Informal Governance for Urban Sustainability in Sub-Saharan Africa

An Institutional Analysis of Community-Led Approaches to Nature-Based Stormwater Solutions

Dissertation
with the aim of achieving a Doctoral degree
at the Faculty of Mathematics, Informatics, and Natural Sciences
Department of Geography
Universität Hamburg

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Hamburg
26.11.2024

Accepted as a Dissertation at the Department of Geography

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Date of Disputation: 04-02-2025

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I hereby declare, on oath, that I have authored the present dissertation by my own and have not used other than the acknowledged resources and aids.

Hamburg, den 26.11.2024 Simon Peter Muwafu

To

A.K.Kafuko of Kagoma and **A.K.Muteteri** of Isingiro, whose grit and steadfast dreams ignite(d) my own.

-Gakyali Mabaga-
(So Much Achieved, Yet Far More Remains to Be Accomplished)

Men became scientific because
they expected Law in Nature, and
they expected Law in Nature because
they believed in a Law Giver

-C.S. LEWIS -

Acknowledgments

The journey toward completing this dissertation has been anything but linear. Its successful completion is primarily due to the remarkable individuals who have challenged, supported, and stood by me throughout this process. I sincerely thank my supervisors, Dr. Máñez Costa, M, and Prof. Dr. Juergen Scheffran, for their patient guidance, enthusiastic encouragement, and insightful critiques of this research. Their generous investment of time and unwavering support in helping me stay on track has been deeply appreciated.

I would also like to thank Dr. Laurens Bouwer for his consistent willingness to offer his time and support, which helped ensure steady progress in my work. My appreciation is extended to my colleagues at the Climate Service Center Germany, whose thoughtful approaches and collaborative spirit have enriched my academic experience.

I am grateful to Dr. Louis Celliers, Dr. Gaby Langendjik, and Dr. Lena Rolfer, with whom I shared many stimulating discussions, critical reflections, and mutual encouragement, especially when my energy seemed to wane. Their camaraderie has been invaluable.

My deepest and most heartfelt gratitude goes to my family for their unwavering love, encouragement, and constant support throughout this journey. I am particularly grateful to my sister Faith for her friendship and unwavering presence as a confidante. I will forever be indebted to my parents, whose teachings of resilience, perseverance, and the importance of dreaming big have shaped who I am today. This achievement is only possible because of their sacrifices and belief.

Finally, I would like to give all the glory and honor to God, whose Guidance and Grace have sustained me throughout this journey.

List of Publications Resulting from Dissertation

The three main chapters of this dissertation have been either published or submitted to peer-reviewed scientific journals or technical books. The table below summarizes the authorship and publication status of each chapter included in this dissertation.

Chap.	Title	Authors	Status	Journal	IF
2	A framework for assessing social structure in community governance of sustainable urban drainage systems: insights from a literature review	Simon Muwafu Lena Rölfer Jürgen Scheffran M. Máñez Costa	Published (2024)	Mitigation and Adaptation Strategies for Global Change	4.3
3	Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management	Simon Muwafu Jürgen Scheffran M. Máñez Costa	Submitted (2024)	Urbanisation	5
4	Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa	Simon Muwafu Louis Celliers Jürgen Scheffran M. Máñez Costa	Published (2024)	Sustainability	3.3

Other Publications:
Peer-reviewed scientific journal articles not included in this dissertation.

1. Motta Zanin, G., **Muwafu, S.P**., & Máñez Costa, M. (2024). Nature-based solutions for coastal risk management in the Mediterranean basin: A literature review. Journal of environmental management, 356, 120667.

Conferences where Publications have been Presented

1. EGU General Assembly 2024: Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management https://doi.org/10.5194/egusphere-egu24-1226
2. System Dynamics Conference 2024: Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management https://proceedings.systemdynamics.org/2024/abstracts/1466.html.

Declaration of Authorship

I Simon Peter Muwafu, born in Kampala on the 24th of August 1987, hereby declare my share in the authorship of the dissertation chapters (research articles), which are either published, submitted, or are to be submitted to peer-reviewed journals, as following

Chap.	Title	First author (Simon P Muwafu) contribution	Co-authors contributions
2	A framework for assessing social structure in community governance of sustainable urban drainage systems: insights from a literature review	• Conceptualization and Research Design: (Predominantly) • Literature Review (Completely) • Analysis of Results: (Completely) • Manuscript Writing: (Predominantly)	Conceptualization and Research Design • Máñez Costa, M Research Design: • Lena Rölfer Manuscript Review: • Lena Rölfer • Máñez Costa, M • Juergen Scheffran
3	Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management	• Conceptualization and Research Design: (Predominantly) • Model Design: (Completely) • Analysis of Results: (Completely) • Manuscript Writing: (Predominantly)	Conceptualization and Research Design • Máñez Costa, M Manuscript Review: • Máñez Costa, M • Juergen Scheffran
4	Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa	• Conceptualization and Research Design: (Predominantly) • Data Collection: (Completely) • Analysis Of Results: (Completely) • Manuscript Writing: (Predominantly)	Conceptualization and Research Design • Maria Manez Costa Manuscript Review: • Máñez Costa, M • Juergen Scheffran • Louis Celliers

Abstract

Rapid urbanization and the intensifying impacts of climate change pose significant stormwater management challenges for Sub-Saharan African (SSA) cities, necessitating sustainable and resilient stormwater management solutions. This study explores the potential of Sustainable Urban Drainage Systems (SUDS) as nature-based solutions (NBS) to address these challenges, focusing on the role of community governance in their successful implementation. While existing literature broadly examines the technical aspects of SUDS and formal governance in the Global North, this research fills a gap by investigating the dynamics of community-led governance in the Global South, specifically within SSA.

To address the central research question—How does community governance shape the management and sustainability of SUDS as nature-based stormwater solutions in Sub-Saharan African cities?-the study employs an integrated methodological approach. This includes a comprehensive literature review, system dynamics modeling to explore interactions between forms of capital (social, human, environmental, financial, and political), and a qualitative case study in a SSA city to gather empirical data on community governance performance. These methods were chosen to provide theoretical and practical insights into the social and institutional dynamics that affect the community led management and of SUDS.

Results indicate that community governance, rooted in local knowledge, social networks, and flexible decision-making structures, can effectively complement formal governance frameworks, enhancing the adaptability and inclusivity of Nature-based stormwater management solutions in urban SSA. The study found that when community governance leverages political capital and local resources, there is a notable improvement in SUDS performance, including reduced urban flooding and increased engagement in environmental stewardship. However, challenges remain regarding coordination with formal governance bodies, securing long-term funding, and overcoming local political resistance.

Key findings underscore the importance of integrating community governance into formal planning processes, recommending that policymakers support decentralized, community-driven NBS projects to build more resilient urban environments. Practical guidelines include enhancing community capacity, fostering collaborative frameworks, and ensuring transparent decision-making processes. The study contributes to theory by extending Ostrom's polycentric governance model to urban stormwater management in SSA, demonstrating how decentralized governance structures can be effectively utilized in contexts with limited formal institutional capacity.

While this study advances understanding of community governance in urban climate adaptation, further research is needed to evaluate the scalability of these models in diverse SSA regions and compare their effectiveness with centralized approaches used in the Global North. Additionally, future studies could explore the long-term sustainability of community-driven SUDS projects.

By linking empirical data to theoretical frameworks, this research provides valuable insights into the role of community governance in advancing sustainable urban resilience. It highlights both the opportunities and limitations of integrating decentralized governance systems within formal urban planning, contributing to a more nuanced understanding of how SUDS can mitigate stormwater challenges in rapidly urbanizing regions vulnerable to climate impacts.

Zusammenfassung

Die rasche Verstädterung und die zunehmenden Auswirkungen des Klimawandels stellen die Städte in Subsahara-Afrika (SSA) vor große Herausforderungen, die nachhaltige und widerstandsfähige Lösungen für die Regenwasserbewirtschaftung erforderlich machen. Diese Studie untersucht das Potenzial nachhaltiger städtischer Entwässerungssysteme (Sustainable Urban Drainage Systems, SUDS) als naturbasierte Lösungen (NBS) zur Bewältigung dieser Herausforderungen und konzentriert sich dabei auf die Rolle der kommunalen Verwaltung bei deren erfolgreicher Umsetzung. Während die vorhandene Literatur im Großen und Ganzen die technischen Aspekte von SUDS und die formale Governance im globalen Norden untersucht, füllt diese Studie eine Lücke, indem sie die Dynamik der gemeinschaftsgeführten Governance im globalen Süden, insbesondere in SSA, untersucht.

Zur Beantwortung der zentralen Forschungsfrage - Wie beeinflusst die kommunale Verwaltung die Bewirtschaftung und Nachhaltigkeit von SUDS als naturbasierte Regenwasserlösungen in afrikanischen Städten südlich der Sahara - wird in der Studie ein integrierter methodischer Ansatz verwendet. Dazu gehören eine umfassende Literaturrecherche, systemdynamische Modelle zur Untersuchung der Wechselwirkungen zwischen verschiedenen Kapitalformen (Sozial-, Human-, Umwelt-, Finanz- und Politikkapital) sowie eine qualitative Fallstudie in einer Stadt in Subsahara-Afrika, um empirische Daten über die Leistung der kommunalen Verwaltung zu sammeln. Diese Methoden wurden gewählt, um theoretische und praktische Einblicke in die soziale und institutionelle Dynamik zu gewinnen, die die Umsetzung und Nachhaltigkeit von SUDS beeinflusst.

Die Ergebnisse deuten darauf hin, dass die kommunale Governance, die auf lokalem Wissen, sozialen Netzwerken und flexiblen Entscheidungsstrukturen beruht, formale Governance-Rahmen wirksam ergänzen und die Anpassungsfähigkeit und Exklusivität der Regenwasserbewirtschaftung in Städten in SSA verbessern kann. Die Studie ergab, dass sich die Leistung von Regenwasserbewirtschaftungssystemen deutlich verbessert, wenn die kommunale Verwaltung politisches Kapital und lokale Ressourcen einsetzt, was zu weniger Überschwemmungen in den Städten und mehr Engagement für die Umwelt führt. Es bestehen jedoch weiterhin Herausforderungen bei der Koordinierung mit formellen Verwaltungsorganen, der Sicherung langfristiger Finanzierung und der Überwindung lokaler politischer Widerstände.

Die wichtigsten Ergebnisse unterstreichen, wie wichtig es ist, die kommunale Verwaltung in formelle Planungsprozesse einzubinden, und empfehlen den politischen Entscheidungsträgern, dezentralisierte, kommunale NBS-Projekte zu unterstützen, um eine widerstandsfähigere städtische Umwelt zu schaffen. Zu den praktischen Leitlinien gehören die Stärkung der kommunalen Kapazitäten, die Förderung kooperativer Rahmenbedingungen und die Gewährleistung transparenter Entscheidungsprozesse. Die Studie leistet einen Beitrag zur Theorie, indem sie Ostroms polyzentrisches Governance-Modell auf die städtische Regenwasserbewirtschaftung in SSA ausweitet und zeigt, wie dezentrale Governance-Strukturen in Kontexten mit begrenzten formalen institutionellen Kapazitäten effektiv genutzt werden können.

Während diese Studie das Verständnis von Community Governance in der städtischen Klimaanpassung vorantreibt, sind weitere Forschungen notwendig, um die Skalierbarkeit dieser Modelle in verschiedenen SSA-Regionen zu bewerten und ihre Effektivität mit zentralisierten Ansätzen im globalen Norden zu vergleichen. Darüber hinaus könnten künftige Studien die langfristige Nachhaltigkeit von SUDS-Projekten auf Gemeindeebene und das Potenzial technologischer Innovationen zur Verbesserung der lokalen Governance-Fähigkeiten untersuchen.

Durch die Verknüpfung empirischer Daten mit theoretischen Rahmenwerken bietet diese Studie wertvolle Einblicke in die Rolle der kommunalen Verwaltung bei der Förderung nachhaltiger urbaner Resilienz. Sie hebt sowohl die Möglichkeiten als auch die Grenzen der Integration dezentraler Governance-Systeme in die formale Stadtplanung hervor und trägt zu einem differenzierteren Verständnis der Frage bei, wie SUDS die Herausforderungen der Regenwasserbewirtschaftung in schnell urbanisierenden Regionen, die anfällig für Klimaauswirkungen sind, abmildern können.

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1 Introduction

The rapid urbanization in Sub-Saharan Africa (SSA), coupled with the escalating impacts of climate change, presents significant challenges to developing climate-resilient cities in the region (IPCC 2022, WMO 2019). As urban areas expand, they increasingly encroach upon natural landscapes, disrupting ecosystems that play critical roles in maintaining environmental balance (Güneralp, et al. 2017). This encroachment mainly affects natural drainage systems, essential for effective stormwater management (Lwasa 2010). Without sufficient space for water to flow and be absorbed, urban areas in the region face increasing difficulties in managing stormwater, especially in the context of more frequent and intense rainfall events driven by climate change (I. Douglas 2017).

In many parts of SSA, urban growth often outpaces the development of formal infrastructure. Traditional stormwater management solutions, typically outdated, large-scale, and capital-intensive grey infrastructure, frequently fail to keep up with this rapid urban expansion due to limited resources and weak governance (N. Armitage 2011). The combination of urban growth, insufficient infrastructure, and intensified rainfall exacerbates the risk of flooding, placing additional strain on already stretched urban systems. This underscores the urgent need for alternative, sustainable stormwater management approaches that complement conventional infrastructure while enhancing long-term urban resilience (Armitage, et al. 2013).

Nature-based solutions (NBS) such as Sustainable Urban Drainage Systems (SUDS) have emerged as a promising complement to traditional stormwater management approaches (Lokidor, et al. 2023, Herslund and Mguni 2019). These solutions utilize natural processes to mitigate runoff, reduce flooding, and improve water quality (Mguni, Herslund and Jensen 2016, Cohen-Shacham, Janzen and Maginnis 2016). SUDS, therefore, offer an adaptable and cost-effective means of managing stormwater, particularly in rapidly growing cities where conventional infrastructure may be insufficient, such as in SSA (Diep, Mulligan, et al. 2022). In these SSA contexts, where many cities face informal settlements and underdeveloped drainage systems, SUDS can provide an affordable, flexible, and sustainable approach to stormwater management while delivering co-benefits such as improved air quality, enhanced biodiversity, and reduced urban heat (Diep, Mulligan, et al. 2022).

Despite the technical potential of SUDS in managing stormwater, their successful implementation and long-term sustainability are heavily dependent on effective management and governance performance in the areas where these solutions are implemented (Du Toit, et al. 2018, I. Douglas 2017). These enable NBS to function efficiently by ensuring proper planning, ongoing maintenance, stakeholder engagement, and long-term financial support (Armitage, et al. 2013). Effective governance performance facilitates collaboration between local authorities, community members, the private sector, and environmental organizations, ensuring that SUDS projects align with local needs, regulations, and environmental goals (Mguni, Herslund and Jensen 2016, L. B. Herslund 2017). Additionally, transparent decision-making processes and clearly defined responsibilities enhance accountability, foster community trust, and encourage participation—factors essential for the sustained success of SUDS initiatives.

In SSA, where formal governance systems may be fragmented or lack sufficient capacity, community governance models could be critical in advancing SUDS (Diep, Mulligan, et al. 2022). These community governance frameworks, rooted in local institutions, knowledge, and social networks, may provide the flexibility, adaptability, and responsiveness that formal systems sometimes lack (Diep, Parikh, & Dodman, 2019). By leveraging local expertise and resources, community-driven approaches can also facilitate the implementation of SUDS that are contextually relevant and culturally fitting (Mguni, Herslund and Jensen 2016, Mguni, P; Jensen, M B; Herslund, L. 2015). Yet the performance of community governance in deploying and managing NBS, particularly in urban stormwater management, remains underexplored (Jiusto and Kenny, 2016, Mulligan, et al. 2020). Current NBS literature predominantly focuses on the technicalities of the solutions and formal management case studies from the global North, with limited attention given to the role of community governance in

ensuring the long-term success of SUDS in global South regions like SSA (Mulligan, et al. 2020). This gap in research highlights the need for targeted studies to evaluate how community governance models perform in shaping the design, implementation, and maintenance of SUDS in urban settings vulnerable to climate change in SSA.

To address this gap, the primary aim of this dissertation was to explore the potential of community governance frameworks to support the implementation and management of SUDS for stormwater management in cities across Sub-Saharan Africa (SSA). This investigation focuses on the social and institutional dynamics that shape SUD's community governance performance in this context.

The study is framed by the central research question: "**How does community governance shape the management and sustainability of SUDS as nature-based stormwater solutions in Sub-Saharan African cities?**

To address this question, the study is guided by the following objectives:

- **To identify and analyze the key social structure determinants that influence the success of community governance of SUDS as NBS for urban stormwater management.**
- **To conduct a case study evaluating the performance of community governance of SUDS for stormwater management in Sub-Saharan Africa.**
- **To assess community empowerment's role in shaping SUDS's community governance as NBS for urban stormwater management.**

The dissertation's chapters are systematically ordered to address the objectives accordingly. Chapter 2 provides a literature review to identify key social determinants of community governance for SUDS, fulfilling Objective 1. Chapter 3 uses a case study to evaluate community governance performance in Sub-Saharan Africa, meeting Objective 2. Chapter 4 assesses community empowerment's impact on SUDS effectiveness through system dynamics modeling, addressing Objective 3. Further details on the structure of the thesis are provided in Section 1.1, which outlines the organization and flow of the dissertation.

The significance of this study lies in its application of an institutional analysis lens to examine how community governance, often operating in the "shadow" of formal systems, can be effectively appropriated to complement formal governance frameworks for managing SUDS within urban sustainability transitions, particularly in Sub-Saharan Africa. This approach is inspired by Ostrom's (2010) work on polycentric approach to coping with climate change, which highlights the importance of multiple, overlapping centers of authority working together to manage complex social and ecological systems, particularly in response to climate change (Ostrom 2010).

Central to Ostrom's work is appropriating decentralized governance and integrating local, community-led initiatives, such as those related to NBS, within formal systems to enhance resilience, adaptability, and resource management. This study posits that informal governance, such as community governance, often more flexible and responsive to local needs, can significantly strengthen the implementation of NBS when appropriated within formal structures, leading to more sustainable urban climate solutions.

Much literature on NBS for urban resilience, such as stormwater management, focuses on Global North contexts, where formal management systems dominate (Goodwin, et al. 2023). In contrast, this study focuses on the Global South, emphasizing the importance of decentralized, "shadow" governance networks in these regions. Local knowledge, social capital, and grassroots organizations are crucial for crafting adaptive NBS to address climate challenges. The study, therefore, aims to demonstrate how community governance can manage and implement NBS in informal spaces, often exceeding the capacity of centralized approaches to deliver scalable and sustainable solutions.

As climate change intensifies pressures on urban environments, understanding how community institutions organize and implement local solutions such as SUDS becomes increasingly vital (Ziervogel, et al. 2022). Sub-Saharan Africa, a region especially vulnerable to climate impacts and often characterized by weak formal institutions, provides a critical context for examining the transformative potential of community-led NBS governance in urban adaptation.

The study utilizes an integrated methodological approach for this examination, combining a literature review (Muwafu, et al. 2024a), system dynamics modeling, and a qualitative case study centered on Sub-Saharan Africa (Muwafu, et al. 2024b). The case study provides empirical insights into how community governance drives the implementation of NBS, particularly SUDS, for urban stormwater management, shedding light on the social and institutional dynamics that influence governance at the community level. By integrating practical case analysis with theoretical perspectives, the study offers a nuanced understanding of how decentralized governance of SUDS can be effectively appropriated within formal systems, fostering more polycentric, inclusive, and resilient urban environments.

1.1 Thesis Structure

As a result of this integrated methodological approach, three empirical chapters have emerged, each addressing an aspect of the research objectives. These chapters have been carefully crafted to respond to the ambitious aim of the dissertation: to explore the potential of community governance to support the implementation and management of SUDS, as NBS, for stormwater management in cities in SSA (Figure 1-1).

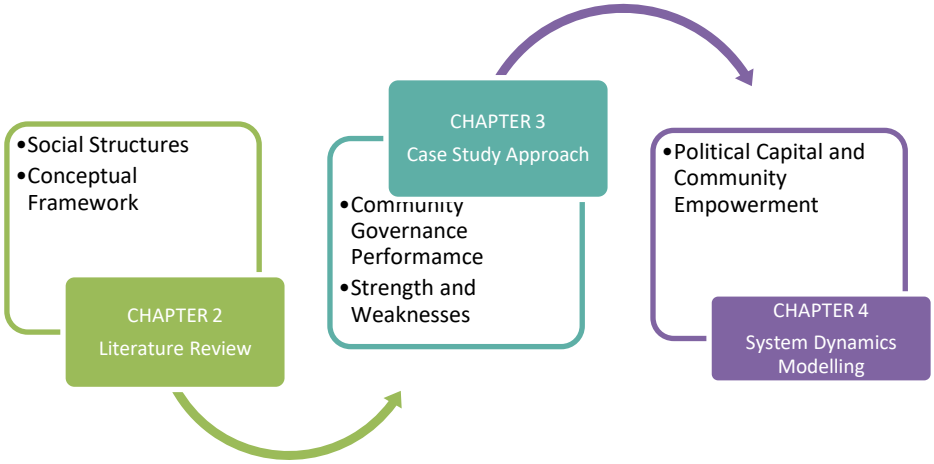

Figure 1-1: Methodological Structure

Chapter 2: A framework for assessing social structure in community governance of sustainable urban drainage systems: insights from a literature review

The empirical chapter two explores the social structures that underpin community governance in nature-based urban stormwater management (Muwafu, et al. 2024a). Recognizing that SUDS are often managed locally; they require governance approaches that cater to specific community needs and foster inclusive decision-making (Evans 2011). This chapter highlights how these social determinants shape collaborative and participatory governance. To support the dissertation's objectives, this chapter uses a literature review to identify and analyze the critical social structure determinants that impact the success and sustainability of community-led SUDS projects such as NBS for urban stormwater management (Muwafu, et al. 2024a).

These identified determinants are categorized according to four key elements—actors, resources, discourses, and rules of engagement—which align with the Policy Arrangement Approach (PAA) (Muwafu, et al. 2024a). The PAA, which links structural, social, and political changes to shifts in everyday policy implementation PAA, is the analytical foundation for this review (Leroy and Arts 2006). For instance, community-based governance functions as a policy arrangement, stabilizing both

the structure and content of a specific policy domain at particular policymaking levels or across multiple levels (Liefferink 2006) The PAA framework's four dimensions are interrelated, so changes in one area often lead to shifts in others (Arts and Goverde 2006).

Chapter 3: Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa

Chapter three presents a case study set in a Sub-Saharan city, illustrating a real-world application of SUDS, and fulfilling the second objective of the dissertation. It evaluates the performance of community-governed SUDS as NBS for stormwater management, offering valuable insights into their strengths, limitations, adaptability, and long-term impact in a Sub-Saharan context. (Muwafu, et al. 2024b)**.**This objective is achieved by testing and assessing the framework's effectiveness, which was developed in the first chapter (Muwafu, et al. 2024a) and then used to evaluate the performance of community governance in SUDS implementation. To understand the conditions that support successful SUDS adoption, the study evaluates various dimensions of community governance, including social structures, engagement processes, local resource management strategies, regulatory frameworks, and cultural attitudes.

Chapter 4: Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management

Chapter four critically examines the interplay between community and formal governance systems in urban nature-based stormwater management. Community governance, often operating in parallel to formal systems, can be perceived as a threat by these formal structures, resulting in the marginalization of community initiatives and heightening the vulnerability of the initiatives and the communities they are intended to support (Diep, Mulligan, et al. 2022). This tension underscores the importance of fostering coordinated interactions between community-driven decision-making and established formal systems to ensure the success and sustainability of nature-based stormwater management projects.

This chapter integrates two theoretical frameworks: the Policy Arrangement Approach (PAA) and the Capital Approach Framework (Máñez, Carmona and Gerkensmeier 2014). The PAA, which focuses on the dimensions of actors, resources, discourses, and rules of engagement, is aligned with the five forms of capital—social, human, environmental, financial, and political—outlined in the Capital Approach. This integrated framework provides a nuanced understanding of how these various forms of capital interact within community governance structures, revealing their critical role in facilitating sustainable management of SUDS and addressing local stormwater challenges.

A particular emphasis is placed on the role of political capital, which influences governance processes and community empowerment. By employing System Dynamics Modeling (SDM), this chapter explores the interdependencies and feedback loops between different forms of capital (Sterman 2000, Gómez Martín, et al. 2020). This approach captures the complex relationships among social actions, environmental factors, and community resources, illustrating how changes in one form of capital reverberate across the governance system. The system dynamics model thus offers a comprehensive framework for understanding how these forms of capital collectively shape stormwater practices and resource allocation within the community.

In addressing the second objective of the dissertation, this chapter contributes to understanding how community political capital impacts governance structures for SUDS. It highlights how leveraging these forms of capital can strengthen community governance frameworks, enhance local empowerment, and promote more effective and equitable urban stormwater management through nature-based solutions.

