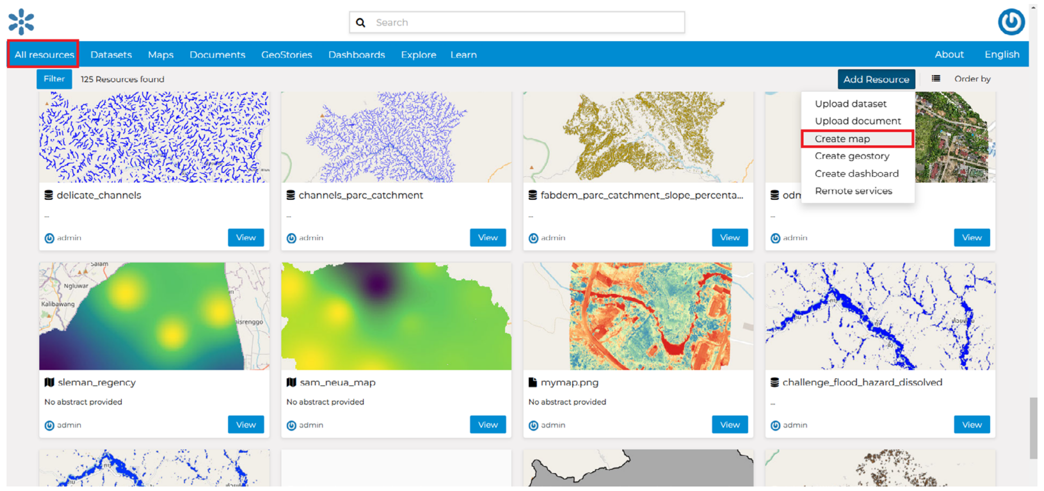

Figure 84.
Creating a new map in GeoNode using the all resources or Maps tab

4. Transformation Pathways Tools / Tool 3

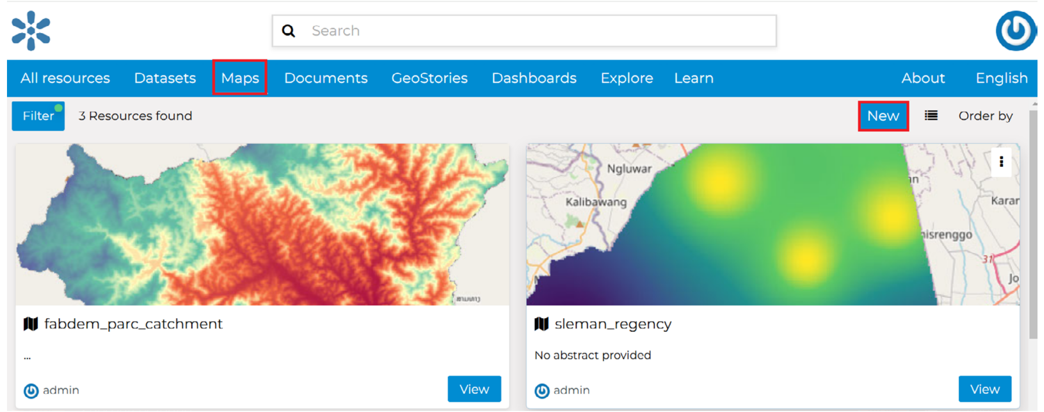

Figure 85.
Listing all existing maps in GeoNode

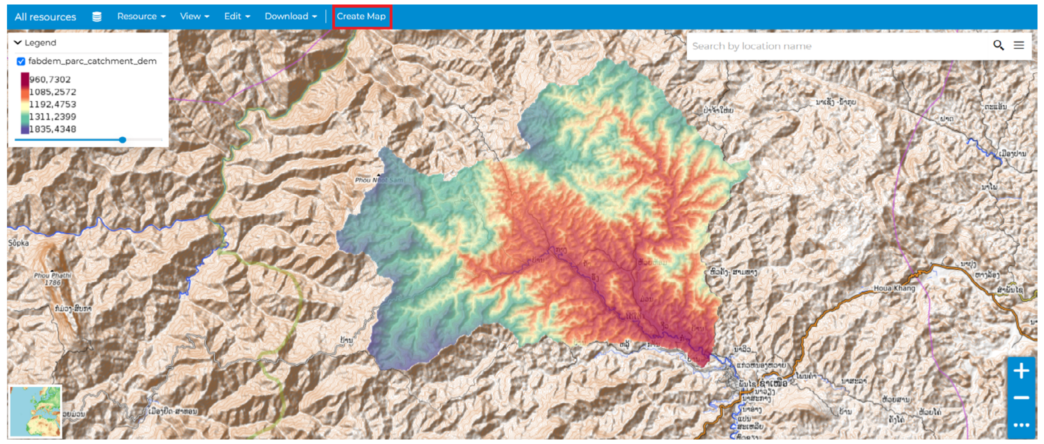

Figure 86.
Interactive visualization of dataset with map creation option in GeoNode