Together, these chapters comprehensively respond to the research question, bridging theoretical

concepts with practical applications in the local context. The dissertation's methodological approach flows seamlessly from developing a novel conceptual framework for assessing community governance to its application in evaluating performance. Ultimately, this approach addresses a significant knowledge gap in existing research, thoroughly analyzing how community governance structures impact the implementation and sustainability of nature-based stormwater solutions in Sub-Saharan Africa. Through this progression, the dissertation contributes theoretical insights and practical assessments, thereby advancing the understanding of community governance in urban climate adaptation.

Chapter 5: Conclusion

The conclusion synthesizes the study's key insights, summarizing the findings from each chapter and linking them to the research objectives. It provides a clear overview of how the study's outcomes address the original research aims and contribute to the field. It also highlights the novelty of the research, emphasizing the innovative methodologies and techniques used. This section demonstrates how the study fills significant knowledge gaps, advancing understanding in the area of focus. Finally, the conclusion discusses the study's limitations and outlines areas for future research. While acknowledging the study's contributions, it stresses the need for further exploration to deepen understanding and address remaining questions in the field.

1.2 Case Study

This case study examines flood resilience efforts in Nalukolongo, a flood-prone area of Kampala, Uganda (Figure 1-2), where rapid urban growth has led to frequent urban flooding due to inadequate drainage and increased runoff (Mukwaya, Sengendo and Lwasa 2010). Residents, especially marginalized ones, face significant challenges, relying on makeshift flood defenses (Güneralp, et al. 2017). Kampala's situation reflects the broader challenges many urbanizing cities across Sub-Saharan Africa face (Muwafu, et al. 2024a). As cities in this region experience rapid population growth, infrastructure often lags, leading to increased runoff and insufficient drainage systems (Lwasa 2010). Like Kampala, many Sub-Saharan cities are impacted by high rates of informal settlement growth, environmental degradation, and limited funding for resilient infrastructure, leaving vulnerable communities to withstand the worst of climate-related risks.

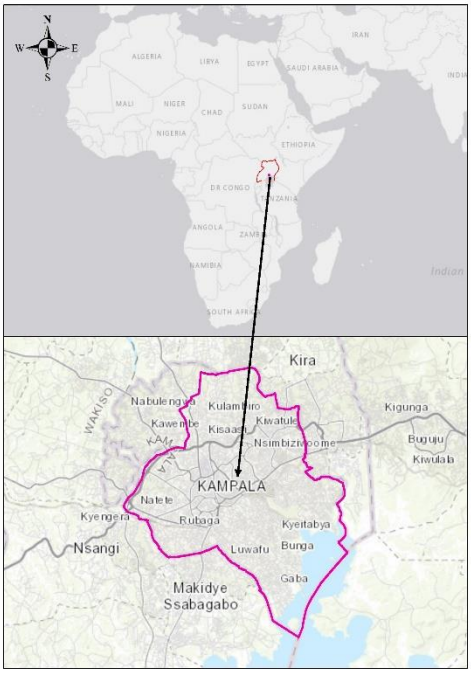

Figure 1-2: Case study area: Kampala City, Uganda

The Greater Kampala Integrated Flood Resilience Partnership was launched in 2021 to tackle these issues in Kampala. This partnership brings together government agencies, international organizations, NGOs, and community leaders to implement sustainable urban drainage projects. Focusing on nature-based solutions like restoring vegetation along drainage channels and installing rainwater harvesting systems, the initiative aims to manage stormwater and strengthen flood resilience. These strategies mirror approaches being adopted in other Sub-Saharan cities, where nature-based solutions are increasingly used to offer sustainable, community-driven flood mitigation.

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2 A framework for assessing social structure in community governance of sustainable urban drainage systems: insights from a literature review

Mitig Adapt Strateg Glob Change (2024) 29:42
https://doi.org/10.1007/s11027-024-10136-2

ORIGINAL ARTICLE

A framework for assessing social structure in community governance of sustainable urban drainage systems: insights from a literature review

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Received: 2 August 2023 / Accepted: 12 April 2024 / Published online: 25 April 2024

Abstract
The utilization of Sustainable Urban Drainage Systems (SUDS) as Nature-based Solutions (NBS) holds significant promise for enhancing resilience against climate change-induced flooding and promoting community well-being in urban areas of Sub-Saharan Africa. While existing research predominantly emphasizes technical aspects within the NBS framework, understanding the socio-governance dynamics at the community level is equally imperative, particularly given the decentralized nature of SUDS. This study aims to complement the prevailing technical focus by examining the social dimensions of community governance related to SUDS implementation. Through a literature review, key determinants of social structure influencing successful community governance in SUDS management are identified, and categorized into actors, resources, discourses, and rules of engagement. An innovative assessment framework comprising 65 indicators is proposed to evaluate these determinants, offering a comprehensive tool for scholars and practitioners. By integrating social considerations into SUDS management practices, this research seeks to inform policy formulation and strategies tailored to Sub-Saharan African cities, facilitating equitable and participatory urban stormwater management initiatives crucial for addressing climate change challenges.

Keywords Urban Stormwater Management · Green Infrastructure · Sub-Saharan Cities · Adaptation · Policy Arrangement Approach · Literature review

1 Introduction

Urban areas globally, especially in Sub-Saharan Africa, grapple with significant challenges in managing stormwater runoff effectively, amidst the challenges of rapid urbanization, population growth, and inadequate drainage infrastructure. (WMO 2019; IPCC 2022a, b) These

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difficulties are compounded by the escalating impacts of climate change, which exacerbate flooding risks and strain existing water management systems (UN-Habitat 2014).

In response, Sustainable Urban Drainage Systems (SUDS) have emerged as promising solutions, leveraging nature-based approaches to mitigate hydrological imbalances (Charlesworth et al. 2017). SUDS, incorporating green infrastructure elements like rain gardens and green roofs, mimic nature's ability to manage stormwater runoff by capturing, treating, and reusing it (Davis and Naumann 2017; Depietri and McPhearson 2017. Notably, SUDS are primarily managed at the local or community levels, necessitating community-level governance for inclusive decision-making and tailored project implementation to meet specific local needs (Evans 2011).

Community governance, emphasizing local management and decision-making, plays a pivotal role in addressing community needs, enhancing capacity, and promoting well-being within the context of SUDS implementation (Totikidis, Armstrong, & Francis, 2005). Through participatory processes, community governance identifies and implements activities, enhancing adaptive capacity and addressing vulnerabilities exacerbated by climate change (Ayers and Forsyth 2009; Reid et al. 2009). However, the influence of social structure determinants significantly shapes the collaborative and participatory nature of community governance, such as in the case of SUDS (Dorst et al. 2022). These determinants, encompassing social factors, guide interactions among community members, governance procedures, and policy processes related to accountability and effectiveness (Máñez et al. 2014; Fazey et al. 2021). Understanding the impact of these social determinants within the community governance framework of SUDS is essential for guiding decision-making processes and enhancing community organization (Mguni et al. 2016a).

Despite the significance of social structures, a notable knowledge gap exists concerning their specific influence on the integration of community governance into urban stormwater policy frameworks, especially regarding SUDS utilization in Sub-Saharan Africa. To address this gap, our study aims to explore the intricate relationship between social structures and effective community governance mechanisms of SUDS for urban stormwater management in the Sub-Saharan context. Through literature review and the Policy Arrangement Approach (Arts and Goverde 2006; Liefferink 2006), we aim to identify key social structure determinants shaping successful community governance patterns within nature-based urban stormwater management systems.

Specifically, our study intends to achieve the following objectives:

i) Review existing literature on social structure determinants influencing successful community governance, particularly in the context of urban stormwater management.
ii) Propose a novel framework for assessing social structure determinants in the integration of community governance of SUDS into policy frameworks.
iii) Discuss the practical implications of assessing social structure determinants for informing policy design and implementation strategies in Sub-Saharan African cities.

This study's significance lies in its ability to guide the development of customized stormwater management policies. Our newly developed framework for evaluating social structure determinants in integrating community governance of SUDS underscores the importance of organized integration in strategy processes. It acknowledges diverse forms of authority and the dynamic nature of change in implementation at the community level, a novel approach not previously applied to SUDS. By empowering

communities to shape their urban environments, our approach fosters resilience and promotes sustainable development practices rooted in local contexts.

2 Methodology

We follow a three-step approach to achieve the aforementioned objectives, including a literature review, analysis, and conceptualization.

2.1 Literature review

In the first step, we conducted a thorough literature search in December 2022, using the SCOPUS database. This search is integral to our research synthesis methodology, which involves selecting, evaluating, and synthesizing relevant existing literature on the topic (Xiao and Watson, 2019). Our goal was to gather diverse studies on governance in implementing nature-based solutions for stormwater management, with a specific focus on Sub-Saharan African cities. We chose the SCOPUS database for its broad coverage, multidisciplinary content, and advanced indexing capabilities, enhancing the likelihood of capturing a relevant body of literature. To expand our investigation, we explored additional sources like Web of Science, Cross-ref, Google Scholar, ResearchGate, and Academia.

Using a combination of OR/AND Boolean search criteria, we utilized selected keywords aligned with the concept domains of our research questions. The keywords, "nature-based solutions," OR "green infrastructure," aimed to explore various aspects of stormwater management through strategically planned natural spaces. We also included "sustainable urban drainage" keywords to focus on sustainable approaches. Recognizing the importance of community involvement, incorporating 'planning' OR 'management' keywords was crucial for gathering literature on the strategic planning and effective management of nature-based solutions, covering policy frameworks, implementation strategies, and project management approaches. Region-specific keywords 'Africa' and 'Sub-Saharan' refined the focus to the African context. This approach aimed to balance exhaustiveness and precision in our search (Xiao and Watson 2019).

To establish inclusion and exclusion criteria, we defined a specific timeframe (2011–2022) to capture noticeable shifts in literature and discourses regarding nature-based solutions. This period also aligns with significant advancements in the field. In the subsequent phase, we limited the search to English literature to ensure linguistic coherence. Articles were selected by reading titles and abstracts, prioritizing those addressing sub-Saharan African contexts. The authors had the freedom to incorporate articles with potential regional significance for sub-Saharan contexts. From the initially identified 87 articles, 47 were deemed relevant after excluding those primarily addressing water systems, stormwater quality, pollution, sanitation, stormwater runoff modeling, and urban forestry.

2.2 Analysis

In the second step, the selected literature was carefully analyzed to identify concepts, arguments, and findings that contribute to defining the critical determinants associated with various dimensions of the policy arrangement approach, which are pertinent to the research objective. This analysis encompasses discussions that potentially affect the community-level governance of SUDS (Fig. 1).

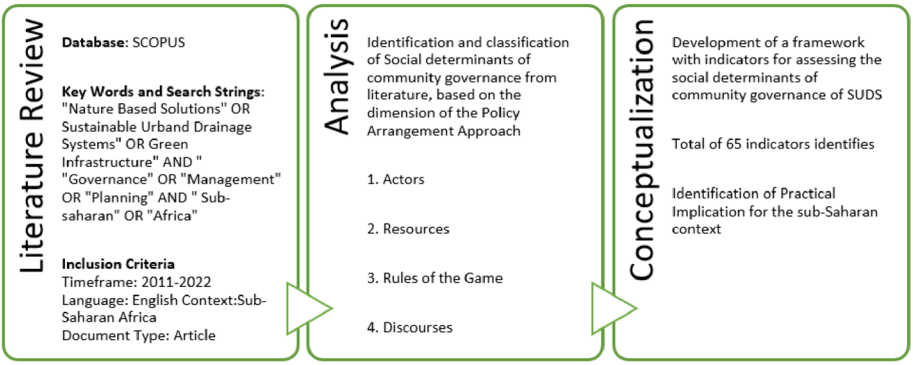

Fig.1 Three-step approach for developing an assessment framework of social structure determinants of community governance of SUDS

The policy arrangement approach used as a foundation for the analysis links structural, social, and political changes to everyday shifts in policy implementation. For instance, community-based governance, as a policy arrangement, stabilizes the structure and content of a specific policy domain at a particular policymaking level or across multiple levels (Leroy and Arts 2006). This approach comprises four interconnected dimensions, with three focusing on organizational or structural aspects: actors and coalitions, formal and informal rules, and resources and associated power. The fourth dimension pertains to substance, encompassing discourses reflecting actors' perspectives. Changes in one dimension correspondingly impact the others (Liefferink 2006). The interplay between the four dimensions is depicted through a tetrahedron, as shown in the Fig. 2 below.

In this study, community governance of SUDS involves coordinating the organizational and policy processes and the interactions between different social and political community

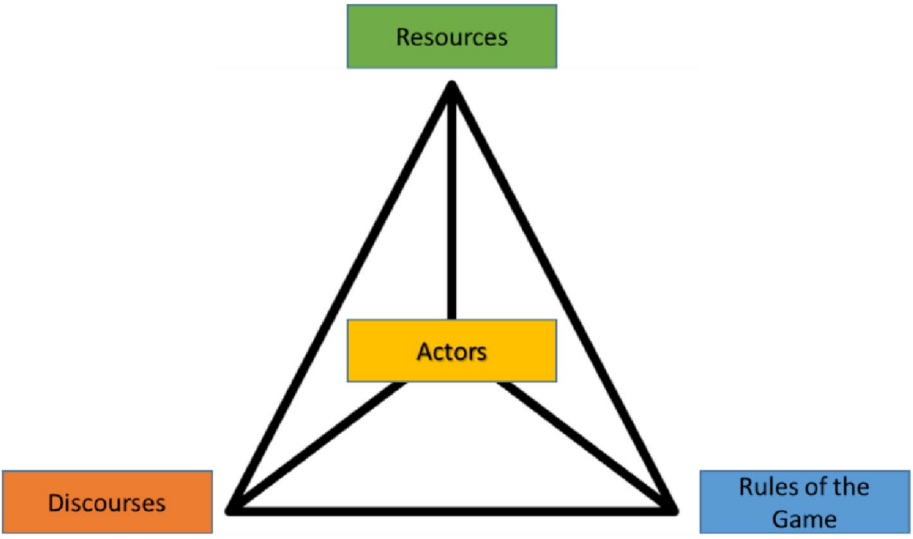

Fig. 2 Model of the Policy Arrangement Approach (adapted from (Arts and Goverde 2006))

actors towards a common public objective of enhancing the sustainability and equity of urban stormwater management using SUDS. The actors involved in the community governance of SUDS potentially include public and private stakeholders such as landowners, community planners, urban planning professionals, and civil society organizations (Qiao et al. 2019). *Resources* include community-level financial resources and facilities, knowledge and skills resources, and land priorities. The *rules of the game* include the formal and informal norms that define the actions of community actors during the implementation of SUDS. At the same time, *discourses* refer to community-level attitudes and perspectives toward SUDS (Qiao et al. 2018). Community change processes can be complex and nonlinear as different actors engage in various ways, potentially leading to solutions and disparities due to varying perspectives on the challenges (Carmen et al. 2021).

2.3 Conceptualization of indicators

In the third step, indicators are formulated based on this analysis to assess the diverse determinants identified in the literature. These indicators aid in identifying the most crucial issues within each of the four dimensions and facilitate the measurement of the performance of these dimensions within the community governance of SUDS for stormwater management.

3 A framework for assessing social structure determinants in local community level governance of SUDS

3.1 Dimensions and social structure determinants

The summary of social structure determinants that affect the community governance of SUDS is categorized according to the four dimensions of the policy arrangement approach: actors, resources, discourses, and rules of the game, as depicted in Table 1.

3.2 Actors

In sub-Saharan cities, the community governance of SUDS involves a range of actors and stakeholders. Public stakeholders may include government officials and local authority representatives responsible for urban planning and infrastructure development (Herslund and Mguni 2019). Private stakeholders, on the other hand, may include landowners, property developers, and consultants involved in urban planning and design. In addition, civil society organizations, community planners, and urban planning professionals may also play a role in the community governance of SUDS (Mguni et al. 2016a, b). The levels and rates of collaboration in developing and implementing strategies for sustainable and effective stormwater runoff management while considering the needs and viewpoints of local communities are primarily influenced by the participation of these actors (Williams et al. 2018).

The range of actors involved in the community governance of SUDS has a significant impact not only on the level and quality of local leadership but also on the allocation of responsibility, which in turn affects the involvement of stakeholders in implementing SUDS (Sutherland et al. 2016). Community perceptions of risk, which are shaped by the local understanding of preparedness, are often influenced by factors such as actors' knowledge

Table 1 Key social structure determinants that influence community governance organized by the four dimensions of the Policy Arrangement Approach

DIMENSION	SOCIAL STRUCTURE DETERMINANTS
ACTORS	• Community leadership and allocation of responsibility
	• Community innovation
	• Technical skills and competencies
	• Private stakeholder involvement
	• Academia involvement
RESOURCES	• Community priorities for funding from both public and private sources
	• Community financial incentives
	• Priorities for land use and development by both public and private entities
	• Human resources
	• Knowledge of SUDS
DISCOURSES	• Management strategies and planning processes
	• Environment regeneration and protection
	• Knowledge of suds ecosystem services
	• Community participation
	• Communication and information dissemination
RULES OF THE GAME	• Regulatory frameworks and legislative support
	• Cultural norms, values, and local languages
	• Quality and reliability of community politics
	• Equitable treatment of all partners
	• Gender Roles and Equality

levels, academic involvement, and the level of innovation in the community (Dodman and Mitlin 2013; Williams et al. 2020; Sañudo-Fontaneda and Robina-Ramírez 2019). These factors can facilitate the implementation of new and creative ideas, productive collaborations, and effective governance, all of which are central to the implementation and management of SUDS (Herslund and Mguni 2019).

Education campaigns can help to increase the adoption of SUDS among private stakeholders by promoting awareness of the benefits of SUDS, such as improved stormwater management, reduced flooding, and improved water quality (Bredhauer 2016; Armitage et al. 2013). However, the time needed for implementing or managing SUDS can be a significant factor in determining private stakeholders' level of engagement, as it may require substantial investments in time and resources (Olumuyiwa 2014). Therefore, it is essential to consider the perspectives and priorities of private stakeholders and the potential barriers they may face when developing and implementing SUDS strategies. Addressing these barriers can help to ensure that private stakeholders are fully engaged in promoting sustainable stormwater management practices.

3.3 Resources

Access to sufficient community resources is essential for successfully implementing SUDS in sub-Saharan cities. These resources encompass a range of financial, infrastructural, technical, and knowledge-based assets at the local level (Winter 2016). Financial resources can be used to invest in the necessary infrastructure, such as permeable pavements, rain

gardens, and green roofs, which can help to reduce runoff and improve stormwater management (Cettner and Ashley 2014).

Technical knowledge and experience levels within the community can also be critical in successfully implementing SUDS (Armitage 2011). Community training programs and educational materials can help to increase awareness of SUDS, influence the availability of labor to oversee implementation, and promote the adoption of sustainable practices. The technical expertise of community members can also be leveraged to support the design, installation, and maintenance of SUDS infrastructure (Bredhauer 2016; du Toit et al. 2018). In addition to financial and technical resources, space availability for SUDS implementation is also essential. Community land priorities, such as designating spaces and areas for green infrastructure, can play a critical role in promoting effective stormwater management (du Toit et al. 2018). The availability of land for SUDS implementation is crucial in areas where land is scarce or competition for land use is high (Mguni et al. 2016a, b).

Finally, market incentives can also play a role in motivating the uptake of SUDS. For example, tax incentives or rebates may encourage homeowners or businesses to invest in SUDS infrastructure, while financial incentives may motivate developers to incorporate SUDS into their projects (Ndeketeya and Dundu 2019).

3.4 Discourses

The discourses surrounding the community governance of SUDS are crucial in determining the structure of local governance arrangements, decision-making processes, and power distribution within the community (Herslund and Mguni 2019). These discourses, which may include local neighborhood meetings, community forums, social groups, and other communication channels, refer to the various forms of communication and exchange of ideas, information, and opinions among community members regarding the governance of their community (Williams et al. 2020). The discourses may also reflect the values and beliefs of community members, as well as their social and political attitudes and perspectives toward environmental sustainability programs (Sañudo-Fontaneda and Robina-Ramírez 2019).

In addition to shaping community norms and rules for behavior, practical community governance discourses necessitate active engagement, respect for diverse perspectives, and a willingness to engage in constructive dialogue. Engaging in such dialogues can nurture a sense of community ownership and collective responsibility for the community's welfare. This involves empowering residents and stakeholders to actively and meaningfully participate in making decisions, managing, and implementing projects or initiatives that directly influence their lives and well-being. Consequently, these inclusive practices contribute to more effective and sustainable governance (Mulligan et al. 2020). Community-level discourses can also influence management strategies and planning processes for the implementation of SUDS, community awareness of and reliance on the ecosystem services provided by SUDS, as well as the community's inclinations towards post-flood environmental regeneration and protection (Shackleton et al. 2015).

3.5 Rules of the game

Rules of the game, whether formal or informal, play a crucial role in shaping the behavior of community actors during the implementation of SUDS. Formal rules may be established through regulatory frameworks or legislative support, guiding issues such as zoning, land

use, environmental protection, risk mapping, emergency planning, and water management (Ndeketeya and Dundu 2019). These formal rules ensure compliance and accountability among community actors (Qiao et al. 2019). However, informal rules, such as cultural norms and local languages, are critical in shaping behavior and determining social rules. For example, community members may have cultural practices that influence how they interact with the environment or other community members.

Similarly, local languages may determine how information is communicated and disseminated among community members, influencing the effectiveness of communication strategies (du Toit et al. 2018). Gender roles and equality are also important considerations when it comes to the implementation of SUDS. Women, for example, may have different roles and responsibilities within the community that may affect their participation in SUDS projects (Dodman and Mitlin 2013). Ensuring equitable treatment of all community partners is also essential for building trust and transparency in local political actions and promoting cooperation among stakeholders involved in the implementation or management of SUDS (Dodman and Mitlin 2013).

3.6 Indicators for assessing social structure determinants

As depicted in Table 2, a set of indicators has been developed to render the social structure determinants more concrete and practical for assessing the potential integration of community governance of SUDS into local urban stormwater management frameworks. These indicators have been specifically designed to facilitate a comprehensive evaluation of community governance in the context of SUDS governance. They serve as a tool for measuring the performance of the social structure determinants and the various dimensions of the policy arrangement within community governance.

Through carefully assessing these elements, it becomes feasible to identify specific dimensions within community governance that may exhibit deficiencies or vulnerabilities. This identification, in turn, creates valuable opportunities for implementing targeted interventions and strategic actions to address these specific dimensions. The objective is to enhance the overall effectiveness of community governance and enable a seamless integration of SUDS into local urban stormwater management frameworks.

The assessment of these indicators can be conducted through interviews with relevant stakeholders or stakeholder groups who have a stake or are affected by the SUDS governance processes, both at the individual and system levels. Each indicator's performance can be evaluated using a predefined scale, such as low, medium, or high, which can be calibrated, based on the community stakeholders' capacities to engage with involvement and participation in SUDS governance processes, such as design and management.

The overall performance of indicators at the system level can be evaluated using a weighted average rating. This involves assigning specific weights to each indicator based on its relative importance within the community governance framework. The performance ratings of all indicators are then multiplied by their respective weights and added to calculate the weighted average rating, providing a comprehensive measure of the system's effectiveness. This approach allows for a holistic assessment that considers the collective impact of various indicators and their significance in managing the community governance aspects being evaluated.