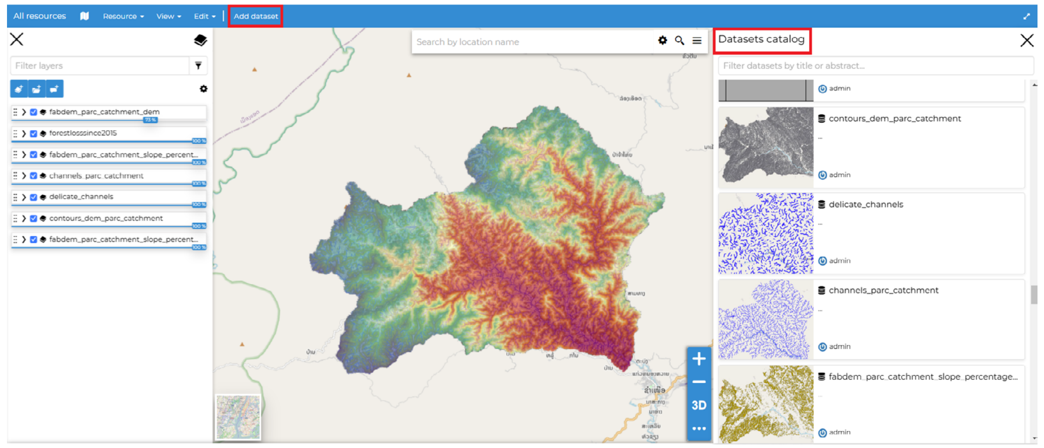

Figure 87.
Add multiple layers to the map from Datasets catalog in GeoNode

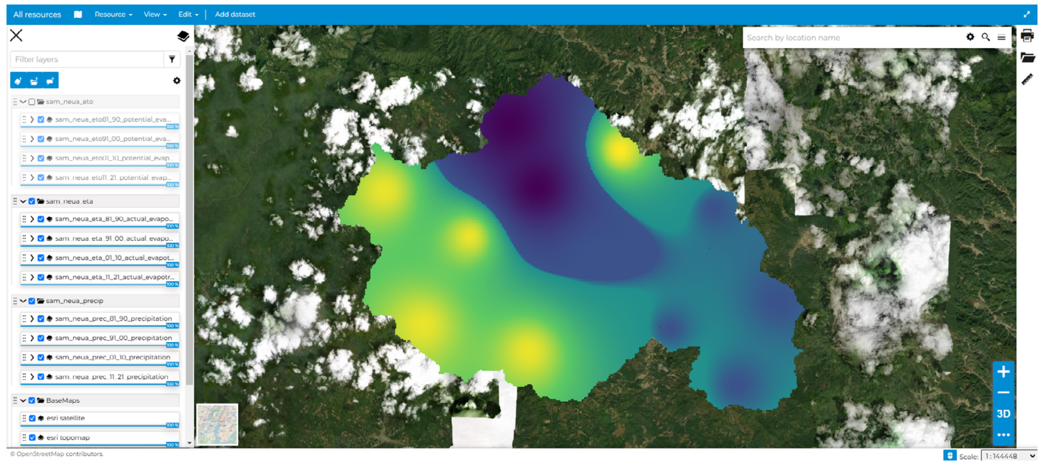

Figure 88.
Interactive map with multiple geospatial datasets and basemaps in GeoNode

5. Sharing and Collaboration

GeoNode emphasizes collaboration by enabling users to share resources and work together effectively:

- **Resource Sharing:** Share datasets, maps, and documents with specific users, groups, or the public. Generate shareable links or embed codes for external websites or platforms.
- **Groups and Communities:** Create user groups to collaborate on projects with specific stakeholders. Assign roles and permissions to group members for controlled data access.
- **Feedback and Comments:** Enable comments on layers and maps to gather input from collaborators. Use annotations to point out specific areas or issues within a dataset.
- **Notifications:** Set up alerts to notify you of updates, comments, or shared resources.

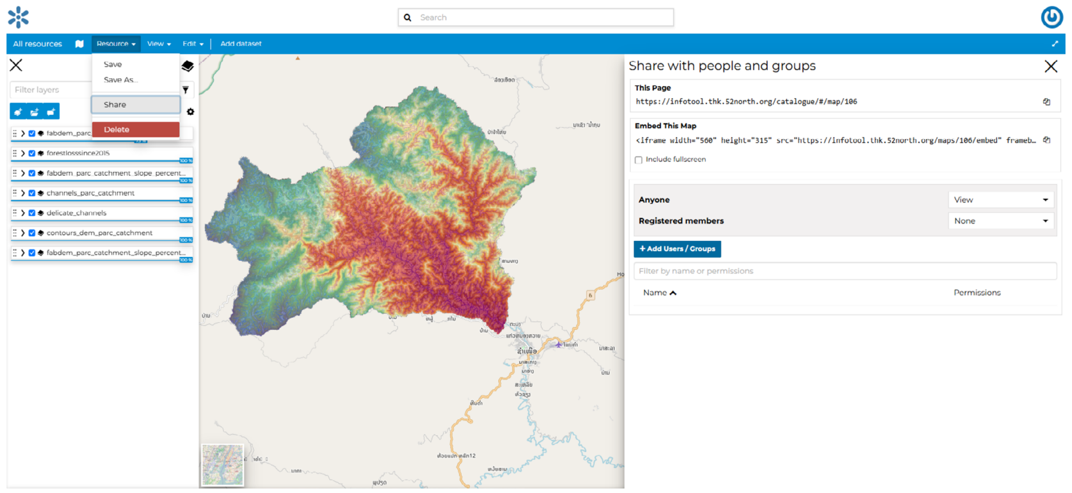

Figure 89.
Configuration of sharing options for datasets, maps and documents

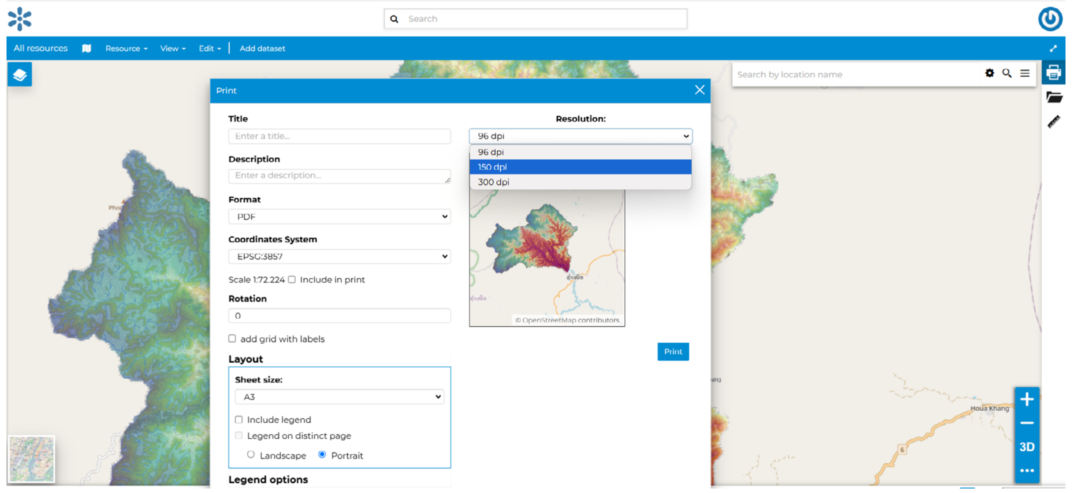

Figure 90.
High resolution map printing option in GeoNode

Step 6: Visualizing Data

Visualization tools in GeoNode transform raw data into meaningful insights:

- **Dashboards:** Combine multiple visual elements, such as maps, charts, and tables, into a single dashboard. Use dashboards to present data summaries and analytics in an interactive format.
- **Filters and Queries:** Apply filters to focus on specific data subsets (e.g., date ranges, geographic areas). Use query tools to extract and display data matching custom criteria.
- **Heatmaps and Graphs:** Generate heatmaps to visualize density or intensity patterns. Create graphs, such as bar or pie charts, linked to geospatial features for statistical analysis.
- **Story Maps:** The storytelling feature combines maps with text, images, and multimedia. Present narratives about urban challenges, water resource management, or other themes.

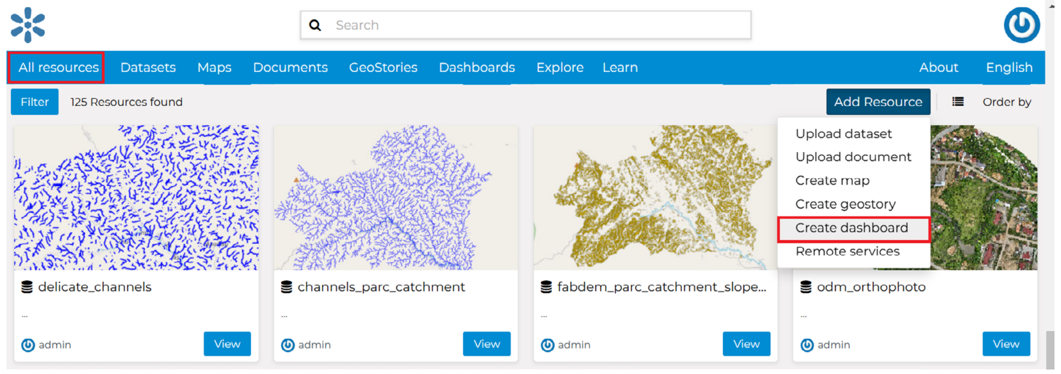

Figure 91.
Creating new Dashboard in GeoNode

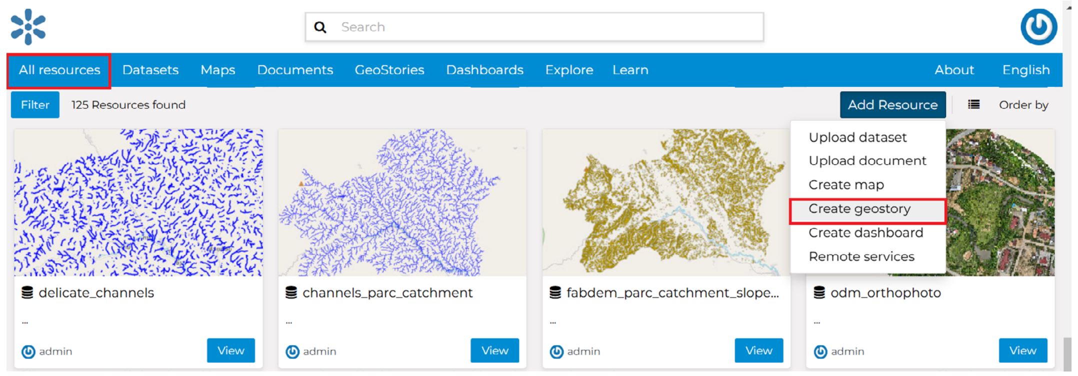

Figure 92.
Creating new GeoStoriy in GeoNode

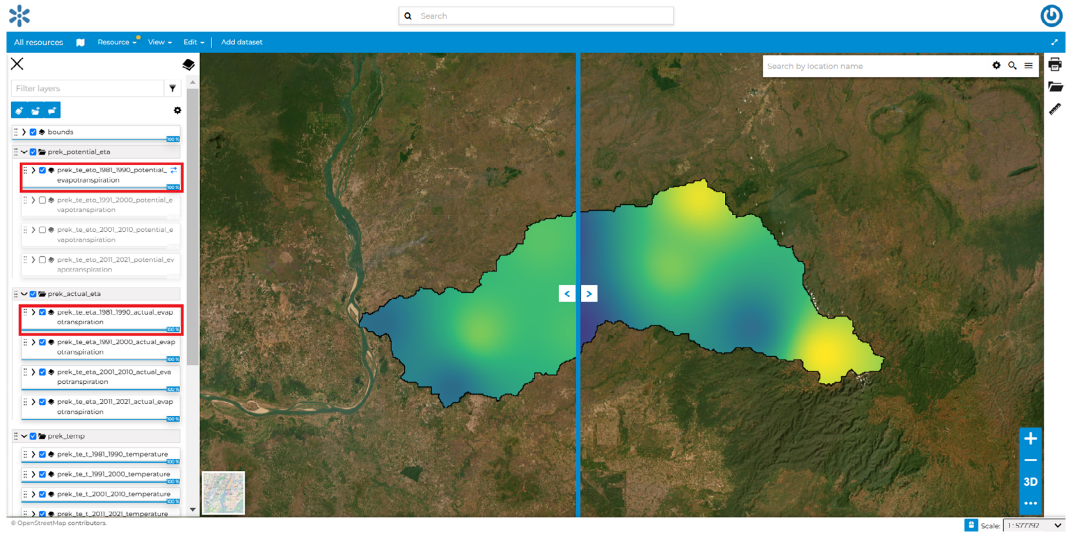

Figure 93.
Dual Map view in GeoNode Map Interface

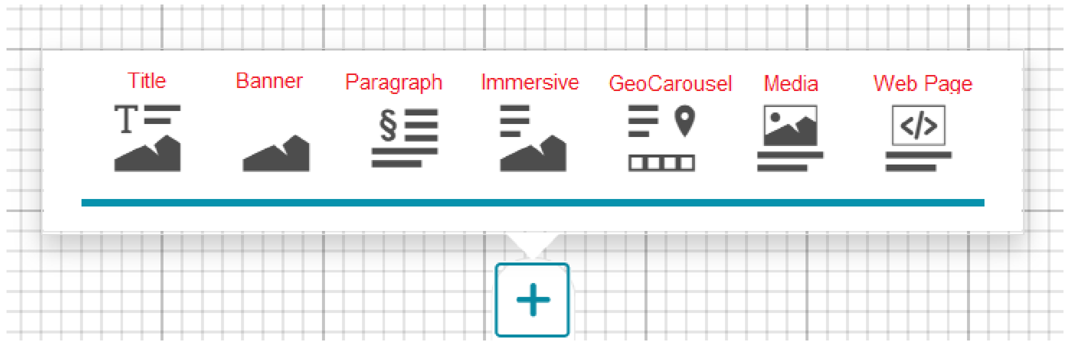

Figure 94.
Available elements for designing GeoStories

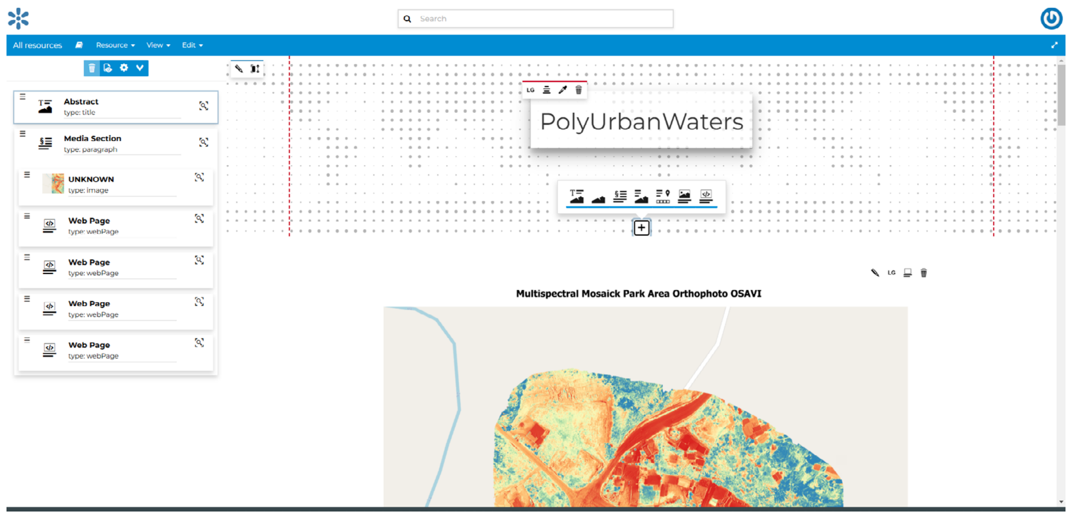

Figure 95.
Designing GeoStory using multiple elements

Step 7: Collaborative Features

GeoNode fosters teamwork by providing robust collaborative tools:

- **Version Control and History:** Monitor changes to datasets and maps over time with built-in version history. Collaborators can view and revert to previous versions if necessary.
- **Real-Time Editing:** Enable simultaneous editing of datasets or maps by multiple users. Use locking mechanisms to prevent conflicts when two users modify the same feature.
- **Integration with External Tools:** Connect GeoNode with external GIS software like QGIS or ArcGIS for advanced editing. Export and import data seamlessly between platforms.
- **Discussion Forums:** Use integrated forums or comment threads for team discussions. Document decisions and feedback within the GeoNode environment.

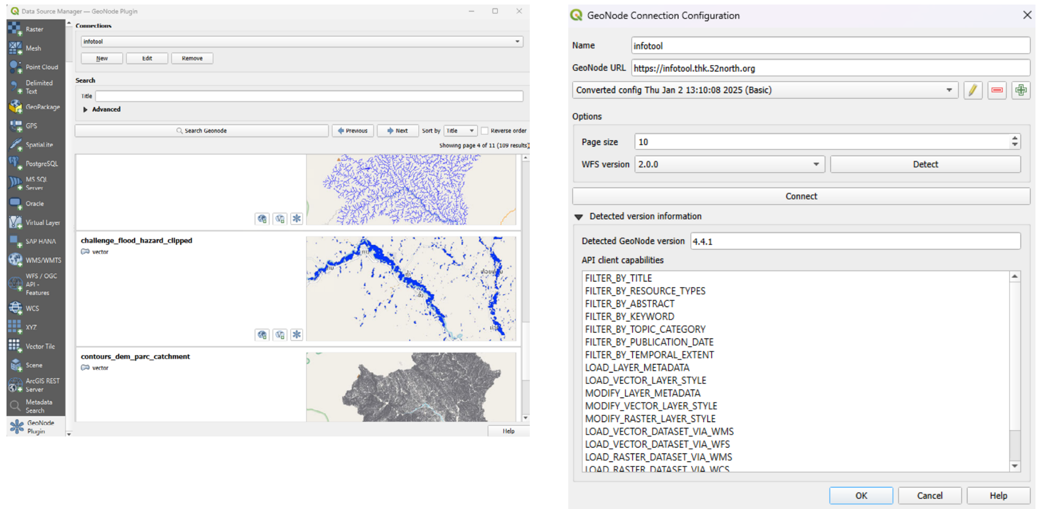

Figure 96.
Browsing Geonode datasets in QGIS platform using Geonode plugin

Further readings

GeoNode Official Documentation: https://docs.geonode.org

5. Similar Tools

Several tools, similar to the developed tools in this toolkit are available, each designed to meet similar needs with its own unique features and approach. Some of tools are easily accessible and offering open-source platforms. Exploring these alternatives, or as called (similar tools), can provide a clear understanding of the broader range of choices, helping users find the solution that best aligns with their goals and workflow. Table 6 summarizes similar tools with a brief description of each.