It is essential to acknowledge that there may not be a need to evaluate all indicators within the framework in a given assessment. The evaluation process can be context-specific and selective, with indicators chosen from different framework dimensions based on the

Table 2 Framework for assessing social structure determinants of community governance for Sustainable Urban Drainage Systems

DIMENSION	DETERMINANT	EXPLANATION	INDICATOR	REFERENCE
ACTORS	Community leadership and allocation of responsibility	Particular assignment and definition of duties related to the implementation and management of SUDS	• Precise definitions of objectives and goals related to sustainable management of stormwater in urban areas and the implementation of SUDS • Degree of community individuals' dedication to participate in the implementation of SUDS	(Sutherland et al. 2016)
	Community innovation	Development of creative ideas, solutions, and practices by community members that contribute to the effective management and maintenance of SUDS	• Level of participation of community members in the planning, design, implementation, and monitoring of SUDS • The extent to which local knowledge and resources are applied to develop efficient SUD solutions that meet the community's needs	(Mguni et al. 2016a)
	Technical skills and competencies	Degree of technical knowledge and proficiency in SUDS within the community	• Level of knowledge about SUDS's design, construction, operation, and maintenance • Level of community understanding regarding the technical dimensions of stormwater management	(Herslund and Mguni 2019; Morison and Brown 2010)
	Private stakeholders' involvement	Participation of non-public community actors, including firms, companies, and private individual investors, in SUDS preparation, development, performance, and management	• Private sector financial contribution to SUDS initiatives • Private sector involvement in SUDS planning and implementation • Transparency of private sector interests and decision-making in SUDS	(Dhakal and Chevalier 2017; Bos and Brown 2015)
	Academia involvement	Participation of academic institutions, researchers, and scholars in the planning, design, implementation, and evaluation of community SUDS initiatives	• Level of involvement and collaboration between academic experts, institutions, and local community organizations on SUDs projects • Quantity and quality of SUDs research publications • Availability of SUDs community training programs and events led by academic institutions	(Bredhauer 2016; Mulligan, et al. 2020)
RESOURCES	Community priorities for SUDS funding from both public and private sources	Identification and allocation of financial resources towards specific SUDS projects and programs based on their level of urgency, feasibility, and potential impact on the community	• The proportion of the budget for community SUDS projects by local governments, NGOs, and private entities • Criteria used for evaluating and prioritizing community SUDS projects, such as impact, feasibility, and cost-effectiveness	(Armitage 2011; Mguni, Herslund and Jensen 2016a, b)
	Community financial incentives	Monetary incentives such as rebates, tax credits, grants, or other forms used by the community or local government to encourage the adoption of SUDS)	• The number of financial incentive programs implemented by the local government to promote the adoption of SUDS • Amount of funding allocated to SUDS programs • The number of individuals or businesses receiving financial incentives to implement SUDS	(Ndeketeya and Dundu 2019)

Table 2 (continued)

DIMENSION	DETERMINANT	EXPLANATION	INDICATOR	REFERENCE
	Priorities for land use and development by both public and private entities	Strategic allocation of land for the implementation of sustainable urban stormwater management practices such as SUDS, taking into consideration the needs and interests of both public and private stakeholders	• Degree of consideration of SUDS implementation in community land use decision-making processes • Percentage of public land allocated for SUDS • Level of collaboration between public and private entities in land use planning and SUDS implementation • The number of policies and regulations promoting SUDS integration in land use planning	(Dhakal and Chevalier 2017; Sutherland et al. 2016)
	Human resources	The presence, proficiency, and competencies of individuals and collectives engaged in the preparation, creation, execution, and supervision of SUDS, e.g., public officials, private industry stakeholders, and specialists with technical expertise in establishing stormwater management infrastructures	• Adequacy of staffing levels and resources allocated to support SUDS implementation and management • Availability and accessibility of relevant training programs and resources for SUDS management • The capacity of local government officials and private sector actors to support SUDS implementation and management	(Dhakal and Chevalier 2017; Morison and Brown 2010)
	Knowledge of SUDS	The community's level of understanding and awareness regarding the technical and operational aspects of sustainable urban drainage systems (SUDS) for stormwater management	• Number of community members with knowledge of SUDS design and implementation • Number of community members with technical expertise in stormwater management and SUDS • Level of community awareness and understanding of the benefits of SUDS • Availability of SUDS-related training and education programs for community members	(Barbosa et al. 2012; Cettner et al. 2014)
DISCOURSES	Management strategies and planning processes	The techniques and steps utilized by community stakeholders involve the creation of policies, regulations, and plans that define the duties, accountabilities, and measures necessary to accomplish the objectives of SUDS	• The number of community stormwater management plans in place • Use of adaptive management to respond to changing conditions • The scale of allocation of resources to support SUDS implementation and management • Regular monitoring and evaluation of SUDS performance for future planning	(du Toit, et al. 2018)
	Environment regeneration and protection	Measures taken to restore, preserve, and enhance natural ecosystems and biodiversity within communities through the implementation of SUDS, e.g., designing or implementing SUDS to promote the sustainable use of natural resources	• Stakeholder collaboration level in sustainable SUDS practices • Community participation in SUDS maintenance and management for habitat and ecosystem protection and restoration • Community knowledge of SUDS' environmental benefits for regeneration and protection	(Shackleton 2015)

Table 2 (continued)

DIMENSION	DETERMINANT	EXPLANATION	INDICATOR	REFERENCE
	Knowledge of SUDS Ecosystem services	Understanding of the pros and cons of SUDS for ecosystem services, including benefits like improved water quality and biodiversity, as well as potential risks like changes to land use and impacts on local communities	• Community knowledge of SUDS ecosystem services • Community familiarity and usage of monitoring methods for SUDS ecosystem services • Incorporation of ecosystem service considerations in SUDS decision-making	(Shackleton 2015)
	Community participation	Active engagement of community members and stakeholders in collaborative SUDS solution development that meets community needs and broader environmental/social goals	• Community ownership, engagement, and management of SUDS infrastructure and projects • Community awareness and understanding of SUDS • Community satisfaction and perceived effectiveness of SUDS • Community-led initiatives and activities for SUDS education and advocacy	(Mguni, Herslund, and Jensen 2016a, b)
	Communication and information dissemination	The various ways in which information about stormwater management using SUDS and related activities are shared among community members, stakeholders, and relevant authorities	• Existence and quality of community communication plan for SUDS projects • Diversity, frequency, and quality of communication activities to stakeholders • Effectiveness of communication activities in raising awareness and increasing knowledge • Effectiveness of feedback mechanisms in assessing stakeholder perception of SUDS	(Mguni et al. 2015)
RULES OF THE GAME	Regulatory frameworks and legislative support	The laws, policies, and guidelines that provide a legal and institutional basis by defining the roles and responsibilities of different stakeholders, outlining the procedures for decision-making and implementation, and establishing standards and criteria for SUDS design, construction, operation, and compliance with environmental and health regulations	• Existence and comprehensiveness of SUDS-related laws and policies at the national and local levels • Level of compliance with environmental and health regulations in the design, construction, and operation of SUDS • Effectiveness of SUDS integration into broader urban planning and development strategies • Frequency and quality of monitoring and evaluation of SUDS regulatory frameworks to assess their effectiveness and identify areas for improvement	(Ndeketeya and Dundu 2019; Jiusto and Kenny 2016)
	Cultural norms, values, and local languages	The cultural practices, beliefs, and language systems influence the attitudes and behaviors of community members towards SUDS	• The scale of diverse cultural group representation in SUDS decision-making and governance • The scale of use of local languages/culturally appropriate communication in SUDS planning • Level of incorporation of traditional knowledge for water management into SUDS design • Respect cultural values related to water/land use in SUDS decisions	(du Toit et al. 2018)

Table 2 (continued)

DIMENSION	DETERMINANT	EXPLANATION	INDICATOR	REFERENCE
	Quality and reliability of community politics and power dynamics	The effectiveness, transparency, and accountability of community-level decision-making processes and mechanisms that guide the planning, implementation, and management of SUDS	• Level of transparency and accountability in community decision-making processes • Level of trust and cooperation among stakeholders of community-led initiatives • Presence of conflict resolution mechanisms • Presence of a mechanism to report the abuse of power	(Dhakal and Chevalier 2017; Armitage et al. 2013)
	Equitable treatment of all partners	The fair and just treatment of all stakeholders involved in the planning, implementing, and managing sustainable urban drainage systems (SUDS), regardless of their socio-economic status, ethnicity, or other characteristics	• Level of inclusivity/diversity of SUDS decision-making and marginalized group representation • Level of equitable distribution of SUDS benefits/costs for all stakeholders • Level of access to SUDS governance information/resources for everyone • The scale of implementation of policies/mechanisms for equal participation and power balance	(Dodman and Mitlin 2013; Cettner et al. 2014)
	Gender Roles and Equality	The extent to which gender considerations are integrated into decision-making processes and implementation of SUDS, such as recognizing the different needs, roles, and responsibilities of women and men concerning water management	• Level of women's participation/representation and gender-specific needs in SUDS • Level of stakeholders' awareness of gender issues in SUDS governance • The scale of implementation of policies/mechanisms for gender equality in SUDS governance	(Dodman and Mitlin 2013; Patt and Suarez 2009)

specific requirements and objectives. This allows for a more focused and relevant assessment, tailored to the unique circumstances, without the burden of assessing every indicator in the framework. Figure 3 illustrates a method for evaluating community governance of Sustainable Urban Drainage Systems (SUDS) within a specific study area.

4 Practical implications of applying assessments of social structure determinants of community governance of SUDS

Assessing the determinants of social structure within the community-level governance of SUDS is crucial for understanding the factors influencing their effectiveness as community-led initiatives (Nóblega Carriquiry et al. 2020). This discussion builds upon the developed framework, delving into practical implications tailored to the sub-Saharan context.

4.1 Local actor empowerment

In sub-Saharan contexts, renowned for successful community-led initiatives, evaluating local actors and leadership in governing SUDS is a foundational step (Mguni et al. 2016a, b). This assessment can contribute to the understanding of vital roles played by local leaders in fostering community engagement. By comprehending the roles of local actors and leaders thoroughly, the assessment can facilitate the identification of entry points for their involvement, empowering them to be catalysts for transformative change, drive community engagement, and ensure that SUDS projects resonate with the unique fabric of each local community (Nemutamvuni et al. 2020). This not only enhances the efficiency of SUDS as stormwater management projects but also reinforces the community's commitment to the initiatives in place, fostering a sense of ownership within the community and contributing to the sustainability and success of SUDS projects.

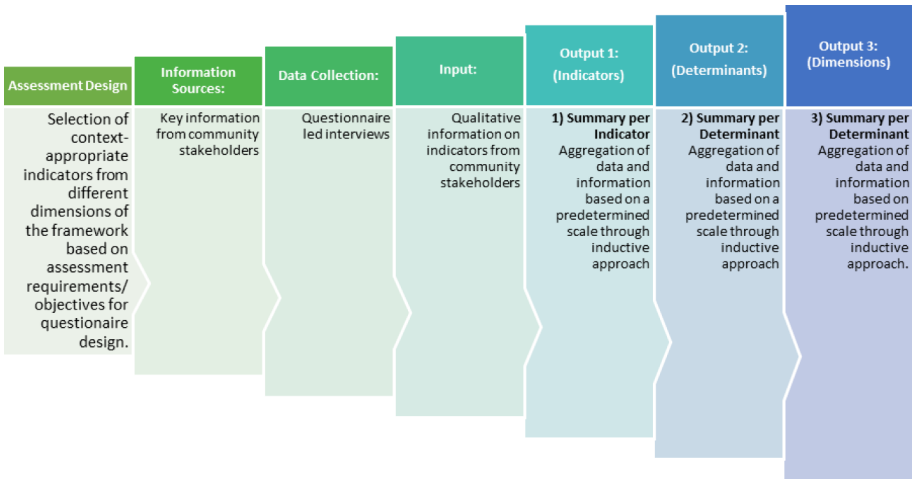

Fig. 3 Methodology for Applying Framework for Assessing Community Governance of SUDS

4.2 Addressing socio-economic considerations and financial constraints

Our assessment framework acknowledges the inherent link between the success of community-led initiatives in Sub-Saharan contexts and socio-economic factors, encompassing elements like income disparities, poverty, and their interconnected association with vulnerability (Cilliers 2019). It recommends a strategic evaluation of governance determinants dependent on resources, including community human resources, available land for implementing SUDS projects, and funding, which significantly influence community engagement. This assessment seeks to identify opportunities to optimize cost-effectiveness, and task allocation based on community skills and capacities, identify incentives for active community participation, and guide fund allocation decisions by weighing synergies and trade-offs among SUD options or other stormwater management approaches. These considerations are essential for bolstering the sustainability of community-governed SUDS projects.

4.3 Assessing regulatory frameworks for transparency and accountability

The evaluation of local regulatory frameworks is essential for transparency and accountability in community-led initiatives, particularly within the sub-Saharan context, which has a historical legacy of corruption and mismanagement of public funds (Williams et al. 2018). It serves to foster good governance practices and ensure responsible utilization of resources. Within the community governance of SUDS, analyzing these frameworks provides possibilities to identify gaps, inefficiencies, or potential areas of improvement that can contribute to a more robust and accountable governance structure (Wijesinghe and Thorn 2021). Moreover, this evaluation can provide a mechanism for instilling public trust and confidence in community-led SUDS initiatives. When regulatory frameworks are transparent and well-monitored, community members are more likely to actively engage and participate in these initiatives, knowing that their contributions and resources are managed in a responsible and accountable manner. This, in turn, contributes to the overall success and sustainability of community-led projects.

4.4 Examining discourse dynamics

In diverse sub-Saharan urban communities, exploring discourse-related determinants within the framework establishes a basis for SUDS community governance rooted in transparent and inclusive planning (Shackleton et al. 2015). This goes beyond technical aspects, delving into community dynamics, where effective discourse acts as a catalyst for meaningful change. Factors like community participation, information dissemination, management strategies, and planning processes empower stakeholders to express perspectives and voice concerns. (Mulligan et al. 2020). This process not only facilitates open communication but also supports the building of trust between community members and decision-makers. Trust becomes pivotal in fostering an environment where collaboration and cooperation are the norm, not the exception (Diep et al. 2022). This, in turn, nurtures a sense of ownership and responsibility among community members, encouraging active participation in decision-making processes that directly impact the implementation of SUDS in their living spaces.

4.5 Innovation and collaboration assessment for effective governance

Broadening the assessment to evaluate community innovation, technical skills, private stakeholder engagement, and academia involvement is a recognition of the nuanced and location-specific traits within local adaptation arenas in sub-Saharan communities (Dodman and Mitlin 2013). This evaluation becomes a crucial tool in shaping SUDS solutions that are tailored to the unique challenges of each community. By acknowledging the distinct context and characteristics, the assessment ensures that SUDS initiatives are not one-size-fits-all but rather responsive to the intricacies of each local environment. Furthermore, the assessment of private stakeholders and academia involvement unveils opportunities to synergize local insights with external expertise. This strategic integration not only opens avenues for private sector investments in stormwater management but also enriches the decision-making processes with diverse perspectives. The collaboration between local and external actors further enhances the robustness of SUDS initiatives, fostering innovation and efficiency.

4.6 Cultural and environmental adjustment

The governance assessment framework places a significant focus on evaluating the influence of integrating cultural values into the design and governance of SUDS. Tailoring assessments to diverse cultural and environmental contexts in sub-Saharan Africa underscores the need to cultivate local knowledge. This approach ensures that vulnerability assessments not only identify key factors but also facilitate the seamless integration of evaluation outcomes into actionable steps within planning processes. The framework, therefore, underscores the dynamic relationship between cultural values, local knowledge generation, and the effective implementation of SUDS initiatives.

5 Conclusion

This study presents a novel assessment framework rooted in the policy arrangement approach to evaluate social determinants influencing community governance in SUDS implementation. By exploring dimensions such as community actors, resources, discourses, and rules of the game, this holistic approach provides insights into the intricate dynamics of community governance systems. The development of 65 indicators offers a comprehensive tool for researchers and practitioners to delve into the complexities of SUDS management.

The contextual nuances within the sub-Saharan context underscore the importance of tailored assessments that account for local adaptation arenas. Moreover, the emphasis on community knowledge and participation highlights the significance of inclusivity in SUDS projects. However, challenges persist in assessing ecological and economic factors, as well as broader issues beyond community control, such as state support and resource distribution.

While this study primarily focuses on social structure determinants, addressing these challenges will be crucial for advancing community governance of SUDS. Future research should strive to develop strategies that effectively navigate these complexities, ensuring equitable and sustainable management of nature-based urban stormwater systems.

Author contributions Simon Muwafu conceived the idea, conducted the literature search and formal analysis, and drafted the initial manuscript. Simon Muwafu and Lena Rölfer devised the research design. María Máñez Costa and Jürgen Scheffran provided guidance and supervision. All authors critically revised and approved the final version, resulting in a comprehensive contribution to the sustainable urban drainage systems field.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability We do not analyze or generate any datasets. One can obtain relevant materials from the references below.

Declarations

Conflict of interest The authors declare no competing interests.

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3 Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa

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Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa

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Abstract: The expansion of cities in Sub-Saharan Africa has led to an increase in impervious surfaces, intensifying stormwater management challenges, especially in informal settlements situated in ecologically sensitive areas like wetlands. This urban growth has heightened flood risks and negatively impacted biodiversity, water quality, and socio-economic conditions, particularly during extreme weather events intensified by climate change. Nature-Based Solutions (NbSs), including Sustainable Urban Drainage Systems (SUDSs), offer sustainable strategies for managing stormwater and mitigating these adverse effects. However, the success of such solutions relies not only on their technical implementation but also on the social and institutional contexts within urban communities. Community-level governance is crucial in integrating NbSs into urban stormwater management frameworks. This research evaluates how community governance of NbSs, specifically SUDSs, can enhance stormwater management and flood resilience in Kampala, Uganda. Using an assessment framework grounded in the Policy Arrangement Approach (PAA)—which considers discourses, actors, resources, and rules of engagement—this study incorporates structural, social, and political factors that influence SUDS community governance performance. Concentrating on the Sembule zones within the Nalukolongo catchment area, this research investigates the impact of community governance dynamics on SUDS implementation. This study examines key aspects such as community engagement, resource management, and regulatory frameworks to assess the effectiveness of these initiatives, providing valuable insights for advancing nature-based urban stormwater management.

Keywords: community governance; Sustainable Urban Drainage Systems (SUDSs); Nature-Based Solutions (NbSs); urban stormwater management; flood risks; climate change; Sub-Saharan Africa

Citation: Muwafu, S.P.; Celliers, L.; Scheffran, J.; Máñez Costa, M. Community Governance Performance of Nature-Based Solutions for Sustainable Urban Stormwater Management in Sub-Saharan Africa. *Sustainability* **2024**, *16*, 8328. https://doi.org/10.3390/su16198328

Academic Editors: Kristian L. Dubrawski, Maleea Acker and Ludwig Paul Cabling

Received: 17 August 2024
Revised: 9 September 2024
Accepted: 22 September 2024
Published: 25 September 2024

1. Introduction

Rapid urbanization in Sub-Saharan African cities frequently leads to inadequate infrastructure planning, increasing impervious surfaces, particularly in ecologically sensitive areas like wetlands [1–3]. This urban expansion exacerbates challenges in managing stormwater, heightening the risk of flooding, and impacting socio-economic factors, water quality, and biodiversity, especially during extreme weather events associated with climate change [4,5].

Acknowledging these challenges, sustainable urban planning is gaining traction, with a focus on integrating Nature-Based Solutions (NbSs) like Sustainable Urban Drainage Systems (SUDSs) into stormwater management systems. These systems leverage natural processes or mimic them through engineered structures, playing a pivotal role in improving stormwater management [6–8]. Increasingly, such strategies are recognized as essential for enhancing urban resilience against environmental pressures, particularly flooding, brought about by climate change.

However, beyond deployment, the effective functioning of SUDSs as NbSs to enhance flood resilience requires consideration beyond mere technical aspects. It underscores the critical role of social and institutional contexts in their implementation [7,9,10]. Factors such as social engagement, resource mobilization, local management structures, regulatory frameworks, and cultural attitudes significantly influence the adoption, maintenance, and integration of these solutions within local and broader urban planning frameworks. Consequently, community-level governance emerges as a critical determinant of the success and sustainability of NbSs like SUDSs.

Community governance is vital for ensuring the effective implementation, maintenance, and adaptation of SUDSs to local conditions [10,11]. Effective community governance fosters ownership, accountability, and stewardship among residents, while participatory methods, a characteristic of community governance, help integrate local knowledge and social perspectives into SUDS designs. This approach not only enhances resilience but also promotes sustainable flood management practices that empower local populations [7,12].

In Sub-Saharan Africa, studies have explored the intersection of governance structures, NbSs, and urban stormwater management, revealing both challenges and opportunities. Wilkinson et al. (2013) [13] highlight that fragmented and weak governance systems complicate the implementation of sustainable solutions. Douglas (2016) [14] notes that a lack of coordination across different governance scales—such as municipal plans, NGO projects, and community actions—hinders effective stormwater management. Lindell (2008) [14] suggests that the diversity of governance actors in Sub-Saharan cities allows for experimentation with new approaches like NbSs. Pelling and Leck (2018) [15] advocate for the development of multi-level governance systems where civil society and local governments collaborate to manage risks and build resilience. For SUDSs, Hamann and April (2013) [16] recommend sub-city-level implementation, while Mguni et al. (2016) [7] stress the importance of integrating SUDSs into local governance frameworks to demonstrate their effectiveness in informal settlements, which can help scale solutions to larger areas [11,17].

Despite these insights, there is a significant research gap in comprehensively assessing community governance performance specifically related to SUDSs. Addressing this gap is essential for identifying strengths and weaknesses and guiding improvements. Such an assessment aligns with the Sustainable Development Goals (SDGs) by promoting governance strategies that foster collective action, ensure accountability, and balance various SDG objectives.

To address the identified research gap, this manuscript pursues two interrelated objectives. The first is to assess the performance of community governance in the implementation and maintenance of SUDSs as NbSs for urban stormwater management in Sub-Saharan African cities, with Kampala serving as a representative case study. To accomplish this, the second objective involves testing and evaluating the effectiveness of an assessment framework developed by Muwafu, Rolfer, Scheffran, and Manez Costa (2024) [18] for measuring the community governance performance of SUDSs.

To understand the conditions for successful SUDS implementation and address the research objectives, the community governance landscape was evaluated across several dimensions: social structure, engagement processes, local resource management strategies, regulatory frameworks, and cultural attitudes.

2. Study Area

The assessment was conducted in Nalukolongo, a catchment area within Kampala City, Uganda. This location exemplifies the urban flooding challenges faced by this rapidly growing East African city. Such challenges are typical of many urbanizing Sub-Saharan cities, which often grapple with infrastructure and environmental issues [19].

As part of the Greater Kampala Metropolitan Area (GKMA), Kampala has a population of approximately 3.6 million as of 2021 and an annual growth rate of 5.6%, making it one of Africa's fastest-growing cities [20]. This rapid urbanization has led to significant

issues, including inadequate infrastructure, environmental degradation, and complex land ownership. Kampala's rapid development has increased impermeable surfaces and reduced water infiltration, leading to higher runoff volumes [21].

Unclear wetland boundaries and outdated drainage systems such as those depicted in Figure 1 further complicate stormwater management, resulting in frequent flash floods that threaten vulnerable communities, cause economic losses, damage assets, and disrupt business operations in areas like Nalukolongo [22].

Figure 1. Aging drainage systems, commonly obstructed by refuse.

Residents in these flood-prone areas often resort to makeshift strategies, such as raising ground around dwellings and constructing protective barriers, due to limited financial resources for flood mitigation. These challenges highlight systemic discrepancies in resource allocation, perpetuating inequality and marginalizing urban poor populations [21]. In response, the Greater Kampala Integrated Flood Resilience Partnership—a coalition initiated in 2021, including stakeholders from the public sector (Ministry of Water and Environment, Kampala Capital City Authority), international organizations (GIZ), local NGOs (ACTogether Uganda, Kampala, Uganda), and civil society (community groups, local leaders)—has initiated sustainable urban drainage projects in Nalukolongo [23].

The partnership focuses on implementing nature-based blue–green infrastructure solutions to improve stormwater management and enhance flood resilience. Key initiatives involve restoring vegetation along drainage channels, installing rainwater harvesting systems, replanting slopes, and fostering behavioral change by training local leaders and "flood champions" to advocate for effective stormwater management.

These NbSs and community engagement efforts offer cost-effective and environmentally friendly alternatives for stormwater management and subsequent flood mitigation, providing multiple co-benefits to the community. This study's assessment aimed to evaluate the community governance of these sustainable urban drainage projects in Nalukolongo. It examined how local social dynamics influence behavioral change and stakeholder empowerment in flood mitigation strategies, assessing the performance of community-led management approaches. It also focused on how inclusive and collaborative methods in planning, investing, and managing these NbSs impact their long-term viability and contribution to community resilience.

Through this evaluation, this study aimed to provide insights into the successes and challenges of community-governed Sustainable Urban Drainage Systems in Nalukolongo. These findings are crucial for understanding how such approaches can be optimized and potentially scaled up to address similar challenges in other rapidly urbanizing regions, underscoring the importance of integrated, community-driven approaches to urban development and climate resilience.

3. Materials and Methods

In this study, community governance is conceptualized as an intricate combination of rules, processes, and structures within a locality that facilitate self-organization, de-

liberation, decision-making, and the pursuit of preferred objectives and outcomes. This governance paradigm encompasses both formalized and informal mechanisms through which community stakeholders engage in decision-making processes, resource allocation, and the resolution of collective issues [24]. Community governance typically operates within broader institutional and policy-making contexts, navigating the dual challenges of contesting established processes or integrating into existing systems to achieve sustainable outcomes [25–27].

The assessment approach employed in this study adopts and applies an innovative and comprehensive framework developed by Muwafu et al. (2024) [18]. This framework adapts the Policy Arrangement Approach, a meso-level theory from environmental policy studies, to the unique socio-ecological dynamics of Sustainable Urban Drainage Systems (SUDSs) as NbSs. Customization is achieved by incorporating criteria that address the ecological, social, and governance aspects of NbSs, such as ecosystem services and adaptive management practices.

The adapted framework synthesizes concepts from complementary theories, enabling a comprehensive understanding of the complex interactions shaping SUDS governance and implementation as NbSs in decentralized, community-driven urban stormwater management contexts. Its strength lies in systematically addressing the multifaceted objectives that underpin successful community-led implementation of SUDS initiatives. The framework delineates 20 determinants across four interrelated dimensions: discourses, actors, resources, and rules of engagement, integrating structural, social, and political factors that characterize the complex landscape of community governance in the context of SUDSs [18].

This multidimensional lens aligns with this study's conceptualization of community governance dynamics, facilitating a comprehensive and holistic analysis of the socio-governance factors shaping SUDS implementation at the community level.

3.1. Characteristics of the Assessment Approach

This assessment utilizes a framework based on the Policy Arrangement Approach (PAA), incorporating discourses, actors, resources, and rules of engagement to provide a thorough evaluation of community governance in Sustainable Urban Drainage Systems (SUDSs). Its inclusiveness is evident through a diverse range of indicators that cover both social and institutional dimensions, ensuring a comprehensive analysis of community governance performance and its effectiveness in improving SUDS outcomes within the community.

3.2. The Foundation of the Assessment Framework

The "actors" dimension of the assessment framework maps the diverse array of stakeholders, from community members to urban professionals and civil society organizations, whose participation is crucial for fostering inclusive and sustained engagement. This directly aligns with this study's objective of assessing the impact of social engagement on the success and maintenance of SUDS projects.

The "resources" dimension goes beyond technical considerations, integrating the varied knowledge, skills, and priorities across sectors and disciplines. This comprehensive assessment of financial, human, and technical resources within the community enables the identification of gaps and optimization strategies, addressing the objective of examining resource mobilization and allocation for SUDS implementation [18].

The "discourses" dimension delves into the narratives, attitudes, and sectoral viewpoints surrounding SUDSs and NbSs, capturing the cultural underpinnings that influence community engagement, stewardship, and the adoption of these NbSs. This dimension directly addresses this study's objective of understanding cultural attitudes towards stormwater water management and their impact on community participation.

Finally, the "rules of engagement" dimension evaluates the formal and informal norms, regulations, and boundary management mechanisms that govern stakeholder interactions and policy implementation related to SUDSs. This critical analysis of the regulatory and

policy frameworks aligns with our objective of identifying enabling or constraining factors for the deployment of SUDS initiatives [18].

3.3. Inclusive Indicators

The assessment framework utilizes a comprehensive set of indicators whose valuation can be customized to suit the specific context of the study area. These indicators span across the four dimensions of the framework: discourses, actors, resources, and rules of engagement. The indicators serve a dual purpose: first, they facilitate the identification of critical issues within each dimension, and second, they enable the measurement of the performance and effectiveness of these dimensions in shaping the community governance of SUDS initiatives [18]. This approach aligns with the growing body of literature that emphasizes the value of indicator-based assessments in evaluating the strengths, weaknesses, and overall resilience of governance systems and institutions in the face of climate change adaptation challenges [28].

Close collaboration with stakeholders ensures the selection of contextually relevant indicators. This approach enhances the relevance and legitimacy of the holistic evaluation, enabling the assessment of sustainable and viable SUDS implementation strategies that are tailored to local contexts and priorities.

3.4. Implementation Phase

In the implementation phase, the assessment framework is rigorously applied to evaluate community governance performance in SUDSs. This phase involves a detailed stakeholder analysis and selection process to identify and engage key actors, thereby improving the relevance and accuracy of the findings. Additionally, a participatory approach to data and information collection is employed, actively involving community members and stakeholders to ensure comprehensive and representative input.

3.5. Application of the Framework

The application of the framework adhered to a structured process, as illustrated in Figure 2. It commenced with a stakeholder analysis approach to identify key stakeholders and relevant information sources, followed by comprehensive data collection through a participatory approach. Subsequently, an iterative data analysis process was employed to extract meaningful insights. This methodical approach ensured a thorough and nuanced understanding of community governance dynamics.

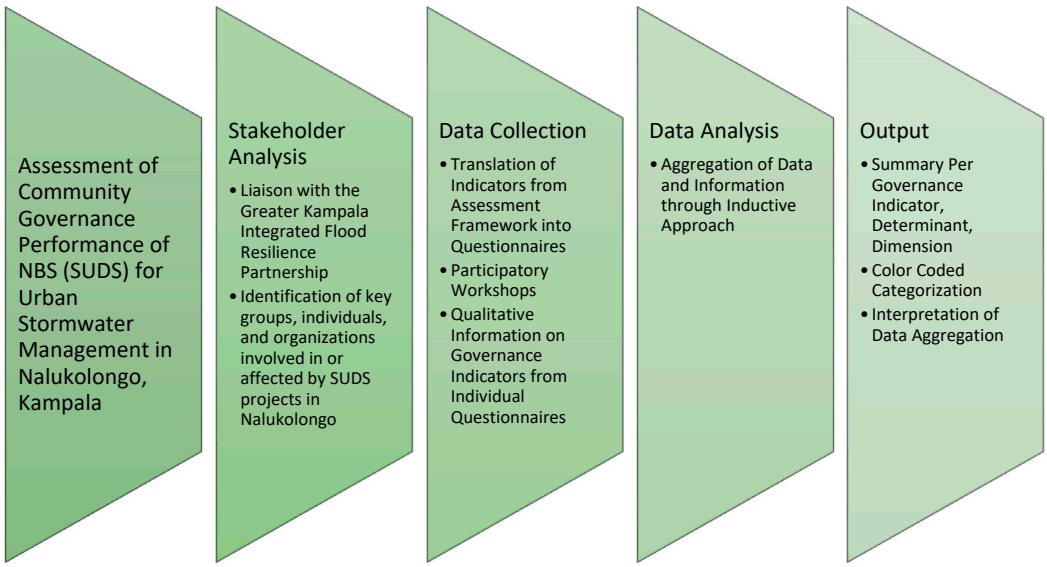

Figure 2. Structure of evaluation process.

3.6. Participatory Approach to Data and Information Collection

Community governance of environmental issues is characterized by its emphasis on participation and relevance to the affected people. It recognizes that the collaboration and support of those impacted are crucial for the successful implementation of interventions [19]. Involving community members and local institutions in defining the issues and selecting solutions makes them more likely to comply with the resulting management program, as it aligns with their values, needs, and beliefs about how their society should function. This participatory approach helps community members see the program as a cohesive whole [29].

Guided by this understanding, the assessment process utilized a structured participatory methodology to collect data and information. This involved a thorough stakeholder analysis and the active engagement of community members, local organizations, and other stakeholders through workshops, interviews, and consultations. The participatory approach is academically justified, as it provides insights into local contexts and fosters collaboration between experts and local participants [29].

Key aspects of the participatory approach included involving a wide array of stakeholders to ensure equitable representation, collaboration, and transparency. This approach offered several benefits, such as enhanced community support, contextual insights, and the promotion of empowerment and respect for all community members during the assessment process.

3.7. Stakeholder Analysis and Selection

To facilitate the participatory approach, a thorough stakeholder analysis was conducted to identify key groups, individuals, and organizations involved in or affected by the implementation of SUDS projects in Nalukolongo. This process aimed to enhance the accuracy of assessing community governance approaches by including relevant stakeholders [30].

The stakeholder analysis process involves systematic and transparent criteria to comprehensively identify and engage crucial stakeholders. These criteria included direct relevance to SUDS projects, gender inclusion, influence and power, beneficiary status, geographical proximity, diverse perspectives, legitimacy, willingness to engage, and avoiding biases. This approach aligns with best practices in stakeholder analysis for environmental management [31].

Ultimately, 24 stakeholders were identified from diverse backgrounds as illustrated in Table 1, representing a broad cross-section of the community affected by or involved in SUDS projects in Nalukolongo. This diverse group included 3 community leaders, 4 educators, 3 civil society professionals, 2 government agency representatives, and 12 representatives from community formal and informal sectors. The research design intentionally incorporated a higher proportion of local community members to comprehensively capture indigenous knowledge and perspectives, crucial for evaluating the multifaceted dimensions of SUDS governance under community governance [18]. By including stakeholders from both formal and informal sectors, the analysis aimed to bridge potential gaps between official planning processes and on-the-ground realities [30].

Table 1. Overview of stakeholder groups, number per group, and selection rationale.

Stakeholder Group	Number	Attributes/Roles
Community Leaders	3	Have deep local knowledge and influence
Educators	4	Provide insights on how flooding impacts schools and education
Civil Society Professionals	3	Have technical expertise in local urban flood planning and environmental management
Government Agencies	2	Formal sector representatives involved in flood management and policymaking
Representatives from Community Formal and Informal Sectors	12	Included established community business owners, small-scale community traders, and community organizations

This varied composition ensured a wide range of perspectives and experiences were captured, from grassroots community concerns to technical and policy considerations. While this stakeholder analysis approach was comprehensive, it is important to acknowledge potential limitations, such as the possibility of overlooking hidden or marginalized stakeholders. Future iterations of this assessment could explore innovative methods for identifying and engaging these harder-to-reach groups.

The identified stakeholders attended a three-hour workshop conducted in Nalukolongo. During the workshop, participants completed questionnaires, with translation assistance provided by ACTogether Uganda staff for community members with limited English proficiency, ensuring linguistic inclusivity and data integrity.

To develop the questionnaire, selected indicators were transformed into a list of questions guiding data collection for each indicator. These questions were assigned units of measure and characterized as binary, ordinal, or cardinal. The performance of these indicators was defined by the capacities of different individuals to engage with various elements or processes involved in the management of Sustainable Urban Drainage Systems (SUDSs) in the community and their impacts on stormwater management. In adherence to ethical research practices and data protection standards, participants received informed consent forms and were given the option to remain anonymous in their responses.

3.8. Data Assessment and Analysis

The data analysis for community governance of NbSs (SUDSs) for urban stormwater management in Nalukolongo involved a systematic assessment of the qualitative interview data using predefined criteria and scores as illustrated in Table 2. Summaries for each indicator, determinant, and dimension were linked to these scores, facilitating the categorization of results. To present the data clearly and accessibly, a color-coded system was employed, with different colors indicating varying levels of performance based on the established performance criteria. This approach enabled a nuanced and comprehensive understanding of governance performance in Nalukolongo, effectively capturing and communicating both common themes and unique insights from the qualitative data.

Table 2. Assessed determinants per dimension, evaluated indicators, and applied metrics [18].

DIMENSION	Determinant	Evaluated Indicator	Metric
ACTORS	Community leadership and allocation of responsibility.	○ Precise definitions of objectives and goals.	Yes/No
	Community innovation.	○ The extent to which local knowledge and resources are applied.	Low/Moderate/High
	Technical skills and competencies.	○ Level of community understanding regarding the technical dimensions of stormwater management.	1 to 5
	Private stakeholder involvement.	○ Private sector financial contribution to SUDS initiatives.	Low/Moderate/High
		○ Availability of SUDS community training programs and events led by academic institutions.	Yes/No
	Academia involvement.	○ Level of involvement and collaboration between academic experts, institutions, and local community organizations on SUDS projects.	1 to 5

Table 2. *Cont.*

DIMENSION	Determinant	Evaluated Indicator	Metric
RESOURCES	Community priorities for funding from both public and private sources.	○ Criteria used for evaluating and prioritizing community SUDS projects, such as impact, feasibility, and cost-effectiveness.	Low/Moderate/High (fair)
	Community financial incentives.	○ Amount of funding allocated to SUDS programs.	Low/Moderate/High
	Priorities for land use and development by both public and private entities.	○ Level of collaboration between public and private entities in land use planning and SUDS implementation.	1 to 5
	Human resources.	○ Availability of SUDS-related training and education programs for community members.	Yes/No
	Knowledge of SUDSs.	○ Level of community awareness and understanding of the benefits of SUDSs.	1 to 5
DISCOURSES	Management strategies and planning processes.	○ The scale of allocation of resources to support SUDS implementation and management.	1 to 5
	Environment regeneration and protection.	○ Community knowledge of SUDSs' environmental benefits for regeneration and protection.	Low/Moderate/High
	Knowledge of NbS ecosystem services.	○ Community knowledge of SUDS ecosystem services.	Low/Moderate/High
	Community participation.	○ Community ownership, engagement, and management of SUDS infrastructure and projects.	Low/Moderate/High
	Communication and information dissemination.	○ Effectiveness of feedback mechanisms in assessing stakeholder perception of SUDSs.	Low/Moderate/High
RULES OF ENGAGEMENT	Regulatory frameworks and legislative support	○ Existence and comprehensiveness of SUDS-related laws and policies at the national and local levels.	Yes/No
	Cultural norms, values, and local languages.	○ Respect cultural values related to water/land use in SUDS decisions.	Yes/No
	Quality and reliability of community politics and power dynamics.	○ Level of transparency and accountability in community decision-making processes.	1 to 5
	Equitable treatment of all partners.	○ Level of equitable distribution of SUDS benefits/costs for all stakeholders.	1 to 5
	Gender roles and considerations.	○ Level of women's participation/representation and gender-specific needs in SUDSs.	1 to 5
		○ Level of stakeholders' awareness of gender issues in SUDS governance.	1 to 5
		○ The scale of implementation of policies/mechanisms for gender equality in SUDS governance.	1 to 5

4. Results

The assessment results aim to identify significant commonalities and divergences in the indicators and determinants that constitute the dimensions of community governance, drawing insights from diverse questionnaire responses. This analysis enhances understanding of community governance dynamics in the context of SUDSs (Sustainable Urban Drainage Systems) for urban stormwater management in Nalukolongo, Kampala. By pinpointing these patterns, the assessment also underscores the framework's applicability and utility in enhancing the nuanced understanding of community governance practices in SUDS design and management for stormwater management.

Additionally, the assessment addresses key objectives such as evaluating the impact of social engagement on the success and maintenance of SUDS projects, analyzing the mobilization and allocation of financial, human, and technical resources for SUDS implementation at the community level, assessing regulatory and policy frameworks that either facilitate or hinder SUDSs effectiveness and understanding cultural attitudes toward water management and NbSs. These insights are crucial for informing strategies and interventions aimed at enhancing governance practices and effectively meeting specific community needs.

The color-coded representation of the assessment results in Table 3 and Figures 3–7 below illustrates the evaluated state of affairs in the specific case study area. It highlights the prevailing responses for each indicator, providing insights into their influence on the overall performance of the assessment. This approach offers a clear depiction of how the indicators relate to the four key dimensions of the governance assessment framework, helping to identify the factors that impact the area's community governance performance. Additionally, acknowledging the interconnected nature of these dimensions within the community governance of SUDSs underscores that changes in one dimension can invariably impact other dimensions [18]. To unravel potential interdependencies and synergies, the combined performance of determinants across various dimensions of the framework is analyzed and also presented in Figure 7.

Table 3. Heat map representation of the evaluated state of affairs in the specific case study.

Evaluated Indicator	Performance		
	Low	Moderate	High
Precise definitions of objectives and goals	8		16
The extent to which local knowledge and resources are applied	2		22
Level of community understanding of technical dimensions of stormwater management	1	20	3
Private sector financial contribution to SUDS initiatives	14	9	1
Availability of SUDS community training programs and events	11		13
Level of involvement and collaboration between academic experts, institutions, and local organizations on SUDS projects	14	3	7
Criteria for evaluating and prioritizing community SUDS projects	16	2	6
Amount of funding allocated to SUDS programs	14	3	7
Level of collaboration between public and private entities in land use planning and SUDS implementation	10	2	12
Availability of SUDS-related training and education programs for community members	8		16
Level of community awareness and understanding of SUDS benefits	5	3	16
Scale of resource allocation to support SUDS implementation and management	12	4	8
Community knowledge of SUDSs' environmental benefits for regeneration and protection	16	4	4
Community knowledge of SUDS ecosystem services	16	3	5
Community ownership, engagement, and management of SUDS infrastructure and projects	4	17	3
Effectiveness of feedback mechanisms in assessing stakeholder perception of SUDSs	9	8	7
Existence and comprehensiveness of SUDS-related laws and policies	14		10
Respect for cultural values related to water/land use in SUDS decisions	7	3	14
Level of transparency and accountability in community decision-making processes	12	6	6
Level of equitable distribution of SUDS benefits/costs for all stakeholders	12	1	11
Level of women's participation/representation and gender-specific needs in SUDSs	2	6	16
Level of stakeholders' awareness of gender issues in SUDS governance	1	6	17
Scale of implementation of policies/mechanisms for gender equality in SUDS governance	1	5	16

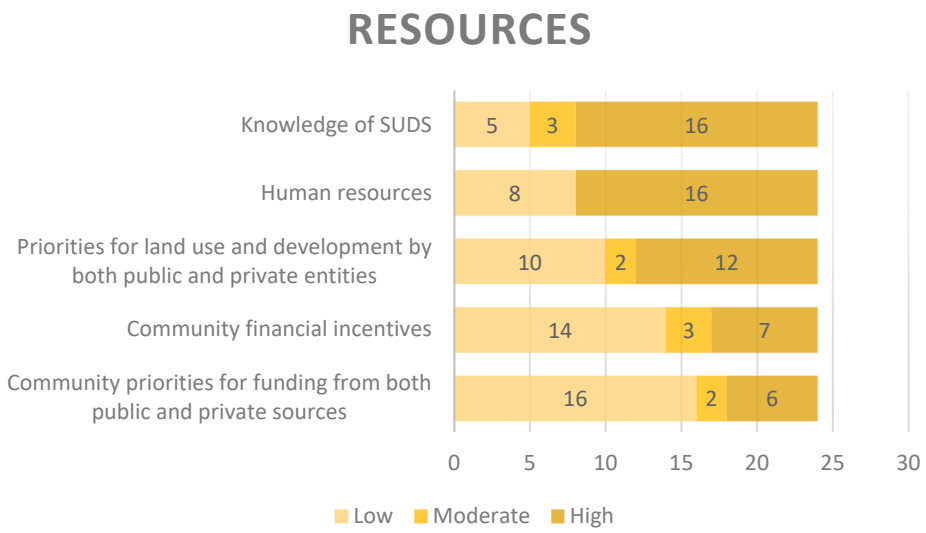

Figure 3. Performance of determinants under the resources dimension.

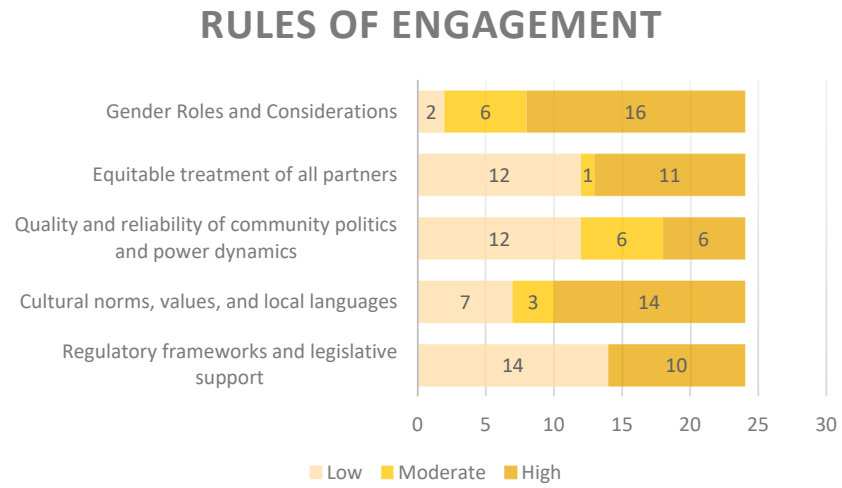

Figure 4. Performance of determinants under the rules of engagement dimension.

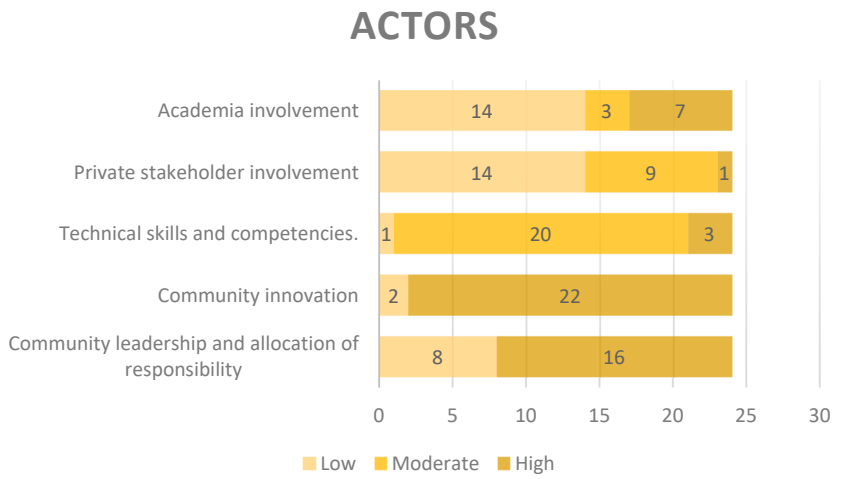

Figure 5. Performance of determinants under the actors dimension.

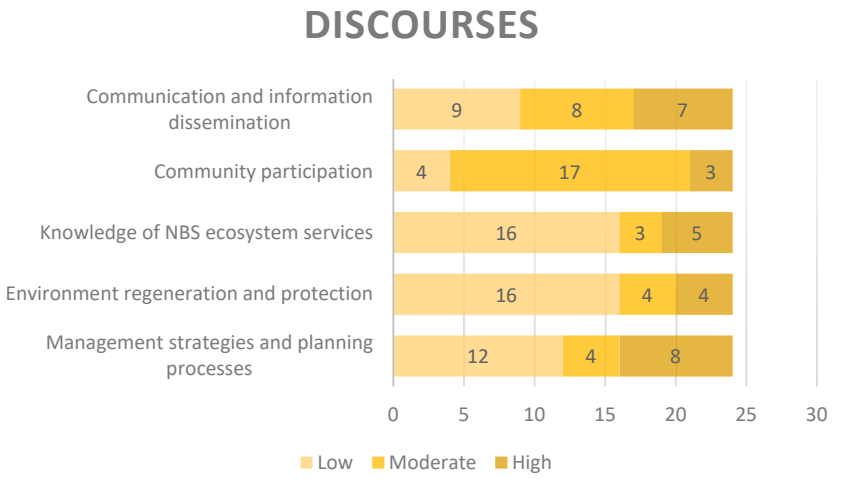

Figure 6. Performance of determinants under the discourses dimension.

The assessment of resource allocation within the governance framework for SUDSs in the community of Nalukolongo, as shown in Figure 3, reveals a complex mix of strengths and weaknesses, as indicated by the number of respondents. Stakeholder knowledge regarding the benefits of SUDSs emerges as a significant strength, with 16 respondents

rating it as "high", 3 as "moderate", and only 5 as "low". This reflects the effectiveness of local training initiatives in building awareness. Similarly, human resource capacity shows a positive outlook, with 16 respondents rating it "high" and 8 rating it "low", indicating the presence of skilled personnel, although training programs could still be further prioritized.

Community priorities for integrating SUDSs into land use and development planning reveal a polarized distribution, with 12 respondents rating this determinant "high" and 10 rating it "low". This suggests inconsistent approaches among both public and private entities.

However, the most significant weaknesses lie in the financial aspects. Sixteen respondents rated the provision of funding from both public and private sources as "low", with only six giving it a "high" rating, reflecting a clear lack of financial support. Similarly, financial incentives for SUDSs adoption were rated "low" by 14 respondents, "moderate" by 3, and "high" by 7, indicating inadequate provision of incentives.

In summary, while knowledge of SUDSs and human resources are strengths, the findings highlight a critical need for improved financial support, both in terms of incentives and equitable, impact-based funding allocation, to ensure the effective implementation and maintenance of SUDSs within the community.

The evaluation of the "rules of engagement" dimension within the community governance of SUDSs in Nalukolongo, as shown in Figure 4, reveals a mix of strengths and weaknesses, as indicated by the respondents. Gender roles and considerations stand out as a strength, with 16 respondents rating this determinant as "high", 6 as "moderate", and only 2 as "low". Cultural norms, values, and local languages also receive a high level of prioritization, with 14 respondents rating this determinant "high", 3 as "moderate", and 7 as "low", suggesting strong cultural sensitivity within the community. However, the equitable treatment of partners presents more polarized outcomes. While 11 respondents rated it as "high", 12 rated it as "low", and only 1 as "moderate", indicating potential barriers to fair collaboration. Similarly, community politics and power dynamics demonstrate mixed results, with 12 respondents rating it as "low", 6 as "moderate", and 6 as "high", pointing to issues in the quality and reliability of governance structures.

Regulatory frameworks and legislative support emerge as the most significant weakness, with 14 respondents rating this determinant as "low" and 10 as "high". This highlights the urgent need for a more robust legal and regulatory foundation to effectively support SUDS initiatives. In summary, while gender considerations and cultural norms are generally well addressed, challenges remain in ensuring equitable treatment, reliable governance, and a stronger regulatory framework to facilitate SUDS implementation.

The "actors" dimension in the community governance of SUDSs in Nalukolongo highlights strong community leadership and innovation, as reflected by the number of respondents. As shown in Figure 5, community leadership, particularly in defining SUDS objectives and allocating responsibility, shows a high level of involvement, with 16 respondents rating it as "high" and 8 as "low". Community innovation is rated even more positively, with 22 respondents indicating "high" and only 2 marking it as "low", underscoring the community's strength in this area.

However, the level of technical skills and competencies among stakeholders presents a mixed picture. Twenty respondents rated it as "moderate", while only three rated it as "high" and one as "low", signaling a need for enhanced technical expertise. Private stakeholder involvement is notably lacking, with 14 respondents rating it as "low", 9 as "moderate", and just 1 as "high". Similarly, academic involvement also shows room for improvement, with 14 respondents rating it as "low", 3 as "moderate", and 7 as "high". Overall, while community leadership and innovation excel, there is a clear need to improve technical skills, private sector engagement, and academic involvement for more comprehensive SUDS implementation.

The assessment of the "discourses" dimension reveals a wide range of performance and engagement outcomes, as indicated by the data on respondents. The analysis, as shown in Figure 6 below, indicates that management strategies and planning processes exhibit

varied performance, with 12 respondents rating this determinant as "low", 4 as "moderate", and 8 as "high". This highlights significant opportunities for improvement in this area.