Table 8. Selection of Similar Tools

Name of the tool	Description	Access/Link
Similar tools for Stakeholder mapping		
The Biodiversity and Environmental Stakeholder Map	An interactive tool that identifies key steps and stakeholders crucial for implementing biodiversity initiatives in the Built Environment Sector. It highlights milestones and roles for successful outcomes.	https://embed.kumu.io/b880c6229d6bc044b-35b9ab0d7cbdfea#b-ng-eng-stakeholder-map/stakeholder-map-final
Similar tools for Identification and Assessment of Ecosystem Services		
Completing and Using Ecosystem Service Assessment for Decision-Making: An Interdisciplinary Toolkit for Managers and Analysts	provides a systematic framework for identifying and assessing ecosystem services by combining quantitative metrics with qualitative insights, ensuring a comprehensive evaluation of benefits such as clean air, water, and climate regulation. It emphasizes an integrated stakeholder approach, involving local communities and experts to capture diverse perspectives and align outcomes with regional priorities.	https://publications.gc.ca/site/eng/9.829253/publication.html
Protected Areas Benefits Assessment Tool + (PA-BAT+)	This tool streamlines the process of identifying and assessing ecosystem services within protected areas. It highlights how nature supports human well-being—providing vital services like carbon storage, water supply, and recreation—to inform more effective conservation and sustainable management decisions.	https://iucn.org/resources/publication/protected-areas-benefits-assessment-tool-pa-bat

Similar tools for Assessment of Local Perception of NbS and Hybrid Solutions		
Survey on nature-based solutions (NBS) in urban areas	Aims to address knowledge gaps in procedural aspects affecting NbS implementation, focusing on bottlenecks and challenges in Europe and Latin America to promote learning and improvement	https://www.lss.ls.tum.de/en/lapl/news-archive/article/survey-on-nature-based-solutions-nbs-in-urban-areas/
Similar tools for Urban Water Accounting		
Site-scale Urban Water Mass Bass Assessment (SUWMBA) Tool	The tool is designed to perform four main steps: • Defines the urban entity to be assessed • Inputs parameters needed to estimate urban water flows • Compiles the urban water mass balance • Generates water sensitive performance indicators.	https://watersensitivecities.org.au/site-scale-urban-water-mass-balance-tool-suwmba/
Urban Water balance model	The tool calculates runoff return periods for small urban areas with uniform hydro(geo)logic conditions, using long-term rainfall and evaporation data (minimum 30 years).	https://publicwiki.deltares.nl/display/AST/
Similar tools for Insights for Urban water Management using Open-Source Datasets		
The Global SPEI database	SPEIbase provides global drought data at 0.5° spatial and monthly time resolution, covering 1–48 month timescales. Based on precipitation and evapotranspiration data since 1901.	https://spei.csic.es/database.html
Global drought Observatory	The platform shows real-time visual insights into global drought conditions. It features various indicators, like the Risk of Drought Impact for Agriculture, to support effective drought monitoring and management.	https://drought.emergency.copernicus.eu/tumbo/gdo/map/
Global Drought Monitor	This tool provides a comprehensive visualization of global drought data. Integrated with the Global Drought Information System (GDIS), it offers a range of indicators to help monitor and manage drought impacts on a global scale.	https://experience.arcgis.com/experience/883e8644b5ed-4f029657565e24fe9968/
Climpact	a web-based application developed by the World Meteorological Organization's Expert Team on Sector-Specific Climate Indices (ET-SCI) that allows users to calculate various climate indicators using their own daily weather data, either from point sources or gridded datasets	https://climpact-sci.org/get-started/

Similar tools for Drone Survey		
Breaking down drone mapping: step-by-step guide	Describes the entire RTK drone mapping work-flow from scratch, using an example	https://blog.emlid.com/breaking-down-the-drone-mapping-a-step-by-step-guide/
Digital Platform for Unmanned Aviation	The current version of the Map Tool is intended to support pilots of drones to plan and carry out drone flights	https://www.dipul.de/homepage/en/help/map-tool-instructions/
Similar tools for Compendium of Nature-based Solutions for Water Resources Management		
NbS / Hybrid Solutions	Tool to identify potential (nature based/hybrid) solutions for a given identified challenge and given local characteristics	http://nwrm.eu/ Or https://www.urban-greenup.eu/resources/final-catalogue-results-of-kpi-and-nbs-evaluated/final-catalogue-results-of-kpi-and-nbs-evaluated.kl Or https://urbinat.eu/nbs-catalogue/
The UNaLab NBS Technical Handbook Factsheets	Designed to offer concise, accessible information on various nature-based solutions (NBS).	https://www.ilpoe.uni-stuttgart.de/files/UNaLab_Handbook.pdf
Similar tools for Selection and Assessment of Potential Nature- based Solutions		
Nature-based Solutions Evidence Platform	An interactive tool that connects NbS with climate change adaptation outcomes, created using insights from a thorough review of peer-reviewed studies.	https://www.naturebased-solutionsevidence.info/evidence-tool/

Similar tools for Assessment of Impact and Effectiveness of Selected NbS		
Evaluating the Impact of Nature-Based Solutions	• **Comprehensive Framework:** Provides a robust impact assessment framework tailored for evaluating nature-based solutions. • **Indicator Toolkit:** Offers a set of reliable indicators and methodologies for measuring environmental and social impacts. • **Broad Societal Coverage:** Assesses impacts across 12 societal challenge areas, including climate resilience, water management, and natural hazards. • **Policy Support:** Equips decision-makers with data-driven insights to promote sustainable, nature-based strategies	https://oppla.eu/sites/default/files/uploads/evaluating-impact-nature-based-solutions-handbook-practitioners.pdf
Similar tools for Rooftop Rainwater Harvesting Calculator		
SamSamWater Rainwater Harvesting Tool	This tool helps to calculate the ideal size for rainwater harvesting reservoir.	https://www.samsamwater.com/rain/
FEMP Rainwater Harvesting Tool	Help evaluate the feasibility of rainwater collection through an interactive and user-friendly approach.	https://pnnl-gis.maps.arcgis.com/apps/dashboards/0a305382f87740ccb2296404d40d0cb0
Similar tools for Hydrological and Hydraulic Modelling		
MIKE+ 2D Overland	Analyse interactions between sewer networks and overland flow to support the realistic planning, evaluation, and design of urban drainage systems	https://www.dhigroup.com/technologies/mikepoweredbydhi/mikeplus-2d-overland
TUFLOW	Handles a diverse range of applications: flooding assessments; infrastructure design and optimisation; dam break assessment; urban drainage	https://www.tuflow.com/
Similar tools for Data Management and Visualization Support		
GeoNode	GeoNode is an open-source platform designed for managing geospatial data. It serves as a web-based tool for building geospatial information systems (GIS) and setting up spatial data infrastructures (SDI).	https://docs.geonode.org/en/master/