In terms of environmental regeneration and protection, the results are more concerning. Sixteen respondents rated this aspect as "low", while only four rated it "moderate" and four as "high", underscoring critical deficiencies and a need for greater focus and investment in these efforts. Similarly, knowledge of Nature-Based Solutions (NbSs) ecosystem services was rated as "low" by 16 respondents, with only 3 rating it "moderate" and 5 "high", highlighting a pressing need for improved education and awareness within the community.

Community participation, while rated "low" by 4 respondents, was assessed as "moderate" by 17 respondents, with only 3 giving it a "high" rating. This suggests a baseline of engagement but also emphasizes the potential for increased active involvement. Communication and information dissemination followed a similar pattern, with 9 respondents rating this determinant as "low", 8 as "moderate", and 7 as "high", pointing to varied effectiveness and an opportunity for improvement in information sharing.

In conclusion, the findings stress the necessity of enhancing environmental protection measures, improving understanding of ecosystem services provided by NbSs, and refining management strategies. While community participation and communication efforts are at a moderate level, the data indicate substantial potential for boosting active involvement and optimizing the effectiveness of information dissemination strategies.

Combination of All the Dimensions

The combined performance across all the determinants within each dimension reveals varying performances as shown in Figure 7 below. Overall, the rules of engagement and resources dimensions show the most positive performance, albeit with significant negative aspects as well. The actors dimension demonstrates a more balanced perception, while the discourses dimension indicates an area of concern with its predominantly negative performance. This assessment suggests that while there are strengths in the regulatory framework and resource allocation for SUDSs, there is a critical need to improve communication and public engagement strategies. The balanced performance in the actors dimension might provide a foundation for addressing these challenges.

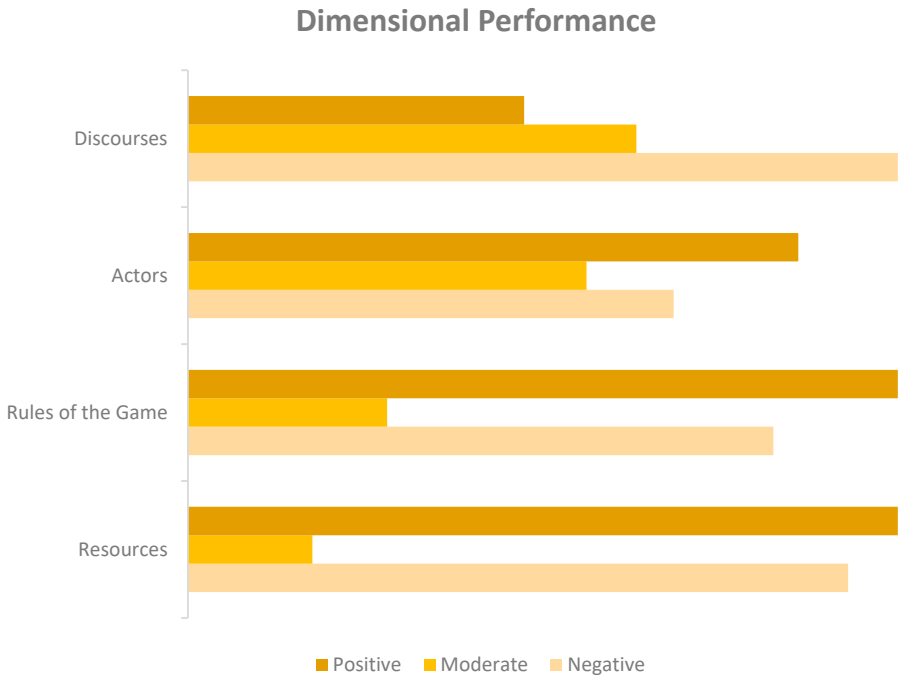

Figure 7. Combined performance within and across dimensions.

5. Discussion

This study aimed to address a notable research gap by providing a comprehensive evaluation of community governance performance in the implementation of Sustainable Urban Drainage Systems (SUDSs) as Nature-Based Solutions (NbSs) for urban stormwater management, with a focus on Kampala as a representative case study for Sub-Saharan cities. This study's findings underscore the significance of adopting effective governance frameworks to tackle the multifaceted challenges of rapid urbanization and climate change, issues that are prevalent across many urban centers in Sub-Saharan Africa.

5.1. Understanding Community Governance for SUDSs

This study's analysis reveals a complex landscape of strengths and weaknesses within the community governance structures supporting SUDS initiatives in Nalukolongo. A notable strength is the high level of stakeholder knowledge regarding the benefits of SUDSs, attributable to effective local training programs. This finding supports existing literature that emphasizes the role of community education in fostering support for environmental initiatives [32]. However, challenges persist, particularly in human resource capacity and financial support. While there is a broad understanding of SUDS benefits, gaps in technical expertise, insufficient financial incentives, and equitable funding mechanisms remain significant barriers to the successful implementation and maintenance of SUDSs at the community level. These issues reflect broader challenges observed in Sub-Saharan cities, where limited resources often undermine the effectiveness of environmental solutions [33].

5.2. Social Engagement and Community Leadership

This study's examination of social engagement within SUDS projects reveals moderate community participation. Although community members are involved in SUDS initiatives, the effectiveness of management strategies and planning processes is inconsistent, indicating a need for more effective management frameworks and enhanced environmental protection efforts. This finding echoes the observations of Cilliers (2018) [34] and Lindell (2008) [14] who emphasize that improved management strategies are crucial for the success of environmental projects. Furthermore, while community leadership in Nalukolongo is generally strong, there is a marked absence of engagement from the private sector and academic institutions. This gap suggests that greater involvement from these sectors could provide additional support and innovation for SUDS initiatives, a challenge common in urban environmental management [28].

5.3. Regulatory Frameworks and Cultural Attitudes

The assessment of regulatory frameworks for SUDSs reveals that existing legal and legislative support is weak, indicating a significant area for improvement. A more robust regulatory and legal framework is essential for the effective deployment of SUDSs, as highlighted by Mulligan et al. (2020) [11], who argue that strong regulatory support is crucial for the success of urban environmental solutions. Additionally, while cultural attitudes towards water management and NbSs are generally positive, there are challenges related to community politics and a lack of awareness about NbSs ecosystem services. These findings align with previous studies that discuss and emphasize the role of cultural norms and political dynamics in shaping environmental management outcomes.

5.4. Ensuring Credibility: Approach and Methodology

The credibility of this study's findings was a primary concern, given the complex nature of community governance and the intricate interplay of structures, rules, processes, and cultural norms. To ensure the credibility of this research, several rigorous methodologies were employed. This study selected inclusive and representative indicators to ensure that the framework's dimensions accurately reflected the diverse aspects of community governance. A thorough stakeholder analysis was conducted to identify and incorporate a wide range of perspectives, which is essential for capturing the complexities of community

governance [31]. Additionally, a participatory approach was adopted to engage community members throughout the assessment process, fostering trust and ensuring that the findings were both reliable and relevant to stakeholders. This approach is consistent with best practices in environmental management research.

5.5. Applicability of the Assessment Framework

The application of the assessment framework grounded in the Policy Arrangement Approach and encompassing the dimensions of actors, resources, rules, and discourses proved to be a comprehensive and effective tool for evaluating community governance of SUDSs. The framework's thorough and adaptable nature allowed for a detailed description of the local implementation landscape and provided a foundation for ongoing evaluations of community governance effectiveness. This supports the framework's potential for broader application in other urban contexts.

5.6. Recommendations for Future Research and Practice

Based on this study's findings, several recommendations emerge for both practice and future research. Practitioners should focus on enhancing financial mechanisms and creating more equitable funding structures for SUDS initiatives. Strengthening regulatory frameworks and addressing community politics are essential for creating a supportive environment for SUDS implementation. Additionally, increasing private sector and academic engagement could provide necessary technical support and innovation for SUDS projects. Future research should explore these dimensions further and refine the assessment framework for application in diverse urban environments.

6. Conclusions

In this study, we applied a novel approach to assess the community governance performance of Nature-Based Solutions (NbSs), specifically Sustainable Urban Drainage Systems (SUDSs), within the context of enhancing urban stormwater management in Sub-Saharan cities. This approach aims to increase flood resilience and address the challenges posed by urbanization and climate change. It is designed to identify the strengths and weaknesses of SUDSs community governance and serves as a framework to pinpoint leverage points, ensuring the long-term sustainability and effectiveness of these solutions.

The combination of stakeholder analysis and a participatory approach with the assessment framework has proven useful for examining community governance across social, environmental, and institutional dimensions that influence the success of SUDSs as NbSs. This integrated approach provides valuable insights into the factors affecting SUDSs' effectiveness and sustainability, helping to identify key governance challenges and opportunities for improvement.

Our results suggest a range of opportunities that could potentially enhance community governance performance for SUDSs as NbSs. These opportunities include the following: (a) enhancing financial support through incentives and equitable, impact-based funding to ensure effective implementation and maintenance; (b) establishing a more robust legal and regulatory framework with legislative backing; (c) improving technical skills, engaging the private sector, and involving academia for more comprehensive implementation; (d) enhancing environmental protection measures, deepening understanding of ecosystem services provided by NBS, and refining management strategies; and (e) boosting active community involvement and optimizing information dissemination strategies.

In addition to identifying these intervention opportunities, it is crucial to maintain well-functioning governance processes for SUDSs to ensure effective stormwater management. Evaluating these systems at the community level helps address the complexity and interdependence of governance processes, which are rarely linear. Since sustainable practices are central to this discussion, these opportunities are relevant not only to the case study in Nalukolongo, Kampala, Uganda, but also to other Sub-Saharan cities with similar characteristics.

We propose developing the assessment collaboratively with stakeholders to encourage reflection on their roles within the broader system and to foster ownership of the outcomes. This research opens the door for a deeper exploration of the social and institutional aspects of SUDSs and how addressing sustainable urban stormwater management can promote sustainable socio-environmental networks and behavior change and uphold essential components of environmental management, such as public participation.

Author Contributions: Conceptualization, S.P.M.; methodology, S.P.M.; formal analysis, S.P.M.; writing—original draft preparation, S.P.M.; writing—review and editing, S.P.M., L.C., J.S. and M.M.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Climate Service Center Germany (GERICS), Helmholtz-Zentrum Hereon.

Institutional Review Board Statement: This paper does not present medical research. Participation in this research was voluntary. The framing and settings were non-coercive. The nature of the collected information posed no harm to participants. The collected information was treated confidentially, and data are available, if requested, only in anonymized form.

Informed Consent Statement: The questionnaires followed the principle of prior informed consent: all participants were informed about this research's background, method, and aim. Additionally, written informed consent was obtained from the participants included in the questionnaire.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available to guarantee the participants' anonymity.

Acknowledgments: The authors are grateful to Peter Mwambu (ACTogether Uganda), Anna Pamberg (GIZ Uganda), and Gaby Langendjik (Deltares) for their invaluable support during participatory workshops, and ultimately to God, the supreme authority, for His guidance and grace throughout the process.

Conflicts of Interest: The authors declare no conflicts of interest.

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4. Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management

4 Community Empowerment and Political Influence in Urban Nature-Based Stormwater Management

4.1 Introduction

Rapid urbanization, population growth, and climate change are intensifying stormwater management challenges globally, particularly in regions like Sub-Saharan Africa (SSA) urban areas, where infrastructure is often inadequate and socio-economic vulnerabilities are pronounced (WMO 2019; IPCC 2022). The combination of poor infrastructure and informalities linked to economic, environmental, and social vulnerabilities of the social-ecological system leads in cases of extreme rains to increased stormwater challenges, water, and ecosystem degradation (Dodman et al., 2022; Saumya & Arun, 2023). Typically, stormwater management infrastructure in urban areas has been conventional grey engineering solutions, such as concrete drainage systems, which often prove insufficient due to high costs, maintenance demands, and inability to adapt to changing environmental conditions (Arinabo, 2022).

In response to stormwater management challenges, Nature-Based Solutions (NBS) have emerged as practical strategies that utilize natural processes to manage stormwater (IUCN, 2016; Charlesworth et al., 2017). NBS, including features such as rain gardens, green roofs, Sustainable Urban Drainage Systems (SUDS), and other types of green infrastructure, replicate nature's ability to capture, filter, and reuse stormwater runoff (Davis & Naumann, 2017; Depietri & McPhearson, 2017).

However, the success of SUDS as NBS extends beyond technical design and is heavily influenced by the social, institutional, and governance contexts of the communities in which they are implemented. In particular, the effectiveness of these interventions is closely tied to the involvement of local communities in decision-making, fostering a sense of ownership and responsibility. This concept aligns with Ostrom's (1990) idea of collective action toward a common good, emphasizing the importance of community participation in managing shared resources.

A key element in ensuring the success of SUDS is community governance, which acts as a collaborative management framework (Totikidis, Armstrong, & Ronald, 2005). This model brings residents, stakeholders, and organizations together to manage and maintain SUDS effectively (Pillory & McKinlay, 2011; Mulligan et al., 2020). It leverages local knowledge, participatory decision-making, and inclusive governance processes, ensuring that diverse voices are heard, particularly in marginalized communities (Mulligan et al., 2020; Katsaura, 2012; Nemutamvuni et al., 2020). Effective governance also involves carefully balancing authority among stakeholders to ensure equity and inclusivity.

Research by Máñez et al. (2014), Goodwin (2003), and Viederman (1994) emphasizes that effective governance models harness diverse resources, often referred to as forms of capital. These include human capital (skills, knowledge, and local expertise), social capital (networks and relationships that facilitate cooperation), political capital (the ability to influence policy and decision-making), financial capital (funding for construction and maintenance), and environmental capital (natural resources that support SUDS functionality). These capitals form the foundation of adaptable governance structures that enable communities to address challenges and promote sustainable development.

Integrating these capitals into governance processes strengthens accountability and enhances resilience, enabling communities to effectively respond to complex climate-related and socio-economic risks (Ostrom, 2011; Gupta et al., 2010). By tapping into these diverse resources, communities can improve collaboration with external stakeholders, enhance decision-making, and more effectively navigate governance challenges. This holistic approach, recognizing the interconnectedness of these resources, empowers communities to prioritize sustainability initiatives

like SUDS, ensuring their long-term viability and fostering resilience against environmental and socio-economic pressures (Máñez, Carmona, & Gerkensmeier, 2014; Emery & Flora, 2006; Gómez Martín et al., 2020).

Building on the importance of leveraging various forms of capital, political capital stands out as vital for the success of community-governed initiatives, especially in regions with less formalized governance structures, such as SSA (Katsaura, 2012). Political capital refers to the power and influence communities can leverage to navigate governance structures, secure resources, and advocate for favorable policies. It supports effective resource management, including developing relevant policies and legislation, clarifying roles and responsibilities, and stakeholder engagement in decision-making processes. Political capital empowers communities with the agency to navigate complex power dynamics, manage resources efficiently, and advocate for policies that align with their interests. By strengthening community agency, political capital also enables local actors to secure critical funding, mediate disputes, and manage conflicts among stakeholders, leading to more cohesive and effective governance (Katsaura, 2012; Mawutor & Hajjar, 2024).

Despite the recognized importance of political capital in community-governed initiatives, significant knowledge gaps remain regarding its specific influence on key NBS initiative outcomes, such as in the case of SUDS (Mulligan et al. 2020). These include equitable benefit distribution, sustained community participation, and the long-term transformative viability of SUDS (Palomo et al., 2021; Himes-Cornell et al., 2018). This study seeks to address this gap by examining **how political capital shapes the effectiveness of community governance models for SUDS**. It will specifically explore how political capital empowers communities to navigate governance challenges, such as improving participation and ensuring equitable benefit distribution, which are critical components for ensuring the long-term sustainability of SUDS initiatives.

A Systems Dynamics Modeling (SDM) approach analyzes the interactions between political capital and other forms of capital—human, social, environmental, and financial—that influence community governance structures for implementing SUDS (Sterman, 2000; Nelson, Adger, & Brown, 2007). This SDM approach draws insights from a case study by Muwafu et al. (2024) conducted in Kampala, Uganda, a rapidly urbanizing city in Sub-Saharan Africa (SSA) that faces urban stormwater management challenges exacerbated by inadequate drainage systems and environmental degradation. The case study evaluates the effectiveness of community-led governance and inclusive planning in managing SUDS as cost-effective solutions to urban stormwater management in fast-growing cities across Sub-Saharan Africa.

This SDM methodology captures the interactions between various forms of capital and their influence on community governance and SUDS implementation. Focusing on political capital, it models how political influence interacts with human (community knowledge), social (networks and collaboration), environmental (ecosystem services), and financial (funding) capital to shape stormwater management using SUDS.

4.2 Conceptual Approach

The conceptual approach described below provides a detailed explanation of the foundational principles that underpin this study, offering a comprehensive framework for understanding the core elements that drive the investigation. By integrating theoretical insights with practical applications, this framework elucidates the interconnections between governance mechanisms and community resources, enabling a sophisticated examination of the study's objectives.

4.2.1 Capitals Within Community Governance

The study builds on the integration of the Policy Arrangement Approach (PAA) and the Capital Approach Framework (CAF) to explore the alignment of PAA dimensions—actors, resources, discourse, and rules of the game—with various forms of community capital (see Figure 4-1). This

alignment demonstrates how governance structures and community resources interact to advance sustainable urban drainage systems (SUDS) and address local stormwater challenges.

The actors dimension of the PAA examines the key individuals, groups, and institutions involved in driving SUDS initiatives, focusing on their roles in shaping governance structures. The nature of these interactions, whether collaborative or fragmented, directly impacts the development and sustainability of SUDS governance. These interactions are closely aligned with social capital, as they foster networks of trust and cooperation, which are essential for collective action. Effective collaboration among actors can reinforce governance frameworks, whereas a lack of coordination may impede progress. Furthermore, the expertise and technical capacities of these actors contribute to human capital, enhancing the community's collective knowledge and skillsets for sustainable stormwater management (Muwafu, Rölfer, Scheffran, & Máñez, 2024).

The resources dimension is concerned with the availability and utilization of assets necessary to implement and maintain SUDS. This dimension is analogous to the financial and environmental capital defined in the CAF. The availability of financial resources is essential for funding infrastructure, while environmental resources, including ecosystem services, provide the basis for implementing sustainable practices. The study elucidates the pathways through which resilience and sustainability are promoted by examining how communities construct and utilize these capitals. Ecosystem services provide natural solutions for stormwater management, while financial investments ensure the long-term viability of these initiatives. Collectively, these capitals facilitate enhancements in environmental resilience and the nurturing of economic sustainability within SUDS projects (Muwafu, Celliers, Scheffran, & Máñez Costa, 2024).

The discourse dimension examines the narratives and framing that influence public understanding, community values, and policy priorities related to SUDS. These narratives are closely intertwined with social and political capital. For example, portraying SUDS as crucial for climate adaptation and community well-being can rally public support and prioritize sustainable infrastructure in policy agendas. By examining these discourses, the study illuminates how governance processes influence and are influenced by prevailing narratives, thus affecting the collective capacity to effectively address stormwater challenges (Muwafu, Rölfer, Scheffran, & Máñez, 2024).

The rules of the game dimension pertain to the formal policies and informal norms that regulate the adoption and maintenance of SUDS. These rules are aligned with political and environmental capital, as they define the frameworks for environmental stewardship, resource allocation, and community participation. For example, regulatory policies that provide incentives for the adoption of SUDS or mandate community involvement strengthen the effectiveness of governance. Conversely, informal norms, such as local traditions of stewardship, can facilitate participation and compliance, strengthening the connection between governance processes and environmental resilience (Muwafu, Celliers, Scheffran, & Máñez Costa, 2024).

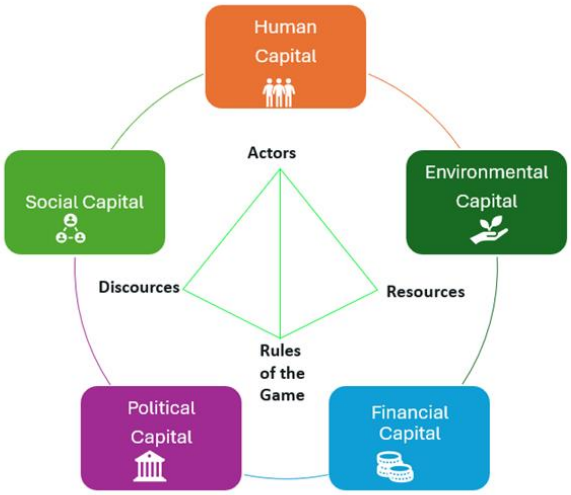

Figure 4-1: Capital Approach Framework (CAF) capitals corresponding to the dimensions of a Policy Arrangement Approach (PAA).

4.2.2 Systems Approach

Building on the integration of the Policy Arrangement Approach (PAA) and the Capital Approach Framework (CAF), as well as the exploration of community governance dynamics, our study employs a systems approach to provide a more comprehensive understanding of the complex interactions that underpin the implementation and sustainability of Sustainable Urban Drainage Systems (SUDS). This approach draws on the foundational principles of systems theory and dynamics set forth by Sterman (Sterman, 2000). It emphasizes system components' interconnectedness and interdependence, enabling a nuanced exploration of governance processes.

4.2.3 Systems Thinking in Community Governance

From a systems perspective, the various forms of community capital—social, human, financial, environmental, and political—are not discrete entities but interacting elements within a dynamic system. These interactions give rise to emergent behaviors that inform the governance of SUDS initiatives. To illustrate, social capital, as evidenced by community trust and engagement, exerts influence upon and reciprocally influences political capital, including policy support and leadership. Similarly, financial capital interacts with environmental capital, whereby investment in ecosystem services can enhance natural resilience while generating economic returns.

Adopting a systems view allows us to identify how feedback loops within these interactions influence governance outcomes. The reinforcement of feedback loops serves to amplify system behaviors. For example, increased community participation may lead to greater trust and resource mobilization, strengthening governance frameworks. Conversely, the balancing of feedback loops serves to stabilize the system. This is exemplified by limiting overinvestment through resource constraints, which ensures the system's sustainability over time (Ross & Wade, 2015).

Feedback Loops in SUDS Governance

a. Reinforcing Loops

The reinforcement of feedback loops in SUDS governance is critical for scaling and deepening success. To illustrate:

- Active community participation (social capital) frequently attracts policy attention and funding (political and financial capital), further enhancing engagement by demonstrating tangible benefits.

- The sharing of knowledge and capacity development are essential elements of this process. Training and skill development (human capital) facilitate the creation of a knowledgeable base that drives innovative solutions, attracting further expertise and investments, thereby fostering a virtuous cycle of improvement.

b. Balancing Loops

The function of balancing loops is to provide stability and prevent the implementation of unsustainable practices. To illustrate,

- Policy guidelines (political capital) ensure that financial investments are directed towards sustainable outcomes, thereby preventing the overexploitation of environmental resources.
- Informal norms (social capital) can counterbalance excessive reliance on formal policies, ensuring flexibility and adaptability to changing conditions.

4.3 Methodology

4.3.1 Model building process

The stages relevant to the model design are illustrated in Figure 4-2 below, reflecting an iterative modeling process. A system dynamic modeling process, as outlined by Sterman (2000, p. 85), provided the overall structure for building the model. The model was developed based on a well-established conceptual approach, incorporating insights from Gkini et al.'s (2020) work on community empowerment in natural resource management. Additional variables influencing community governance of SUDS were identified through a systematic literature review (Muwafu et al., 2024a). This process was further enriched by feedback from a recent stakeholder meeting in Nalukolongo, Kampala, as discussed in Muwafu et al. (2024b).

Figure 4-2: stages relevant to the model design

Engagement with community stakeholders in the case study was instrumental in prioritizing key governance dimensions and aligning them with different forms of capital—each critical for effective SUDS governance. The stakeholders also provided valuable data on the typical timelines and delays associated with developing various capital types. This temporal information was essential for accurately calibrating the model, ensuring it reflects realistic patterns of capital accumulation over time. The combination of theoretical foundations and practical stakeholder insights creates a robust basis for understanding and predicting the dynamics of community governance in SUDS, such as examining political capital transfer from outside to inside the community and assessing its impacts on community-level SUDS governance.

STELLA Architect was used as the primary modeling tool to construct the model and simulate these dynamics. STELLA is well-suited for creating dynamic, graphical models that capture the complexities of systems, such as in the case of SUDS community governance. The STELLA Architect relies on four essential components: stocks (representing quantities that accumulate over time), flows (indicating the rates of change in stocks), converters (factors that influence flows), and connectors (links that establish relationships between elements). These components facilitate the simulation of different scenarios, in this case modeling how various types of capital develop and interact. STELLA's visual and analytical capabilities were critical for illustrating feedback loops and understanding the consequences of shifts in political capital within the governance system.

4.3.2 Model Structure

As mentioned before, the system dynamics model in this study integrates various forms of capital—social, financial, environmental, human, and political—to simulate the dynamics of community governance in SUDS. The model comprises interconnected modules that interact through positive and negative feedback loops, influencing SUDS initiatives' overall success and sustainability, as illustrated in the simplified format in Figure 4-3 and Table 4-1.

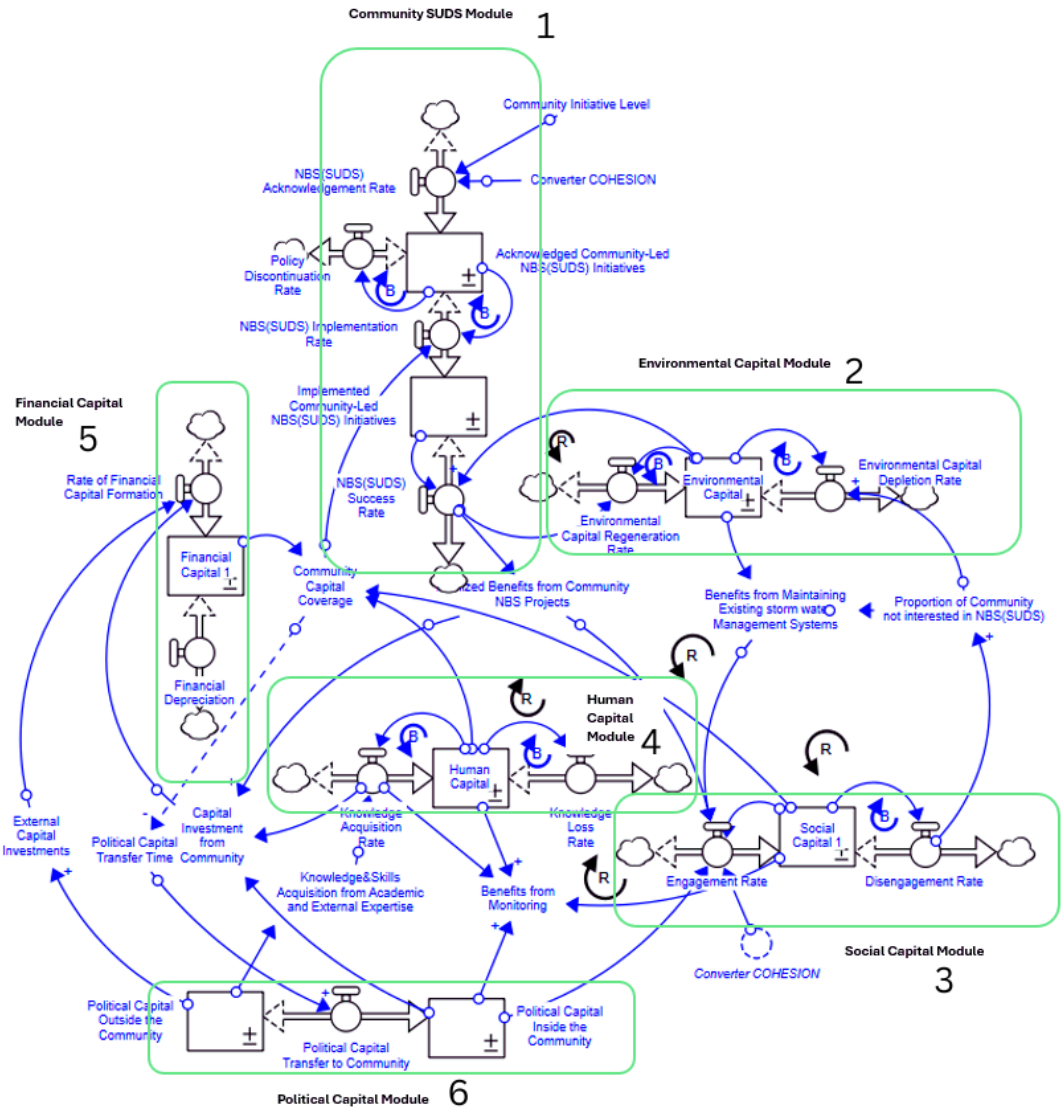

Figure 4-3: A simplified version of the model illustrating the various modules that drive the dynamics.

Table 4-1: Symbol Descriptions

Indicates Flows	Indicates Stocks	Indicates Connectors	Indicates Converters	Reinforcing Relationship	Balancing Relationship	Polarity

M***odule 1(Community SUDS)***, which serves as the model's core, tracks the flow of SUDS initiatives. It monitors the progression from the stock of acknowledged Community SUDS initiatives[1]—shaped by factors like community cohesion and local initiative levels—to the stock of successfully implemented initiatives[2]. An implementation rate guides this flow. This rate denoting the annual number of activities the community can implement for SUDS initiatives depends on the previously acknowledged activities and the available capital coverage[3]. If capital coverage is zero, acknowledged SUDS activities cannot be implemented. However, if capital coverage is fully satisfied, all acknowledged activities will be executed within the expected timeframe for implementation.

Equations *I* and *II* below describe the accumulation of the stocks in this module.

I. *Acknowledged Community (SUDS) Activities (t) = Acknowledged Community (SUDS) Activities (t - dt) + (Community Acknowledgment Rate – Implementation rate – Policy Arrangement Phase-out Rate) * dt*

II. *Implemented Community (SUDS) Activities(t) =Implemented Community Governed NBS-SUDS Activities (t - dt) + (Implementation rate – Success Rate) * dt*

The Community SUDS module is linked to ***module 2(Environmental Capital)*** through the *success rate*. This success rate at which implemented activities in SUDS initiatives produce results directly depends on the availability of the necessary environmental capital. The activities cannot be effectively executed if this environmental capital is depleted. Conversely, if the environmental capital is maintained at its initial levels, the implemented activities will yield results within the expected time frame. Furthermore, the success rate influences the benefits gained from these initiatives, which can boost community support. Positive outcomes encourage greater community engagement, leading to an increase in social capital. The accumulation of the stock of environmental capital in this module is derived from Equation *III* below:

III. *Environmental Capital(t)= Environmental Capital (t - dt) + (Environmental Capital Regeneration Rate – Environmental Capital Depletion Rate) * dt*

Within ***module 3(Social Capital),*** an increase in social capital strengthens overall capital coverage, facilitating the implementation of additional SUDS initiatives. In the model, social capital represents the fraction of the community population actively involved in the SUDS initiatives, directly or indirectly. The initial value of social capital is determined by the community's perception of the initiative and the level of coherence[4] within the community. It is assumed that communities that have already started SUDS initiatives will have members engaged in the initiatives. However, if community coherence is very low, the number of committed members may be significantly fewer compared to communities with a high degree of communication among their members. A decline in social capital—due to a perceived lack of benefits or a preference for existing stormwater systems—can negatively impact environmental capital. This disengagement accelerates environmental degradation and hampers future initiatives' success. The accumulation of the stock of social capital in this module is derived from the Equation *IV* below:

IV. *Social Capital(t) = Social Capital (t - dt) + (Community Engagement – Community Disengagement) * dt*

M***odule 4(Human Capital)*** incorporates developing knowledge and skills within the community that

[1] The stock of acknowledged activities reflects the proportion of activities that the community has identified and agreed upon in relation to the SUDS initiatives. These acknowledged activities may either be implemented by the community or phased out if they are not executed within a specified time frame.
[2] Implemented activities are those that the community has executed but have not yet yielded any results.
[3] The coverage in terms of capital is defined as a weighted average of three types of capital: Social Capital, Human Capital, and Financial Capital. This approach ensures that each form of capital is considered according to its importance and contribution to the overall capacity of the community to effectively implement and sustain the SUDS initiatives.
[4] Social coherence is vital for the success of community initiatives like SUDS. Communities that are divided by cultural or ethnic lines often encounter conflicts that hinder collaboration, while smaller, more homogeneous communities typically find it easier to succeed. Diverse communities may struggle to achieve consensus and cohesion, which can complicate unified efforts toward effective stormwater management and sustainable development.

are relevant to SUDS initiatives. This encompasses an understanding of the potential benefits of these initiatives, including their strengths, weaknesses, and significance for the well-being of individuals and the community. It also includes the technical expertise and skills available in the community associated explicitly with SUDS initiatives and the management capabilities necessary for the effective execution and ongoing sustainability of these initiatives.
Additionally, it involves the community's capacity to establish institutions and decision-making frameworks that support SUDS initiatives. Human capital is dynamic; it can grow through acquiring new information and diminish as individuals forget previously learned skills and knowledge about SUDS. The initial value of human capital is regarded as equivalent to the existing traditional stormwater management knowledge within the community. The stock of human capital in this module is determined by the equation presented in Equation *V* below:

*V. Human Capital(t) = Human Capital (t - dt) + (Knowledge/Skills Acquiring Rate – Knowledge/Skills Forgetting Rate) * dt*

M***odule 5(Financial Capital)*** tracks the formation of the stock of financial capital, which represents the fraction of the necessary financial resources required to implement the SUDS initiatives successfully. Additionally, Financial capital increases as new funds are acquired and decreases over time due to expenditures and depreciation. Its stock is determined by the equation presented in Equation *VI* below:

*VI. Financial capital(t) = Financial Capital (t - dt) + (Financial Capital Build Up -Financial Capital Depreciation) *dt*

M***odule 6(Political Capital)*** models political support from external sources (such as NGOs) and internal community investments (including community leadership and members). This helps to understand how political backing can facilitate or hinder community-led initiatives. The module consists of the stock of **Political capital outside the community**, representing the control or influence of external actors—such as government bodies, regional authorities, NGOs, or international donors- over SUDS initiatives. This external political capital reflects the guidance and resources these entities provide, setting policies and shaping the initiatives' direction until the community develops the capacity to assume full ownership. Over time, as local capacity and engagement grow, this external influence is expected to decrease, allowing for a more community-driven approach. The stock of Political capital held outside the community in this module is determined by the equation presented in Equation *VII below*:

*VII. Political Capital Outside the Community(t) = Political Capital Outside the Community (t - dt) + (- Political Capital Transfer to the Community) * dt*

The module also includes the stock of **Political capital in the community**, reflecting the degree of ownership and influence the community holds over the SUDS initiatives. This encompasses decision-making authority, the distribution of benefits, and the responsibilities associated with managing the initiatives. Additionally, it signifies the community's rights and control over the environmental resources that the initiative aims to protect and enhance. The initial level of this political capital is primarily determined by the extent of the community's involvement in initiating the project. The stock of Political capital within the community in this module is determined by the equation presented in Equation *VIII below*:

*VIII. Political Capital in the Community(t) = Political Capital in the Community (t - dt) + (Political Capital Transfer to the Community) * dt*

Community initiative level and community cohesion are modelled to influence SUDS acceptance rates. These factors, in turn, affect the implementation rate of SUDS initiatives by controlling the stock of acknowledged initiatives. For the modules in the model, the different flows that indicate rates of change in the stocks are described in Table 4-2 below. N.B. This list is not exhaustive. Further

information on the model input parameters and corresponding descriptions can be found in Model documentation in the **Appendix A.**
.

Table 4-2: Overview of Model Modules and Flow Descriptions Indicating Rates of Change in Stocks

Module	Rate	Description
Community SUDS Module	Implementation rate = (Acknowledged Community Governed Suds Activities *Capital Coverage)/Normal Implementation Time	The annual number of activities the community can implement for SUDS initiatives depends on the previously acknowledged activities and the available capital coverage. If capital coverage is zero, acknowledged SUDS activities cannot be implemented. However, if capital coverage is fully satisfied (value of 1), all acknowledged activities will be executed within the expected timeframe for implementation.
	Success Rate = MAX (0, Implemented Community Governed NBS-SUDS Activities *effect of relative Environmental Capital on success realization/result realization time)	The rate at which implemented activities in SUDS initiatives produce results directly depends on the availability of the necessary environmental capital. The activities cannot be effectively executed if this environmental capital is depleted. Conversely, if the environmental capital is maintained at its initial levels, the implemented activities will yield results within the expected time frame. Additionally, the MAX function ensures that the stock of implemented activities cannot drop below zero, as negatively implemented activities are not viable.
Environmental Capital Module	Regeneration Rate = Fractional Regeneration Rate*Environmental Capital	The regeneration rate of environmental capital depends on its current level and fractional regeneration rate, which indicates how quickly the resource can replenish itself over time.
	Depletion Rate = (Normal Depletion Rate*Environmental Capital * Effect of Alternative Drainage System on Environmental Capital Depletion Rate)	The depletion rate of Environmental Capital is influenced by the current level of Environmental Capital, the standard depletion rate, and the impact of community members not participating in the NBS (SUDS) initiatives on the depletion of these resources.
Social Capital Module	Engagement Rate = (Social Coherence * Realized Benefits * Pop Willing to Participate) *(1-Social Capital//Pop Willing to Participate)	The rate at which individuals in the community can engage with the SUDS initiatives is modeled using a formulation similar to that commonly applied in epidemiology (the SI model, see Sterman, 2000, pp. 300–303). The underlying

		assumption of this model is that those already participating in the SUDS initiatives can "influence" the remaining community members who are willing to engage. Community coherence reflects the likelihood of interaction between those who are "influenced" and those who are "susceptible." Additionally, the value of the realized benefits from the initiative serves to indicate the probability that those "susceptible" individuals will be persuaded to actively join the initiative (the more significant the benefits, the more likely they are to become "influenced."
	Disengagement Rate = Social Capital/Average Time to Disengage	Individuals participating in the SUDS initiatives tend to disengage after an average period of disengagement time.
Human Capital Module	Knowledge Acquisition Rate = Gain in Knowledge/Skills from External Actors" +Gain from monitoring) *Max Human Capital Adjustment	The rate of acquiring knowledge for SUDS initiatives is the combined effect of knowledge gained from external sources, such as NGOs and government officials, and knowledge developed internally through community monitoring and reflection on the SUDS initiatives. The maximum adjustment limit of Human Capital ensures that its value does not exceed 1, or 100% of the target knowledge level.
	Knowledge Loss Rate = Human Capital/Normal Time to Retain Knowledge and Skills	The rate of forgetting in Knowledge for SUDS initiatives is determined by the amount of knowledge and skills already acquired, divided by the typical retention period for this knowledge and skills. A shorter retention period results in a higher rate of forgetting, while an extended retention period reduces this rate.
Financial Capital Module	Rate of Financial Capital Formation = MIN (Target investment, maximum available investment)	The formation of Financial Capital takes the lesser of either the target investment in Financial Capital or the maximum available investment in Financial Capital. The MIN function ensures that, regardless of the investment capacity, the Financial Capital stock will never exceed a value of 1 (100%).

	Depreciation of Financial Capital= Financial Capital/Financial Capital Lifetime	The financial capital in place decreases over time due to expenditures and depreciation.
Political Capital Module	Political Capital Transfer Rate = (Target political capital inside community-Political Capital in the community)/Actual Time to Transfer Political Capital	The transfer of political capital from external actors to the community is guided by a target level of local control, with the transition occurring over a set time frame. This process is designed to build the community's capacity gradually and ensure lasting local ownership of the SUDS initiatives.

4.3.3 Analytical Approach

Our analysis examines the dynamics of community governance in SUDS initiatives by investigating the effects of different levels of political capital transferred to the community. The analysis explores scenarios ranging from the community holding 50% of the political capital over SUDS initiatives to scenarios where the community has complete (100%) control. The aim is to test the hypothesis that, in contexts where political capital within the community is underdeveloped, external actors often dominate decision-making processes, potentially resulting in community management structures that lack sufficient agency to ensure the long-term success of SUDS initiatives.

To assess the outcomes of varying levels of political capital, our analysis employs a well-being index adapted from Wiseman and Brasher (2008). This index integrates key dimensions of social, human, financial, and environmental capital and the benefits derived from SUDS initiatives. Additionally, it considers the internal political capital of the community as an indicator of the benefits associated with community-driven SUDS initiatives. By capturing both the ecological services provided by SUDS and their broader socio-economic impacts, the index offers a comprehensive evaluation of the effectiveness, inclusivity, and sustainability of community-based governance in managing SUDS.

Furthermore, our analysis continuously monitors the evolution of other forms of capital—social, financial, and human—as changes are made to the degree of political capital transferred to the community. This approach acknowledges the interconnected nature of these capitals and their role in enhancing the success and sustainability of community-driven SUDS initiatives within the broader urban stormwater management context. By comparing scenarios with different levels of community political capital, from partial to complete control, our analysis provides a detailed exploration of how varying degrees of political empowerment influence governance effectiveness and project outcomes. This comparison enables a deeper understanding of the complex interplay between political capital and the overall success of community-led SUDS initiatives.

4.4 Results

The results section presents the model's outcomes, examining how varying levels of political capital in community governance affect the effectiveness and sustainability of SUDS initiatives. Key assumptions driving the model include:

- The greater weight of social capital compared to other forms, with human and financial capital weighted equally, shapes the capital dynamics assessment. This assumption adopts the importance of social capital in community settings.
- The analysis spans a 50-year horizon to capture the gradual evolution of governance and capital dynamics.
- Governance is influenced by interactions between community capitals, which guide decision-making and resource allocation. Reinforcing feedback loops, such as increased community trust, are assumed to foster positive outcomes, while balancing loops, such as resource constraints, stabilize system behaviors.
- The degree of community involvement is assumed to significantly affect SUDS implementation, highlighting the importance of community engagement.
- The model also acknowledges the influence of external political capital held by regional governance structures on SUDS effectiveness in promoting climate resilience.
- Although not explicitly modeled, external factors like climate variability, economic conditions, and demographic changes are assumed to be reflected when environmental capital depletes, introducing uncertainty into governance and resource dynamics.

Our results reveal a significant positive correlation between the transfer of political capital to communities and improvements in community well-being, particularly in the context of SUDS, over 50 years. The graph in Figure 4-4 displays changes in the Well-Being Index over 50 years, with trends shown in colors that match the corresponding modifications in political capital indicated in the

legend.

As shown in Figure 4-4, at lower levels of political capital transference to the community (0.5–0.7), the Well-being Index (evaluated as Dimensionless (dmnl)) initially increases but begins to decline after approximately ten years, eventually stabilizing at 0.38. In contrast, the transfer of moderate political capital to the community (0.8–0.9) achieves a slightly higher well-being index of 0.48, although this also levels after an initial rise. Notably, the highest level of political capital (1.0), equivalent to 100%, yields a substantial and sustained increase in SUDS-related well-being, ultimately achieving an index of 0.52 in the long term. This consistent upward trend, which begins around year 30, underscores the importance of sustained political capital engagement.

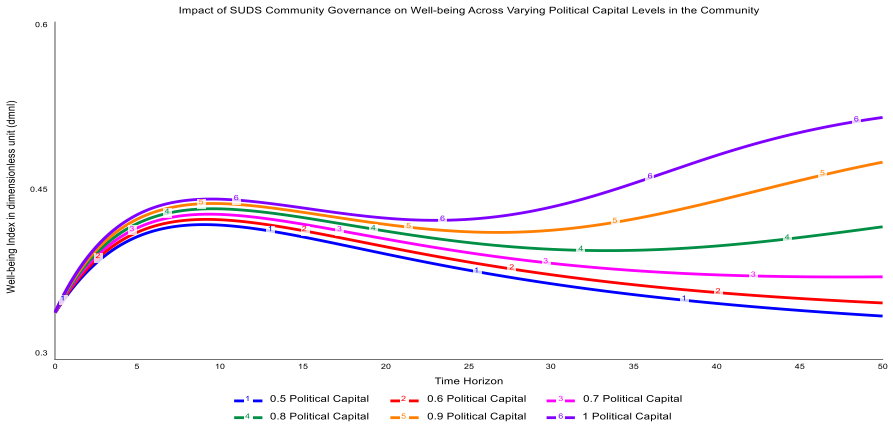

Figure 4-4: Impact of Community-Governed SUDS on Well-being Across Different Political Capital Levels in the Community

Additionally, the results of our analysis highlight the role of political capital in enhancing community social capital over the long term, as illustrated in Figure 4-5. At low political capital levels (0.5–0.7), social capital initially declines and stabilizes at low levels, with minimal recovery over time. Moderate political capital levels (0.8–0.9) within the community allow for a partial recovery, leading to a gradual increase in social capital. At the highest level of political capital (1.0), which corresponds to full community autonomy over SUDS projects, social capital experiences a pronounced and sustained increase, ultimately exceeding initial levels.

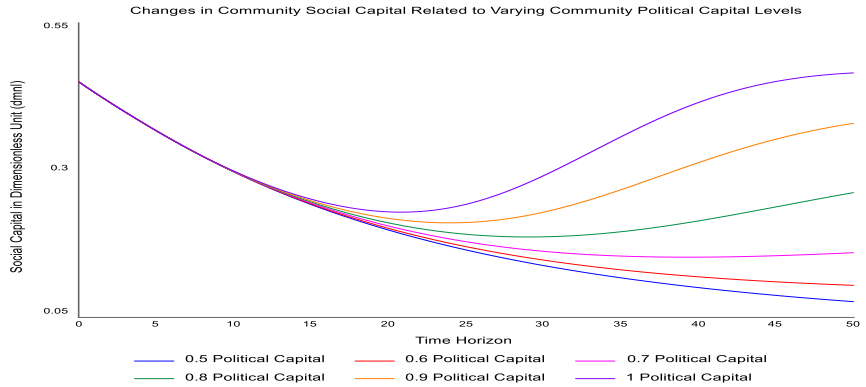

Figure 4-5: Changes in Social capital related to various Community Political Capital levels

This trend is attributed to the notion that high community agency, achieved through robust political capital, fosters lasting social capital growth. Furthermore, increased political capital enhances local governance participation, yielding immediate and enduring benefits for communities engaged in SUDS projects.

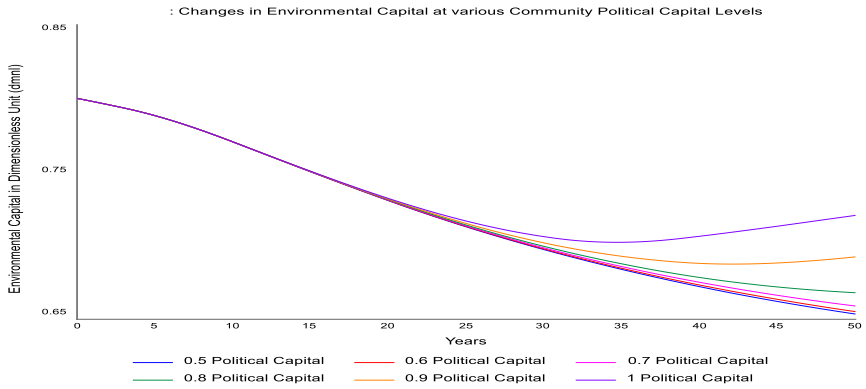

Figure 4-6: Changes in Environmental Capital at various Community Political Capital Levels

As shown in Figure 4-6, the results also indicate that at low political capital levels (0.5–0.6) within the community, environmental capital initially declines steeply and decreases over time, with little sign of recovery. At moderate community political capital levels (0.7–0.9), the decline in environmental capital slows, with a more gradual decrease over time and a slight stabilization toward the end. At the highest political capital level (1.0), environmental capital declines at the slowest rate, showing minimal change over the 50 years, indicating a more sustained and gradual decrease with the potential for some stabilization.

4.5 Discussion

This study aimed to address a knowledge gap concerning the role of political capital in the community governance of SUDS as NBS for stormwater management. It examined how political capital influences the effectiveness of community governance models for SUDS by empowering communities to navigate governance challenges, such as enhancing participation and ensuring equitable benefit distribution, which are key components for the long-term sustainability of these initiatives. The findings underscore the intricate interplay between various forms of capital, including political, social, human, financial, and environmental, within community governance models for SUDS.

4.5.1 Political Capital and Community Governance

Political capital emerges as a pivotal driver in the governance of SUDS, enabling communities to influence decision-making processes, control resources, and negotiate with external stakeholders. In contexts where formal governance structures may be less robust, such as Sub-Saharan Africa, empowering local communities becomes essential for effective SUDS implementation. Higher levels of political capital correlate with greater community participation, equitable distribution of benefits, and governance success, forming a foundation for sustainable outcomes.

However, an overemphasis on political capital and community agency can hinder the development of other capital forms, such as human and financial capital, particularly in the absence of external actors. This tension highlights the need for a balanced approach that empowers communities politically while integrating external resources and expertise to bolster human and financial capital. Fostering partnerships with external stakeholders like NGOs, governmental agencies, and private investors can provide the financial backing and training communities need. Future research should explore mechanisms for effectively linking external actors with community-led governance frameworks to avoid potential trade-offs.

4.5.2 Community Coherence and Social Capital

Community coherence, defined by social cohesion and shared purpose, is critical for the success of SUDS initiatives. Results from our study show that higher social coherence cultivates strong social

capital, enhancing engagement and knowledge sharing. This, in turn, facilitates broader community participation and increases the likelihood of equitable benefit distribution and long-term project success. Conversely, lower social coherence can weaken social bonds, limiting participation and mobilization initiatives. Strategies that foster community coherence, such as leadership development and capacity-building initiatives, are essential for creating a supportive social foundation for effective governance, particularly in contexts marked by fragmentation and distrust.

4.5.3 Positive Feedback Loops of Capital Growth

A critical takeaway from the study is the series of positive feedback loops generated by the interaction between different forms of capital within community governance structures. As political and social capital increase, they lead to higher participation levels, which drive human capital growth through experiential learning and governance practice. Over time, improvements in skills and knowledge enhance SUDS implementation effectiveness.

These advancements and successful SUDS initiatives' tangible environmental and economic benefits contribute to financial capital growth per the modeled dynamics. As these forms of capital grow, the likelihood of success for community-governed SUDS initiatives increases significantly, creating a self-reinforcing cycle. The benefits of SUDS initiatives, such as improved ecosystem services and reduced environmental degradation, further motivate community participation and ensure equitable distribution of benefits. This dynamic suggests that investing in one form of capital can cascade benefits across others, leading to robust and sustainable governance outcomes.