6. Closing Chapter

The *Water-Sensitive Infrastructure Development Toolkit,* developed within the framework of the *Polycentric Approaches of Urban Water Resources Management in South-East Asia (PUW)* project, represents a significant step forward in supporting sustainable urban development in Southeast Asia. This toolkit is designed to address the pressing challenges faced by rapidly growing cities and peri-urban areas in the region, with pilot projects in Kratie (Cambodia), Sariharjo (Indonesia), and Sam Neua (Laos).

The toolkit's comprehensive approach, encompassing 12 practical tools categorized into project management and stakeholder decision support, empowers diverse stakeholders to engage in polycentric urban development and integrated water resources management. By facilitating baseline assessment, vision building, and transformation pathways, these tools enable cities to adopt more resilient and inclusive water management strategies.

A key strength of the toolkit is its emphasis on leveraging innovative technologies, such as drones, and utilizing open-source datasets to overcome data scarcity challenges prevalent in the region. This approach not only enhances data accuracy but also supports informed decision-making processes.

The promotion of Nature-based Solutions (NbS) for water resource management is another critical aspect of the toolkit. NbS offer effective and sustainable ways to mitigate urban water challenges, aligning with the broader goal of fostering sustainable, inclusive, and water-sensitive cities.

The toolkit's focus on collaborative governance structures and capacity building among local stakeholders underscores its commitment to ensuring long-term sustainability and adaptability. By engaging a broad range of stakeholders, including government agencies, urban planners, researchers, private sector participants, and NGOs, the toolkit ensures that urban water management strategies are both equitable and effective.

In conclusion, the *Water-Sensitive Infrastructure Development Toolkit* provides a valuable resource for cities in Southeast Asia seeking to navigate the complexities of urban growth while prioritizing sustainability and resilience. As urbanization continues to shape the region's landscape, this toolkit stands as a testament to the potential of polycentric approaches and integrated water management to create more livable and sustainable urban environments.

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Abbreviations

AI	Aridity Index
AOI	Area of Interest
BGI	Blue-Green Infrastructure
BT	Brightness temperature
CBO	Community-Based Organizations
CICES	Common International Classification of Ecosystem Services
CN	Curve Number
DDF	Depth-duration-frequency
DSM	Digital Surface Model
DJI	Da-Jiang Innovations (Company)
DTM	Digital Terrain Model
EPEs	Extreme Precipitation Events
ES	Ecosystem Services
ESC	Environmental Sanitation Cambodia
BORDA	Bremen Overseas Research and Development Association
Eta	Actual evapotranspiration
ETo	Potential evapotranspiration
FFA	Flood Frequency Analysis
FGD	Focus Group Discussion
GIS	Geographical Information System
GLI	Green Leaf Indicator
HEC-HMS	Hydrologic Engineering Center's Hydrologic Modeling Software
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HSG	Hydrological Soil Group
IDF	Intensity-duration-frequency
JPEG	Joint Photographic Experts Group (file format)
KPIs	Key Performance Indicators
LST	Land Surface Temperature
LULC	Land use/land cover
NbS	Nature-based Solution
NDVI	Normalized Difference Vegetation Index
NGOs	Non-Governmental Organizations
ODM	Open Drone Map (Open-source Software)
PUW	PolyUrban Water
QGIS	Quantum Geographical Information System (Open-source Software)
RGB	Red-Green-Blue (photograph spectral composition)
RRWH	Rooftop Rainwater Harvesting
RWH	Rainwater Harvesting
SDGs	Sustainable Development Goals
SEA	Southeast Asia

SET	Social, Environmental, and Technological framework
SMRF	Simple Morphological Filter
SOU	Scale of Users
SPEI	Standardized Precipitation and Evapotranspiration Index
SPI	Standardized Precipitation Index
SPU	Ecosystem Services Providing Unit
SWMM	Stormwater Management Model
TCI	Temperature Condition Index
TP	Transformation Pathways
UAVs	Unmanned Aaerial Vehicles
VB	Vision Building
VCI	Vegetation Condition Index
VHI	Vegetation Health Index
VOI	Value of Importance
VOT	Value of Trend
WP	Work Package
WRM	Water Resources Management
WSE	Water Surface Elevation
WSUD	Water-sensitive Urban Design
WSUGs	Water and Sanitation User Groups
WUAs	Water User Associations

Terminology and Definitions

Aridity index: The Aridity Index (AI) is a numerical indicator that assesses the degree of dryness in a region's climate. Developed by *Middleton & Thomas (1992)*, it is calculated as the ratio of potential evapotranspiration (ETo) to precipitation (P). This index is widely used to characterize regional climate conditions and evaluate the aridity of specific areas (Liu et al., 2013).

Blue-Green Infrastructure: Refers to strategically planned networks of natural and semi-natural areas such as forests, wetlands, or green corridors designed to protect water resources, enhance biodiversity, and provide recreational space *(Gupta & De, 2024)*.

Common International Classification of Ecosystem Services (CICES): A standardized framework used globally to identify, classify, and describe Ecosystem Services. It ensures consistent terminology for comparing ES across different regions and projects. *(Maes et al., 2018; Roy Haines-Young & Potschin, 2018a)*.