4.5.4 Challenges in Sustaining SUDS Initiatives and the Path Forward

Despite the results suggesting the overall success of community-governed initiatives, several challenges remain. Initial financial and human resource constraints are significant, particularly in the early stages of SUDS implementation. Without external investment and capacity-building efforts, communities may struggle to scale their initiatives and realize their full potential in managing stormwater. Additionally, integrating community governance models within broader governance frameworks poses institutional challenges. To address these challenges, we advocate for a community-driven and externally supported governance model, focusing on building human and financial capital while maintaining political autonomy. Collaborative governance frameworks involving multiple stakeholders—local communities, governments, NGOs, and private sector actors are essential for overcoming resource limitations and ensuring the long-term sustainability of SUDS.

Additionally, a phased transfer of political capital is particularly relevant in contexts where gradual empowerment can build local capacity without overwhelming community structures. This approach involves a step-by-step increase in community authority over governance decisions, allowing local actors to acquire the necessary skills, financial resources, and institutional knowledge. In the initial stages, external partners can provide critical technical guidance, funding, and capacity-building support while the community builds confidence in governance roles. Over time, as local expertise and human capital grow, political authority can be progressively transferred to the community, with external actors shifting to a supportive advisory role. This gradual transfer mitigates the risks associated with sudden shifts in governance and helps to establish a foundation for long-term, locally driven SUDS.

4.6 Conclusion

The systems approach adopted in this study highlights the pivotal role of diverse forms of capital—political, social, human, financial, and environmental—in the success of community-governed Sustainable Urban Drainage Systems (SUDS) for stormwater management. Political capital emerges as a crucial driver, enabling community participation, equitable benefit distribution, and local commitment. Through more robust networks, social capital activates reinforcing feedback loops that amplify governance effectiveness. Human capital development, achieved through capacity-building programs, catalyzes innovation and efficient resource utilization, enhancing economic growth and

sustainable development. Financial capital, aligned with policy incentives and funding mechanisms, ensures resources are directed toward impactful and sustainable initiatives.

However, transferring decision-making authority (political capital) to communities is complex and context dependent. While greater autonomy enhances commitment and broader engagement at the local level, the level of community engagement must be carefully evaluated and nurtured to ensure the success of SUDS initiatives. External actors, particularly in the early stages of SUDS initiatives, play a critical role by providing expertise and resources. The timing and process of transferring authority are pivotal: initiatives risk failure if autonomy is granted prematurely before sufficient capacity and capital are developed. Conversely, faster transitions are feasible for lower autonomy levels, while higher autonomy levels require a phased transfer approach with mechanisms to monitor and support capital formation.

The findings underscore the need for a balanced and integrated approach that leverages synergies among diverse forms of capital, fosters stakeholder collaboration, and aligns external expertise with community engagement. This strategy addresses resource limitations and enhances the long-term sustainability of SUDS, strengthening governance frameworks while generating lasting benefits for both people and ecosystems. By carefully managing the process of autonomy transfer, communities can build resilience to climate change, mitigate environmental degradation, and advance sustainable development amidst ongoing environmental challenges.

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5 Conclusion

Nature-based solutions (NbS) have gained increasing recognition as cost-effective and sustainable strategies for urban stormwater management, flood risk mitigation, and resilience enhancement, particularly in the context of rapid urbanization and climate change in Sub-Saharan Africa. This dissertation advances sustainable urban development by critically examining the functioning and performance of community governance of Sustainable Urban Drainage Systems (SUDS) as nature-based stormwater management solutions, specifically focusing on Sub-Saharan Africa.

The research investigates how communities can be empowered to effectively govern and maintain SUDS, underscoring the importance of integrating local knowledge, fostering stakeholder collaboration, and ensuring equitable participation in developing governance frameworks for NbS as climate adaptation strategies. These insights are pivotal in understanding how decentralized, community-led approaches to SUDS management can be effectively integrated into formal governance systems, thereby enhancing urban resilience to climate change.

In this context, leveraging community-based solutions is essential for crafting adaptive, sustainable urban management strategies in Sub-Saharan African cities. The synthesis of this dissertation weaves together its core themes, systematically addressing the research objectives and exploring the broader implications of the findings. Furthermore, it offers valuable perspectives for future research, drawing upon key insights from analyzing social structures, political dynamics, and the performance of community governance in the context of SUDS.

Analyzing Social Structures for Successful Community Governance of SUDS

Chapter 2 introduces a novel framework with 65 indicators to assess the social structures influencing community governance of SUDS, rooted in the Policy Arrangement Approach (PAA). The framework identifies key indicators of governance assessment along the dimensions of—community actors, resources, discourses, and rules of the game—providing a comprehensive that can also be utilized to evaluate community governance elements such as community engagement, cultural relevance, and equitable resource distribution within SUDS management. The practical findings stress the importance of tailored, localized assessments to reflect the unique social, cultural, and environmental contexts in Sub-Saharan Africa, recognizing that a one-size-fits-all model is inadequate. The framework's challenges in integrating broader ecological and economic factors call for a more holistic approach to governance assessment considering political and environmental landscapes.

Assessing the Performance of Community Governance of SUDS

Chapter 3 evaluates the performance of community governance in a case study in Sub-Saharan Africa, revealing strong community knowledge of SUDS but significant barriers in technical expertise and financial support. The absence of private sector and academic involvement limits innovation, while weak regulatory frameworks and political dynamics pose further obstacles. The study finds that inconsistent management strategies reflect the need for more robust governance frameworks. The developed framework from the second chapter proves effective in evaluating community governance, and its applicability in other urban contexts offers a tool for ongoing evaluation and improvement. Recommendations include enhancing financial mechanisms, strengthening regulatory frameworks, and fostering increased collaboration with the private sector and academia to improve SUDS' technical capacity and sustainability.

Empowering Communities and Navigating Political Dynamics

Inspired by Chapter 2's call for a more holistic approach to community governance assessment that considers both the political and environmental landscapes, Chapter 4 examines the role of political

dynamics in enabling community participation, equitable resource distribution, and local commitment to the governance of SUDS. Political dynamics empower communities to influence governance processes and secure sustainable urban stormwater management resources. The findings underscore the need for a balanced approach to transferring political authority to local communities, highlighting that while greater autonomy strengthens local ownership, it must be implemented gradually and strategically. The study advocates for an integrated governance model combining political, social, financial, human, and environmental capital while ensuring community-led SUDS initiatives harmonize with formal governance frameworks. This approach promotes long-term sustainability in addressing urban stormwater challenges while contributing to broader environmental goals.

The findings from all three chapters emphasize the importance of an integrated governance approach that addresses social, environmental, and institutional factors. Strengthening the synergy between community engagement, political dynamics, and governance frameworks is critical for improving SUDS's sustainability, effectiveness, and resilience in urban areas, particularly in Sub-Saharan Africa. This research provides valuable insights into how decentralized, community-led governance can be scaled and integrated into formal systems to enhance urban resilience to climate change. Through a comprehensive approach incorporating local knowledge, stakeholder collaboration, and equitable participation, communities can better govern nature-based stormwater management solutions and ensure long-term sustainability.

5.1 Key Innovation

This dissertation presents innovative contributions regarding the community governance of SUDS across multiple dimensions—spatially, methodologically, and theoretically:

Spatially, it addresses a significant knowledge gap by focusing on Sub-Saharan Africa (SSA), a region that remains underrepresented in studies of Nature-Based Solutions (NBS), particularly in urban stormwater management. By developing a novel 65-indicator conceptual framework to assess the social structure determinants essential for effective community governance of SUDS, grounded in SSA-specific literature, the research provides both a practical governance performance assessment tool and regionally relevant insights. This combination enables culturally appropriate analyses that can directly inform NBS policy and practice within SSA, thus broadening the geographical scope of NBS research beyond the Global North.

Methodologically, the dissertation breaks new ground by integrating established frameworks, such as the Policy Arrangement Approach (PAA) with the Capital Approach Framework. This integration establishes a comprehensive foundation for evaluating the performance of community governance driven by local empowerment. A system dynamics modeling approach moves beyond static, compartmentalized analyses, developing a model that captures the complex interdependencies and emergent behaviors within governance systems. This innovative approach allows a more profound understanding of the dynamic relationships between governance factors and facilitates predictions regarding how SUDS governance systems may respond to policy shifts and capital allocations. This predictive capacity enables more targeted, effective interventions, fostering long-term sustainability. Furthermore, the focus on relational dynamics and feedback loops refines the evaluation of governance outcomes over time, leading to actionable strategies that enhance the resilience of urban stormwater management systems.

Additionally, the systematic alignment of the dimensions of the PAA with corresponding forms of capital presents an innovative theoretical perspective underscoring the collective role of community governance and resource dynamics in supporting the effective implementation and sustainability of SUDS. The perspective emphasizes the strategic use of diverse capital forms to cultivate resilient and adaptive nature-based community responses to urban water management challenges.

Additionally, based on the model's behavior, the dissertation suggests a gradual decentralization of

political power to local communities as a key theoretical advancement. This approach mitigates the risks of abrupt governance changes while promoting greater local ownership and control over urban water resources. This model is particularly relevant in rapidly urbanizing regions like SSA, where governance structures must remain adaptable and responsive to shifting socio-political and environmental conditions. By connecting the strategic use of diverse capital forms with gradual political decentralization, the dissertation presents a flexible and nuanced framework that promotes sustainable urban water management, particularly in regions most vulnerable to climate change impacts.

5.2 Limitations and Suggestions for Future Research

The innovations presented in this research demonstrate promising advancements in community governance of SUDS as nature-based stormwater management solutions. However, the study has several limitations. The conceptual assessment framework developed has been applied only to a single case study. While the case study provides valuable insights, its findings may not be easily generalized across different urban contexts in sub-Saharan Africa. Moreover, although the framework primarily focuses on social structures, it does not fully address ecological, economic, or broader systemic challenges, such as state support and resource distribution. Future research should refine the framework by incorporating these factors, ensuring a more comprehensive, equitable, and sustainable approach to managing nature-based stormwater solutions.

A key limitation of systematically aligning the Policy Arrangement Approach (PAA) with the various forms of capital within the Capital Approach Framework to apply it in understanding the collective role of resource dynamics in the implementation and sustainability of community-governed SUDS lies in the complexity and variability of capital interactions across diverse contexts. The alignment, while innovative, is an approximation and may struggle to fully capture how these forms of capital truly interact in rapidly evolving urban environments, as their dynamics can fluctuate significantly depending on issues such as local political climates, economic conditions, and levels of community engagement.

A key limitation of the innovative system dynamics modeling approach used to assess SUD community governance dynamics is the challenge of accurately capturing and quantifying the various forms of capital, particularly under conditions of uncertainty. Additionally, the model may struggle to account for internal community processes, such as negotiations and conflict resolution. These limitations could hinder the model's ability to effectively assess the interrelationships and dynamics of these capitals in real-world settings, where external factors—such as global economic trends, policy shifts, or climate shocks—may also influence these capitals in ways that the model cannot predict or adapt to, potentially reducing its applicability and robustness.

6 Appendix: A
Model Documentation

SYSTEM DYNAMICS MODEL DOCUMENTATION:

{the model has 100 (100) variables (array expansion in parens).
in root model and 0 additional modules with 9 sectors.
stocks: 9 (9) flows: 14 (14) converters: 77 (77)
constants: 32 (32) equations: 59 (59) Graphicals: 9 (9)
there are also 20 expanded macro variables.}

Top-level model:
Acknowledged Community Governed NBS SUDS Activities (t) = Acknowledged Community Governed NBS-SUDS Activities(t - dt) + (Community Acknowledgment Rate – Implementation rate - Policy Arrangement Phase-out Rate) * dt
Init "Acknowledged Community Governed NBS-SUDS Activities" = 0
Units: dmnl
Document: the stock of acknowledged activities reflects the proportion of activities that the community has identified and agreed upon in relation to the NbS (suds) initiatives. These acknowledged activities may either be implemented by the community or phased out if they are not executed within a specified time frame.

Environmental Capital(t) = Environmental Capital (t - dt) + (Environmental Capital Regeneration Rate – Environmental Capital Depletion Rate) * dt
Init Environmental Capital = .8
Units: dmnl
Document: the stock of environmental capital represents the environmental resources primarily utilized in the NbS (suds) initiative. These resources regenerate at a specified regeneration rate and deplete at a defined depletion rate. In this conceptual framework, higher values of environmental capital are considered preferable. The initial value of 0.8 reflects the current level of these resources, representing the equilibrium state of environmental capital assuming no human impact—either from the NbS project or from community activities that deplete the environment.
Financial capital(t) = financial capital (t - dt) + (Financial Capital Build Up – Depreciation of Financial Capital) * dt
Init Financial capital = 0
Units: dmnl
Document: the stock of financial capital represents the fraction of the necessary financial resources required for the successful implementation of the NbS (suds) initiatives. Additionally, financial capital increases as new funds are acquired and decreases over time due to expenditures and depreciation.

Human Capital(t) = Human Capital (t - dt) + (NBS Knowledge/Skills Acquiring Rate - NBS Knowledge/Skills Forgetting Rate) * dt
Init Human_Capital = Traditional Knowledge in Community
Units: dmnl
Document: human capital pertains to the development of knowledge and skills within the community that are relevant to NbS(suds) projects. This encompasses an understanding of the potential benefits of these initiatives, including their strengths, weaknesses, and significance for the well-being of both individuals and the community as a whole. It also includes the technical expertise and skills available in the community that are specifically associated with NbS (suds) projects, as well as the management capabilities necessary for the effective execution and ongoing sustainability of these initiatives. Additionally, it involves the community's capacity to establish institutions and decision-making frameworks that support NbS (suds) projects. Human capital is dynamic; it can grow through the acquisition of new information and diminish as individuals forget previously learned skills and

knowledge about suds. The initial value of human capital is regarded as equivalent to the existing traditional storm water management knowledge within the community.

Implemented Community Governed NBS-SUDS Activities (t) = Implemented Community Governed NBS-SUDS Activities (t - dt) + (Implementation Rate – Success Rate) * dt
Init "Implemented Community Governed NBS-SUDS Activities" = 0
Units: dmnl
Document: implemented activities are those that the community has executed but have not yet yielded any results.
Political Capital in the Community(t) = Political Capital in the Community (t - dt) + (Political Capital Transfer to the Community) * dt
Init Political Capital in the Community = Community Initiative
Units: dmnl
Document: The stock of political capital within the community reflects the degree of ownership and influence the community holds over the NbS (suds) initiatives. this encompasses decision-making authority, the distribution of benefits, and the responsibilities associated with managing the program. additionally, it signifies the community's rights and control over the environmental resources that the initiative aims to protect and enhance. the initial level of this political capital is largely determined by the extent of the community's involvement in initiating the project.

Political Capital Outside the Community(t) = Political Capital Outside the Community (t - dt) + (-Political Capital Transfer to the Community) * dt
Init Political Capital Outside the Community = (1-community initiative)
Units: dmnl
Document: The stock of political capital held outside the community represents the control or influence that external actor—such as government bodies, regional authorities, NGOs, or international donors—have over NbS (suds) initiatives. this external political capital reflects the guidance and resources these entities provide, setting policies and shaping the program’s direction until the community develops the capacity to assume full ownership. over time, as local capacity and engagement grow, this external influence is expected to decrease, allowing for a more community-driven approach.

Social Capital(t) = Social Capital (t - dt) + (community engagement – Community Disengagement) * dt
Init Social Capital = Equilibrium Switch*0+ (1-equilibrium switch) * Community Initiative*Social coherence
Units: dmnl
Document: Social capital represents the fraction of the community population actively involved in the NbS (suds) initiatives, either directly or indirectly. the initial value of social capital is determined by the community’s perception of the initiative and the level of coherence within the community. it is assumed that communities that have already started NbS projects will have members engaged in the initiatives. however, if community coherence is very low, the number of engaged members may be significantly fewer compared to communities with a high degree of communication among their members. the switch in the initial value ensures that no participants can contribute to the initiative’s social capital if there is no active project in place

Willingness to Participate (Community Solidarity)"(t) = Willingness to Participate (Community Solidarity)(t - dt) + (Increase in willingness) * dt
Init "Willingness to Participate (Community Solidarity)" = 1/3
Units: dmnl
Document: The stock of willingness to participate / communal commitment provides a measure of the degree willingness of the population to participate in the community NbS(suds) initiatives

Community Acknowledgment Rate = Effect of consent on acknowledgment*target yearly acknowledge activities

Units: dmnl/year
Document: The number of activities that the community can acknowledge each year for NbS (suds) initiatives is influenced by the standard annual rate of acknowledged activities and is adjusted by the impacts of both moral and legal consent. this means that the extent to which the community agrees to and supports these activities directly affects how many can be officially recognized and pursued each year.

Community Disengagement = Social Capital/Average Time to Disengage
Units: dmnl/year
Document: individuals participating in the NbS (suds) initiatives tend to disengage after an average period of disengagement time

Community Engagement = (Social coherence*Realized Benefits*POP willing to Participate) *(1-Social Capital//POP willing to Participate)
Units: dmnl/year
Document: The rate at which individuals in the community can engage with the NbS (suds) initiatives is modeled using a formulation similar to that commonly applied in epidemiology (the si model, see Sterman, 2000, pp. 300–303). the underlying assumption of this model is that those already participating in the NbS (suds) project (the stock of human capital participation) can "infect" the remaining community members who are willing to engage. community coherence reflects the likelihood of interaction between those who are "infected" and those who are "susceptible." additionally, the value of the realized benefits from the project serves to indicate the probability that those "susceptible" individuals will be persuaded to actively join the initiative (the greater the benefits, the more likely they are to become "infected").

Depreciation of Financial Capital = Financial Capital/Financial Capital Lifetime
Units: dmnl/year
Document: The Financial Capital in place decreases over time due to expenditures and depreciation.

Environmental Capital Depletion Rate = (Normal Depletion Rate*Environmental Capital*Effect of Alternative Drainage System on Environmental Capital Depletion Rate)
Units: dmnl/year
Document: The depletion rate of environmental capital is influenced by the current level of environmental capital, the standard depletion rate, and the impact of community members not participating in the NbS (suds) initiatives on the depletion of these resources.

Environmental Capital Regeneration Rate = Fractional Regeneration Rate*Environmental Capital
Units: dmnl/year
Document: The regeneration rate of the environmental capital resource depends on both its current level and the fractional regeneration rate, which indicates how quickly the resource can replenish itself over time.

Financial Capital Build Up = MIN (Target investment, Maximum Available Investment)
Units: dmnl/year
Document: The acquisition of financial capital takes the lesser of either the target investment in financial capital or the maximum available investment in financial capital. the MIN function ensures that, regardless of the investment capacity, the financial capital stock will never exceed a value of 1 (100%).

Implementation rate = (Acknowledged Community Governed NbS-suds Activities"*Capital Coverage)/normal implementation time
Units: dmnl/year
Document: The annual number of activities the community can implement for NbS (suds) initiatives depends on the previously acknowledged activities and the available capital coverage. if capital coverage is zero, acknowledged NbS (suds) activities cannot be implemented. however, if capital

coverage is fully satisfied (value of 1), all acknowledged activities will be executed within the expected timeframe for implementation.

Increase in Willingness = (Indicated Solidarity- Willingness to Participate (community solidarity))/Solidarity Adjustment time
Units: dmnl/year
Document: The willingness to participate / community solidarity changes according to an indicated value of willingness to participate / community solidarity over the necessary time for the solidarity to be adjusted.

NBS Knowledge/Skills Acquiring Rate = (Gain in NbS knowledge/skills from external actors+ gain from monitoring) *Max Human Capital Adjustment
Units: dmnl/year
Document: The rate of acquiring knowledge for NbS (suds) projects is the combined effect of knowledge gained from external sources, such as NGOs and government officials, and knowledge developed internally through community monitoring and reflection on the suds project. the maximum adjustment limit of human capital ensures that its value does not exceed 1, or 100% of the target knowledge level.

NBS Knowledge/Skills Forgetting Rate = Human Capital/Normal Time to Retain Knowledge and Skills
Units: dmnl/year
Document: The rate of forgetting in knowledge for NbS(suds) projects is determined by the amount of knowledge and skills already acquired, divided by the typical retention period for this knowledge and skills. a shorter retention period results in a higher rate of forgetting, while a longer retention period reduces this rate.

Policy Arrangement Phase-out Rate = (Acknowledged Community Governed NBS-SUDS Activities/Time to Phase Out)
Units: dmnl/year
Document: Acknowledged activities related to NbS (suds) initiatives that are not implemented will not remain under community consideration indefinitely. the rate at which these activities are phased out depends on the total number of acknowledged NbS activities and the time it takes for them to be removed from consideration. if activities are not acted upon within a certain timeframe, they will be considered for elimination from the community’s agenda.

Political Capital Transfer to the Community = (Target political capital inside community-Political capital in the community)/actual time to transfer political capital
Units: dmnl/year
Document: The transfer of political capital from external actors to the community is guided by a target level of local control, with the transition occurring over a set time frame. this process is designed to gradually build the community's capacity and ensure lasting local ownership of the NbS (suds) initiatives.

Success Rate = max (0, "Implemented Community Governed NBS-SUDS Activities"*effect of relative environmental capital on success realization/result realization time)
Units: dmnl/year
Document: The rate at which implemented activities in NbS (suds) initiatives produce results is directly dependent on the availability of the necessary environmental capital. if this environmental capital is depleted, the activities cannot be effectively executed. conversely, if the environmental capital is maintained at its initial levels, the implemented activities will yield results within the expected time frame. additionally, the max function ensures that the stock of implemented activities cannot drop below zero, as negative implemented activities are not a viable option.

Actual_annual_benefits_achieved =

success_ratio*Max_Benefits*Political_Capital_in_the_Community
units: dmnl/year
document: the annual benefits the community realizes from the NbS (suds) initiatives depend on the program's success, as measured by the success ratio, as well as the maximum potential benefits the community can achieve. additionally, the degree of community ownership—represented by their agency in managing these initiatives—plays a crucial role; if the community lacks ownership, the benefits from improved stormwater management practices are not fully realized. therefore, strong community engagement and a sense of ownership are essential for maximizing the advantages gained from the initiatives, including reduced flooding and enhanced green spaces.
Actual Time to Transfer Political Capital = Adaptive political capital transfer switch*Time to Transfer Political Capital+ (1-Adaptive political capital transfer switch) *Normal Time to Transfer Political Capital
Units: year
Document: the actual time required for political capital to be transferred to the community is determined by two conditions: it is equal to the standard time for transferring political capital when the switch or policy is off, and it is adjusted according to specific criteria when the switch is on.

Adaptive Political Capital Transfer Switch = 1
Units: dmnl
Document: this switch initiates the policy for the gradual transfer of political capital to the community.

Adj time for Knowledge Acquisition = 3
Units: years
Document: The time needed for NbS (suds)-related knowledge to be fully acquired at the community level reflects the slower process of gathering, organizing, and sharing information specific to these projects. this duration also includes the time required to coordinate among different community stakeholders, negotiate varying perspectives, establish agreed-upon procedures, and build institutions or structured decision-making frameworks. while individuals may learn quickly, this broader community adaptation takes longer.

Average Time to Disengage = 25
units: years
Document: The average time it takes for an individual involved in the NbS (suds) initiatives to disengage is assessed. it is assumed that people who actively participate in these initiatives do not withdraw rapidly. due to the system's insensitivity to this value, a more precise determination is not considered essential.

Benefits realized by Non-policy participants from Environmental Capital (environmental capital*Max_Benefits from utilization of Environmental Capital)/Non_policy_participants
Units: dmnl/year
Document: The benefits realized by the fraction of the community not participating in the NbS (suds) initiatives represent the advantages individuals can gain from utilizing environmental capital resources that could otherwise be directed toward these initiatives. these benefits arise from utilizing the resources in ways that differ from or oppose the goals of the initiative. the value of these benefits is determined by the level of environmental capital and the maximum potential benefits from its use, which are distributed among non-participants in the NbS (suds) initiative. this calculation sheds light on the trade-offs and opportunities available to those not engaged in the program.

Benefits realized by policy participants from community governance policy arrangement = Distributed benefits from the policy//Social_Capital
Units: dmnl/year
Document: The benefits received by community members participating in the NbS (suds) initiatives are determined by dividing the total value of benefits generated by the initiatives by the number of participants.

Capital Coverage = (Weight of Human Capital*Human Capital + Weight of Social Capital* Social Capital + Financial Capital * Weight of Financial Capital)
Units: Dmnl
Document: The coverage in terms of capital is defined as a weighted average of the three types of capital: social capital, human capital, and financial capital. this approach ensures that each form of capital is considered according to its importance and contribution to the overall capacity of the community to effectively implement and sustain the NbS (suds) initiatives.

Capital Investment from Outside Community = Political Capital Outside the Community*Decision to Invest by External Actors
Units: Dmnl/Year
Document: Investment from external sources—such as government agencies, international donors, and private companies—is shaped by their level of control over NbS (suds) initiatives and their investment decision-making. the more influence these entities hold, the more likely they are to allocate resources for developing the financial capital needed to support these initiatives within the community. this investment is crucial for implementing the initiatives

Community Initiative = Equilibrium Switch*1+ (1-Equilibrium Switch) *Degree Of Initiative By Community
Units: Dmnl
Document: The equilibrium switch, when on (value of 1), ensures that, when no project is initiated, the value for the initiative by community is constant and not equal to the value of the degree of initiative by the community.