Conservation: Solutions that involve making better use of existing natural or protected ecosystems (e.g. measures to increase fish stocks in an intact wetland to enhance food security) *(Eggermont et al., 2015; Cohen-Shacham et al., 2016)*

Desk-based Research: Desk-based research is the systematic analysis of existing data and information, including literature reviews, internet searches, and secondary analysis, to build on or contextualise existing knowledge *(Moore, 2006)*.

Digital Surface Model: A Digital Surface Model (DSM) is an elevation model that captures both the environment's natural and artificial features. It includes the tops of buildings, trees, powerlines, and any other objects. Commonly, this is seen as a canopy model and only 'see's ground where there is nothing else above it *(Marwaha & Duffy, 2021)*.

Digital Terrain Model: A Digital Terrain Model (DTM) is a bare-earth elevation model. DTMs do not contain any features above the bare-earth, even persistent ones. Thus, they can be paired with DSMs to derive height information regarding objects on the surface *(Marwaha & Duffy, 2021)*.

Drought hazard indices: are computed numerical representations used to provide a quantitative assessment of the severity, location, timing, and duration of drought events. These indices transform complex hydrological dynamics into accessible, interpretable metrics that facilitate effective communication across multidisciplinary stakeholder groups, enabling a comprehensive understanding of drought characteristics *(Svoboda & Fuchs, 2016)*.

Ecosystem Services (ESs): Refer to the advantages that humans derive from ecosystems, which are crucial for sustaining and enhancing human life *(Brown & Fagerholm, 2015)*.

Ecosystem Services Providing Units (SPUs): A location or habitat (e.g., a forest or wetland) that supplies one or more ES. SPUs can be delineated through GIS and local stakeholder input to identify exactly where the services originate *(Roy Haines-Young & Potschin, 2018b)*.

Extreme Precipitation Events indices: are quantitative measures to assess and characterize the frequency, intensity, and duration of heavy rainfall events. These indices help climate scientists and hydrologists to analyze trends in extreme precipitation patterns over time *(Climdex, 2021)*.

Flood Frequency Analysis: is a statistical technique for predicting the magnitude and probability of flood events along a river or stream. It involves analysing historical peak flow data to estimate the likelihood of floods of various sizes occurring in the future *(Dalrymple, 1960)*.

Fluvial Flooding: Fluvial flooding occurs when rivers and streams break their banks and water flows out onto the adjacent low-lying areas (the natural floodplains) (OPW, n.d.).

GeoNode: GeoNode is a user-friendly platform designed for managing and publishing geospatial data. It integrates reliable open-source tools into a cohesive system, enabling users, even those without specialized expertise, to share data and develop interactive maps *(AGSRT, 2024; GeoNode Project, 2024)*.

Geospatial Data: Geospatial data refers to information linked to particular places on the Earth's surface, forming the basis for numerous analyses and applications. This enables sectors such as urban planning and environmental science to take advantage of data-informed decision-making processes *(AGSRT, 2024)*.

Hydraulic Modelling: A hydraulic model is a collection of mathematical equations that give a simple representation of reality. They estimate flow, water level and velocity in river channels, pipe networks, tidal systems, open coast processes and floodplains (Environment Agency, 2023)

Hydro-meteorological Baseline assessment: is a comprehensive evaluation of existing water resource and climate conditions in a specific area. This baseline involves collecting and analyzing data on hydro-meteorological parameters and serves as a reference point for future monitoring and climate change scenario analysis *(Sahani et al., 2019)*.

Hydrological Modelling: A hydrologic model simulates a flux, flow, or change of water storage with time within one or more components of the natural hydrologic cycle *(Ogden, 2021)*.

Hydrological Year: A continuous 12-month period, the hydrological year, during which an entire annual water runoff cycle occurs. It commences with the start of the season of soil moisture recharge, includes the season of maximum runoff (or season of maximum groundwater recharge), if any, and concludes with the completion of the season of maximum evapotranspiration (or season of maximum soil moisture utilization) *(AMS, 2024)*.

Indicators: Quantifiable or qualifiable measures used to evaluate the effectiveness and impact of NbS. Indicators typically address water management, climate resilience, biodiversity enhancement, green space management, air quality, place regeneration, social capacity building, and other relevant domains *(European Commission, 2021a)*.

Installation: Solutions that involve creating new ecosystems (e.g. establishing green buildings (green walls, green roofs)) *(Eggermont et al., 2015; Cohen-Shacham et al., 2016)*.

Interviews: An interview is a method of collecting data where the researcher personally engages with the participant, asking questions and noting their answers. Interviews can follow a structured format with a set list of questions or take a more open-ended approach, allowing for flexible and detailed responses *(Kuter & Yilmaz, 2014)*.

Land Use – Land Cover (LULC): An integrated approach that classifies and analyzes both the natural physical characteristics of the land (land cover) and the human-driven activities or functions applied to it (land use). (FAO, n.d.)

Monitoring and Evaluation: The systematic collection and assessment of data regarding NbS interventions. Monitoring and Evaluation ensures that information is gathered on whether the intervention is meeting its stated objectives and producing measurable outcomes (e.g., reduced flood frequency, improved water quality (European Commission, 2021b).

Nature-based Solutions (NbS): strategies to conserve, manage sustainably, and restore natural or altered ecosystems to tackle societal challenges effectively and adaptively, while providing benefits to both human well-being and biodiversity (Cohen-Shacham et al., 2016).

Participatory Approaches: Participatory research methods acknowledge participants as co-creators of knowledge, aiming to promote education, transformative action, social or economic justice, and reflexivity *(Bergold & Thomas, 2012).* These approaches address power imbalances and employ iterative, self-reflective processes to adapt and evolve within the research context *(J. Bergold & Thomas, 2012; Cargo & Mercer, 2008)*

Photogrammetry: Photogrammetry literally means the act of deriving precise measurements from photographs. It involves taking a set of overlapping photos of an object, building, person, or environment, and converting them into a 3D model using a number of computer algorithms. Photogrammetry allows 3D coordinates, of a surface, to be derived from points within two 2D pictures that have been taken from different positions (MAWLAWI, 1998).

Pluvial Flooding: Flooding that when the amount of rainfall exceeds the capacity of urban storm water drainage systems or the ground to absorb it (OPW, n.d.).

Point Cloud: A point cloud is a collection of points in 3D space representing the surface exposure of an object. Each point has a 3D coordinate (x, y, and z). In addition to coordinates, other useful data can be associated with each point, such as Red-Green-Blue (RGB) colour *(Daghigh et al., 2022).*

Questionnaires: Questionnaires are like structured interviews but without the interviewer. Participants fill out a form on their own and then return it to the researcher, typically by mail, through a Dropbox, or in person *(Bryman, 2019).*

Rainwater Harvesting Potential: The volume of water that can be effectively collected by a rainwater harvesting system *(Guhathakurta et al., 2016).*

Rainwater Harvesting: A technology of collecting and storing rainwater from land surface catchments, and rooftops using different and easy techniques like jars and pots and sophisticated techniques as underground check dams *(Sivanappan, 2006).*

Reanalysis datasets: contain various types of observations (from weather stations, satellites, ships, etc.) with short-range weather forecasts using modern weather forecasting models. This process creates a consistent and complete record of weather and climate variables across the globe, even for areas and times where direct observations are sparse (ECMWF, 2025).

Restoration: Solutions based on developing sustainable management protocols and procedures for managed or restored ecosystems (e.g. re-establishing traditional Agro-forestry systems based on commercial tree species to support poverty alleviation) *(Eggermont et al., 2015; Cohen-Shacham et al., 2016).*

Runoff Coefficient: The ratio of total runoff volume to total rainfall, on either an annual, seasonal, or event basis *(Fassman-Beck et al., 2016).*

Secondary and Tertiary Cities: Urban centres that are smaller than primary metropolitan areas *(Brian Roberts, 2014).*

Spectral indices: Spectral Indices derived from multispectral remote sensing products are extensively used to monitor Earth system dynamics (e.g. vegetation dynamics, water bodies, fire regimes). Often one has to combine specific bands when studying a certain phenomenon or material. Such combinations of bands, named spectral indices, supply condensed information on specific sub-systems, materials, or processes. For different application domains, multiple proposals for ideal spectral indices exist, and the field is constantly developing and testing novel spectral indices (Montero et al., 2023).

Stakeholder Engagement: Stakeholder engagement refers to the aims, activities, and impacts of stakeholder relations in a moral (e.g. ethical considerations and the responsibilities organizations have towards their stakeholders), strategic (e.g. involves aligning stakeholder engagement with organizational goals and long-term value creation), and/or pragmatic manner (e.g. addresses the practical aspects of engagement, including the methods and processes used to involve stakeholders effectively) *(Kujala et al., 2022).* This definition emphasizes the multifaceted nature of stakeholder engagement, incorporating ethical considerations, strategic objectives, and practical implications.

Stakeholder Mapping: A process of identifying and analysing individuals or groups with an interest, influence, or impact on a project *(Grégoire, 2024).*

Standardized Precipitation Index: is a widely used meteorological drought indicator developed by Mckee et al. (1993) and recommended by the World Meteorological Organization in 2009. It quantifies precipitation anomalies by comparing accumulated precipitation over a specified period with long-term averages, enabling comparison across different climates.

Standardized Precipitation and Evapotranspiration Index: introduced by Vicente-Serrano et al., 2010, is a drought index that incorporates both precipitation and temperature effects by calculating the difference between precipitation and potential evapotranspiration (P - PET).

Surface Runoff: The flow of a water layer over the surface and through the pores of soils and sediments that is coming out of the watershed (Guo et al., 2019).

Survey: Surveys in research represent a broad approach to gathering information through structured questioning. They encompass both questionnaires and structured interviews. The main goal of surveys is to design a set of clear, targeted questions that can be quantified and easily converted into numerical data for analysis (Bryman, 2019).

Temperature Condition Index (TCI): is a satellite-based drought monitoring index that illustrates the state of the energy balance at the Earth's surface on both regional and global scales. It is designed to indicate temperature-related drought situations by utilizing Land Surface Temperature (LST) or Brightness Temperature (BT) data. The TCI assumes that higher temperatures are detrimental to crops, while low to moderate temperatures are favourable for vegetation growth *(Svoboda & Fuchs, 2016).*

Theory of Change: A logical framework that outlines the causal pathways through which an intervention is expected to bring about desired outcomes. It maps the interconnections from inputs and activities to outputs, outcomes, and long-term impacts, clarifying the underlying assumptions that drive the change process (European Commission, 2021).

Type of Action: The typology of NbSs includes three distinct types, based on two main factors: the number of ecosystem services and stakeholder groups involved, and the level of engineering effort required in the planning and construction of the NbS (Eggermont et al., 2015).

Urban Water Management: Urban Water Management is a comprehensive approach to planning, controlling, and optimizing water resources within urban environments. It integrates water supply, sanitation, stormwater, and wastewater management, aligning them with urban development and basin management. The approach aims to ensure sustainable water use, minimize environmental impacts, and enhance urban water system resilience, addressing the complex challenges of water resources in rapidly growing urban areas (GWP, 2013)

Vegetation Condition Index (VCI): is a remote sensing-based drought monitoring index developed by Kogan (1995, 1997). It is calculated using multi-temporal Normalized Difference Vegetation Index (NDVI) data and is designed to assess vegetation stress and examine vegetation response

Vegetation Health Index (VHI): is a drought monitoring index composed of two components: the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI). It is designed to assess vegetation health by combining information on vegetation condition and thermal stress. The VHI operates on the principle that low NDVI values coupled with high land surface temperatures indicate poor vegetation health (Zeng et al., 2023)

Water Balance: is a quantitative accounting of water inputs, outputs, and storage changes within a defined hydrological system (such as a soil column, drainage basin, irrigation area, or city), over a specific time period. The water balance approach is fundamental in hydrology, used for water resource analysis, irrigation planning, and assessing water needs in various contexts (Mohajerani et al., 2021).

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