Community Population = 1
Units: Dmnl
Document: The population of the community takes a value of 1 (100%). no population growth is explicitly considered in the model.

Community's Retention Of Benefits For Investment = Actual Annual Benefits Achieved* Decision To Invest By Community
Units: Dmnl/Year
Document: The benefits that the community chooses to invest in building financial capital for the NbS (suds) initiatives are derived from the product of the actual benefits the community has realized through the projects and the decision-making criteria established by the community concerning the allocation of those benefits

Decision to invest by Community = Human Capital
Units: Dmnl
Document: The community's decision to allocate their earned funds towards the development of necessary financial capital is assumed to be directly and linearly influenced by the human capital within the community. this means that the greater the community's understanding and skills in managing the NbS (suds) initiative, the more likely they are to choose to invest in building their financial capital.

Decision to invest by External Actors = 1
Units: dmnl/year
Document: the model assumes that the investment decisions made by external actors aim to fully fund the establishment of the necessary financial capital for the NbS (suds) initiatives. a value of 1 indicates that external actors are committed to covering all costs required for the financial capital to reach its maximum value of 1, or 100%. this investment is crucial for ensuring that the community has the financial resources needed to successfully implement and sustain stormwater management practices.

Degree of initiative by community = .5
Units: Dmnl
Document: The degree to which an NbS (suds) program is initiated by the community (bottom-up approach) is a key factor in its successful implementation. consequently, the value attributed to community involvement should be evaluated based on the specific context and characteristics of each initiative.

Distributed Benefits From The Policy = If Financial Capital = 1 Then Actual Annual Benefits Achieved Else (1-Decision To Invest By Community) *Actual Annual Benefits Achieved
Units: Dmnl/Year
Document: The benefits realized by the community from the NbS (suds) initiatives, such as savings from reduced damage costs for homes and infrastructure and minimized reliance on expensive grey infrastructure, are calculated by subtracting the portion of these benefits reinvested into financial capital from the total benefits achieved through improved storm water management practices. When financial capital reaches its maximum value of 1 (or 100%), community members can enjoy the full benefits without further investment. This ensures that, once the community has secured adequate financial resources for the suds initiative, they can fully appreciate advantages like significant cost savings from reduced flooding, enhanced water quality, and increased green spaces, all contributing to the community's overall well-being and resilience.

Effect of Alternative Drainage System On Environmental Capital Depletion Rate = Graph(Non policy participants)
Points: (0.000, 1.000), (0.100, 1.004), (0.200, 1.018), (0.300, 1.061), (0.400, 1.112), (0.500, 1.198), (0.600, 1.318), (0.700, 1.671), (0.800, 1.866), (0.900, 1.964), (1.000, 2.000)
Units: Dmnl
Document: Non-participation in NbS (suds) initiatives can double the environmental capital's depletion rate. When few abstain, depletion remains normal, but high non-participation leads to unsustainable practices, fueled by a “herding effect” as more community members follow suit.

Effect of Capital Coverage on Time to Transfer Political Capital = Graph(Capital Coverage)
Points: (0.000, 1.997), (0.100, 1.987), (0.200, 1.928), (0.300, 1.736), (0.400, 1.252), (0.500, 1.000), (0.600, 0.891), (0.700, 0.849), (0.800, 0.800), (0.900, 0.800), (1.000, 0.800)
Units: Dmnl
Document: The relationship between capital coverage and the timeline for transferring political authority to the community acts as a monitoring mechanism for external actors. This mechanism assesses when to transfer authority based on the levels of social, human, and financial capital achieved by the community. Specifically, when capital coverage reaches 100% (a value of 1), the time required to transfer political authority is reduced by 20%. Conversely, lower levels of capital coverage extend this timeframe, with the potential to double the normal duration for transfer. At a capital coverage level of 50%, the time to transfer political authority aligns with its standard duration. This structured approach ensures that the transfer of authority is contingent upon the community's capacity to manage its resources effectively, fostering sustainable community-led initiatives.

Effect of Community Governance Policy Success on Environmental Regeneration Rate = Graph(Success_ratio)
Points: (0.000, 1.0000), (0.100, 1.0014), (0.200, 1.0014), (0.300, 1.0014), (0.400, 1.0140), (0.500, 1.0644), (0.600, 1.1359), (0.700, 1.2269), (0.800, 1.3599), (0.900, 1.4692), (1.000, 1.5000)
Units: dmnl
Document: Community governance of the NbS (suds) policy is expected to positively influence the regeneration of environmental capital. initially, the success of the policy, as represented by its success ratio, is not believed to affect the regeneration rate, as low levels of success are unlikely to lead to significant changes in how quickly the environmental capital regenerates. however, once the policy achieves average success, it can begin to significantly impact the regeneration rate. the maximum potential increase in this rate is assumed to be 50% when the policy reaches full success.

Effect of Consent on Acknowledgment = Equilibrium Switch*0+ (1-Equilibrium Switch) *("Effect Of Legal Consent on Acknowledgment of Community Governed NbS-Suds Activities * Effect of Moral Consent on Acknowledgment of Community Governed NbS-Suds Activities")
Units: Dmnl
Document: This factor represents the combined effects of both moral and legal consent on the acknowledgment of NbS (suds) activities. It is assumed that these effects function in a multiplicative relationship; thus, if legal consent is absent (with a value of 0), moral consent alone will not result in any acknowledgment of activities, and vice versa. This means that both forms of consent are necessary for activities to be recognized. Additionally, when the system is in equilibrium, it indicates that no consent can be obtained for activities that do not exist. This relationship underscores the importance of securing both types of consent for the successful implementation and recognition of community-led initiatives.

Effect of Legal Consent on Acknowledgment of Community Governed NbS-SUD Activities" = Graph(Legal_Consent)
Points: (0.000, 0.000), (0.100, 0.014), (0.200, 0.063), (0.300, 0.139), (0.400, 0.201), (0.500, 0.292), (0.600, 0.427), (0.700, 0.611), (0.800, 0.875), (0.900, 0.976), (1.000, 1.000)
Units: Dmnl
Document: Legal consent is essential for the successful implementation of NbS (suds) initiatives within a community. If there is no legal consent for the activities associated with these initiatives, the community will not acknowledge them at all, resulting in an acknowledgment rate of zero. Initially, small changes in the level of legal consent have a minimal impact on the acknowledgment rate. However, once legal consent exceeds 50%, even small increases in consent can lead to significantly greater acknowledgment rates. This means that gaining legal consent becomes increasingly influential as the level of consent rises. Ultimately, at very high levels of legal consent, further increases may have less of an effect, indicating a point of diminishing returns in terms of acknowledgment.

Effect of Moral Consent on Acknowledgment of Community Governed NbS-SUDS Activities" = Graph(Moral_Consent)
Points: (0.000, 0.000), (0.100, 0.031), (0.200, 0.094), (0.300, 0.226), (0.400, 0.392), (0.500, 0.538), (0.600, 0.663), (0.700, 0.826), (0.800, 0.920), (0.900, 0.981), (1.000, 1.000)
Units: Dmnl
Document: Similar to how legal consent affects the acknowledgment rate of activities, a lack of moral consent from the community results in no recognized activities, effectively setting the acknowledgment rate to zero. However, the relationship between moral consent and acknowledgment rate is thought to be more pronounced than that of legal consent. Even small levels of moral consent can lead to significant increases in the acknowledgment rate, suggesting a more responsive relationship. This effect, however, tends to taper off at higher levels of moral consent, particularly when moral consent exceeds 80%, indicating that while support remains important, its incremental impact diminishes as community backing becomes nearly universal.

Effect of perceived political capital on change in solidarity = Graph (Perceived Political Capital in Community)
Points: (0.000, 0.004), (0.100, 0.032), (0.200, 0.099), (0.300, 0.190), (0.400, 0.381), (0.500, 0.655), (0.600, 0.774), (0.700, 0.857), (0.800, 0.925), (0.900, 0.988), (1.000, 1.000)
Units: Dmnl
Document: The assumption regarding the effect of perceived political capital on community commitment is that a stronger perception of authority within the community increases members' willingness to participate in the initiative. If the community believes that all authority rests outside of its control (resulting in a perceived political capital value of 0), members are likely to feel unmotivated to engage with the NbS (suds) initiative, as they lack a sense of empowerment. Additionally, this relationship is expected to saturate at both high and low levels of perceived political capital; thus, minor differences in perceived authority at these extremes will not significantly impact community commitment.

Effect of Political Capital Transfer on Knowledge/ Skills Acquisition = Graph(Political Capital in the Community)
Points: (0.000, 0.000), (0.100, 0.008), (0.200, 0.044), (0.300, 0.145), (0.400, 0.297), (0.500, 0.522), (0.600, 0.671), (0.700, 0.851), (0.800, 0.932), (0.900, 0.976), (1.000, 0.996)
Units: Dmnl
Document: The greater the political capital a community holds within a community-led NbS (suds) project, the stronger its ability to acquire knowledge and skills. Communities with significant political capital can monitor activities more effectively, thereby enhancing their knowledge acquisition capacity through monitoring these projects. In contrast, communities with little or no political capital lack the influence needed to establish and use monitoring mechanisms. This effect levels off at both high and low ends of political capital, meaning that small changes in political capital at these extremes do not result in substantial differences in knowledge acquisition.

Effect Of Relative Environmental Capital On Success Realization = Graph(Environmental Capital/Init(Environmental Capital))
Points: (0.000, 0.000), (0.100, 0.008), (0.200, 0.044), (0.300, 0.083), (0.400, 0.127), (0.500, 0.206), (0.600, 0.297), (0.700, 0.448), (0.800, 0.619), (0.900, 0.806), (1.000, 0.996)
Units: Dmnl
Document: The condition of environmental capital is crucial for the success of NbS (suds) initiatives. When environmental capital is preserved at its initial levels at the start of the initiative, projects can achieve optimal success rates. However, if there is a decline in environmental capital, the success rate of these projects will diminish. Significant reductions, where environmental capital approaches zero, can severely compromise the effectiveness of NbS (suds) initiatives. This underscores the importance of maintaining environmental capital for effective stormwater management and overall project success.

Environmental capital carrying capacity = 1
Units: Dmnl
Document: The carrying capacity of the environmental capital is 1, or 100%

Equilibrium Switch = 0
units: dmnl
Document: The equilibrium switch, when activated (value of 1), represents the dynamics of the system in the absence of any ongoing NbS (suds) initiatives. In this state, the community operates without the influence of the project, allowing for the observation of existing storm water management systems and their behaviors without the complexities introduced by nbs (suds) projects activities.

Favorable bias = .3
Units: Dmnl
Document: The "favorable bias" reflects the observed tendency of communities to engage in NbS (suds) initiatives, even if the initiative was not originally community led. this willingness to participate is represented by a 0.3 (30%) increase in engagement. although this value may be challenging to estimate precisely, the model’s low sensitivity to variations in this parameter suggests that a more exact calculation is not essential.

Financial Capital Lifetime = 10
Units: Years
Document: The average lifetime of the financial capital selected for the NbS (suds) initiatives is 25 years. In this model, we do not refer to a specific type of financial capital; instead, this value serves as an average across different forms of financial resources. For example, long-term funding sources, such as grants for green infrastructure projects, may be available for more than 25 years, while shorter-term financial resources, like operational budgets for ongoing maintenance, may only cover a period of 5 to 10 years. For scenarios involving financial capital with different average lifetimes, the variable "optimal maximum available investment" can be adjusted to reflect those specific durations, such as setting it to 15 years for temporary funding for pilot projects or 30 years for comprehensive

watershed management investments.

Fractional Regeneration Rate = ((1-Environmental Capital)/Environmental Capital Carrying Capacity) *(Normal Regeneration Rate*Effect Of Community Governance Policy Success On Environmental Regeneration Rate)
Units: Dmnl/Year
Document: The fractional regeneration rate of the environmental capital resources is based on a widely accepted model of natural resource regeneration. this model considers the "distance" of the current resource level from the environment's carrying capacity: the further the resource level is from this capacity, the higher the regeneration rate; conversely, as the resource approaches its carrying capacity, the regeneration rate slows down. additionally, the success of the NbS (suds) initiatives is assumed to positively influence the normal regeneration rate of these environmental capital resources.

Gain From Monitoring = Human Capital*"Effect Of Political Capital Transfer On Knowledge/Skills Acquisition"*Social Capital*"Max Rate Of Knowledge/Skills Acquisition From Monitoring"
Units: Dmnl
Document: The mechanism by which a community enhances its human capital through monitoring and learning from its actions is a crucial aspect of community-led NbS (suds) initiatives and is recognized as a key determinant of their success. The knowledge and skills gained through community monitoring and learning are primarily dependent on the existing knowledge and skills within the community; without an understanding of how to monitor and effectively manage and disseminate the results, further knowledge acquisition becomes unattainable. Another important factor is the community's agency and autonomy to manage the community-led program, represented by the nonlinear effect of political capital realization on knowledge acquisition. Communities that lack the authority to manage the NbS initiatives cannot establish effective monitoring mechanisms or engage in the learning process. Participation is equally vital in building human capital, as it encompasses what is known as "social learning." social learning refers to the process of learning through interactions among community members or within social networks, which may involve deliberate sharing of perspectives and insights, collaborative activities and monitoring, or the spontaneous emergence of knowledge through unstructured social interactions (Cundill, Leitch, schultz, armitage, & peterson, 2015; Cundill & rodela, 2012). In this context, if human capital is absent, knowledge and skills cannot be acquired through the monitoring mechanism. Finally, the maximum rate of knowledge and skills acquisition from monitoring signifies the highest potential for learning through this mechanism. These factors exist in a multiplicative relationship, as the absence of any one factor would impede knowledge acquisition through monitoring.

Gain in NBS Knowledge/Skills from External Actors = political capital outside the community*max rate of knowledge acquisition from external actors*(1-resistance factor for knowledge acquisition)
Units: Dmnl
Document: Gaining knowledge and skills from external actors depends primarily on the extent of their authority or responsibility within the community-led NbS (suds) project. if external actors lack authority, they are considered absent in terms of transmitting knowledge and skills to the community. additionally, external actors can provide a maximum level of knowledge and skills based on their expertise, though this contribution is adjusted to reflect any resistance within the community toward knowledge introduced by individuals or groups outside the community.

Indicated Solidarity = MIN (1, (Effect Of Perceived Political Capital On Change In Solidarity + Relative Realized Benefits + Ratio Of Benefits From Policy To Other Benefits)/3)
Units: Dmnl
Document: The indicated solidarity is a weighted average of the effects of perceived power at the community level, the realized benefits from the community NbS-suds initiative, and the comparison between the benefits of the initiative and benefits acquired through other uses of the natural resource. the MIN function ensures that the stock of willingness to participate / communal commitment will never increase above 1.

Initial Communal Commitment = MIN (1, Community Initiative+ Favorable Bias)
Units: Dmnl
Document: The initial value for the communal commitment is given by the value of initiative by the community adjusted upwards due to a favourable bias. the MIN function ensures that the initial value for the communal commitment does not rise above 1 (100%).

Initiative By Government/NGOs = Equilibrium Switch*0+ (1-Equilibrium Switch) *1-Community Initiative
Units: Dmnl
Document: To prevent the value of the initiative source from exceeding 1 (100%), the influence of external actors on NbS (suds) initiatives is determined by subtracting the community-led initiatives from 1 (100%). when the equilibrium switch is activated (value of 1), it ensures that no externally led NbS (suds) projects are initiated, thereby allowing community-driven efforts to take precedence.

Legal Consent = SMTH3(Political Capital in the Community, time for community to get legal consent, "Initiative by Government/NGOs") {delay converter}
Units: Dmnl
Document: Legal consent refers to the legal framework governing NbS (suds) initiatives, either for the program as a whole or for specific activities within it. activities initiated by external actors are assumed to have already secured legal consent, so the initial value of this variable reflects the proportion of the initiative under external control. however, communities can negotiate and obtain legal consent through a process best represented by a third-order information delay (smth3), which accounts for the discrete steps involved in establishing an appropriate legal framework.

Max Benefits = 1
Units: Dmnl/Year
Document: The maximum benefits achievable through the implementation of the NbS (suds) initiatives are capped at 1 (or 100%). this indicates that the program has the potential to deliver its full range of advantages, such as optimal stormwater management, reduced flooding, and improved community resilience, if successfully executed and fully embraced by the community.

Max Benefits from Utilization of Environmental Capital = 1
Units: Dmnl/Year
Document: The maximum benefits derived from utilizing environmental capital in ways other than those proposed by the NbS (suds) initiative is assumed to be equal to 1, representing the benefits achievable through the initiative itself. while this may not always reflect reality, it serves as a reasonable assumption since not all non-policy participants will necessarily benefit from alternative uses of the environmental resources. this simplification acknowledges the complexities of benefit distribution among different users while providing a baseline for comparison.

Max Human Capital Adjustment = (Target Knowledge And Skills-Human Capital)/Adj Time For Knowledge Acquisition +"NbS Knowledge/Skills Forgetting Rate"
Units: Per Year
Document: The maximum adjustment of human capital for NbS (suds) projects is calculated as the difference between the target level of human capital and its current level, divided by the time required for knowledge acquisition. this adjustment also factors in the rate of knowledge loss, ensuring that any gradual decline over time is considered. this approach keeps human capital within a range of 0 to 1, representing 0% to 100% of the desired level

Max rate of knowledge acquisition from external actors = 1
Units: Dmnl
Document: The maximum amount of knowledge and skills that external actors can transmit to the community is set at a value of 1. this represents the ideal scenario in which external actors help the community acquire 100% of the knowledge needed to raise its human capital to the maximum level of 1, or 100%.

Max Rate of Knowledge/ Skills Acquisition from Monitoring = 1
Units: Dmnl
Document: Similar to the maximum rate of knowledge acquisition from external actors, this variable indicates the highest level of NbS (suds)-related knowledge and skills that the community can gain through monitoring its own activities. in an ideal scenario, the community would achieve 100% of the knowledge and skills necessary to elevate its human capital stock to the maximum value of 1, or 100%.

Maximum available investment = (Capital Investment From Outside Community + Community's Retention Of Benefits for Investment) *Optimal max available investment
Units: Dmnl/Year
Document: The maximum available investment in financial capital is the sum of the investments made by external actors and the contributions from the community itself. the optimal maximum available investment represents the total investment needed from both parties to achieve and maintain the target value of financial capital. the multiplication of these two investments ensures that any decision by the community or external actors to invest as needed will not result in an infinite increase in financial capital but will instead lead to the establishment of 100% of the required capital for the NbS (suds) initiatives.

Moral Consent = (Perceived Political Capital In Community +Social Coherence +"Willingness To Participate (Community Solidarity)")/3
Units: Dmnl
Document: The degree to which a community morally supports the activities of NbS (suds) initiatives is influenced by several key factors. these include how empowered the community feels in managing the initiatives and the resources involved, the level of social cohesion within the community, and the willingness of community members to participate. when any of these factors are strong—such as a high sense of ownership, good social ties, or a strong desire to get involved—the likelihood of the community giving their moral consent to the initiatives increases. this, in turn, enhances the potential for successful implementation and collaboration in managing stormwater effectively.

Non-Policy Participants = (Community Population-Social Capital)
Units: Dmnl
Document: The difference between the total community population and those participating in the NbS (suds) initiative provides the fraction of individuals not engaged in the program.

Normal Depletion Rate = 0.01
Units: 1/year
Document: The normal depletion rate is assumed to be 0.01. this value was chosen to maintain the stock of natural resources at equilibrium without external influences.

Normal Implementation Time = 4
Units: Year
Document: The average time required for an NbS (suds) policy to be implemented is assumed to be 4 years. this time frame serves as a benchmark for communities to plan and manage their initiatives effectively, ensuring that they allocate sufficient resources and efforts to achieve successful implementation.

Normal Regeneration Rate = 0.05
Units: 1/Year
Document: The normal regeneration rate of the environmental capital resources is established at 0.05. this value is chosen to maintain the stock of environmental capital at equilibrium in the absence of external influences.

Normal Time to Retain Knowledge and Skills = 10

Units: Year
Document: The average time before knowledge specific to NbS (suds) projects begins to diminish is estimated to be 10 years, indicating a gradual rate of forgetting in this specialized area.

Normal Time To Transfer Political Capital = Normal implementation time + Result Realization Time {Summing Converter}
Units: Year
Document: The standard or average time for transferring responsibility to the community is defined as the sum of the normal implementation time and the result realization time. this time frame reflects a rational decision by external actors to transfer responsibility and political capital, aligning with the typical duration required for the project to demonstrate tangible outcomes.

Optimal max available investment = Graph(Time)
points: (0.00, 0.200), (1.00, 0.170955904892), (2.00, 0.147184056414), (3.00, 0.127727406861), (4.00, 0.111802637183), (5.00, 0.0987686207873), (6.00, 0.0881006119655), (7.00, 0.0793691197863), (8.00, 0.0722226169152), (9.00, 0.0663733872258), (10.00, 0.0615859424327), (11.00, 0.0576675414015), (12.00, 0.0544604304466), (13.00, 0.0518354922142), (14.00, 0.0496870474547), (15.00, 0.0479286004073), (16.00, 0.0464893565054), (17.00, 0.0453113722083), (18.00, 0.044347222211), (19.00, 0.0435580901151), (20.00, 0.0429122056919), (21.00, 0.0423835658226), (22.00, 0.0419508876198), (23.00, 0.041596751585), (24.00, 0.0413069003044), (25.00, 0.0410696644498), (26.00, 0.0408754929747), (27.00, 0.0407165685921), (28.00, 0.0405864930524), (29.00, 0.0404800295525), (30.00, 0.0403928919026), (31.00, 0.0403215719664), (32.00, 0.0402631984241), (33.00, 0.0402154211737), (34.00, 0.0401763167171), (35.00, 0.0401443107202), (36.00, 0.040118114631), (37.00, 0.0400966738024), (38.00, 0.0400791250329), (39.00, 0.0400647618143), (40.00, 0.0400530058875), (41.00, 0.0400433839622), (42.00, 0.0400355086627), (43.00, 0.0400290629316), (44.00, 0.0400237872657), (45.00, 0.0400194692681), (46.00, 0.0400159350977), (47.00, 0.0400130424696), (48.00, 0.0400106749275), (49.00, 0.040008737155), (50.00, 0.0400071511377)
Units: Dmnl
Document: The optimal maximum available investment is a variable that describes the ideal acquisition of financial capital for the NbS (suds) initiatives. it is equivalent to the capital acquisition rate in a scenario where the investment in financial capital is equal to 1 (or 100%). thus, it serves as an assessment of how much should be invested in financial capital by either the community or external investors. this variable is utilized instead of the target investment to reflect a more realistic decision-making framework, as actors do not always have precise information about what the target investment should be at any given moment. instead, they rely on past evaluations, which, while more accurate than typical assessments, still fall short of perfect accuracy.

Perceived Political Capital in community = smth1(Political Capital in the Community, Time to realize political capital transfer and benefits) {delay converter}
Units: Dmnl
Document: The community’s perception of its political capital is expected to change gradually, following a first-order information delay. this means that the community's understanding of the growing agency they hold will develop over time as they recognize their evolving authority within the initiative. this delayed response reflects the time it takes for the community to internalize and adapt to their increasing political capital and the implications it has for decision-making and resource management.

POP willing to participate =Community population*"Willingness to Participate (Community Solidarity)"
Units: Dmnl
Document: The value of the fraction of the community population willing to participate in NbS (suds) initiatives is determined by multiplying the total community population by the fraction of that population expressing a willingness to engage.

Ratio_of_benefits_from_policy_to_other_benefits = Benefits realized by policy participants from community governance policy arrangement/benefits realized by non-policy participants from environmental capital
Units: Dmnl
Document: This ratio evaluates the benefits gained by participants in the NbS (suds) initiative against those obtained from the environmental capital resource by non-participants. a higher value of this ratio indicates that the community perceives the NbS (suds) initiative as more advantageous compared to alternative uses of the environmental capital.
Realized benefits = smth1(Distributed Benefits From The Policy, Time To Realize Political Capital Transfer And Benefits)
Units: Dmnl/Year
Document: The community's awareness of the benefits derived from the NbS (suds) initiatives is assumed to be represented by a first-order information delay.

Relative Realized Benefits = Realized Benefits/Target Benefits
Units: Dmnl
Document: The relative realized benefits represent the ratio of the benefits achieved through the NbS (suds) initiatives to a target value for those benefits. this ratio provides insight into how effectively the community is capitalizing on the potential advantages of the initiatives compared to what was initially anticipated.

Resistance factor for knowledge acquisition = 0.5
Units: dmnl
Document: Communities may exhibit biases toward external actors and their ideas, proposals, and methods for implementing NbS (suds) projects. conflicts between traditional storm water management practices and new approaches, as well as varying levels of tension in relationships between communities and existing policy frameworks, exemplify the social dynamics represented by this factor. while community resistance to external knowledge may evolve over time due to specific actions taken by external actors, these measures are often complex and not the primary focus of the model. as such, this variable is represented as an adjustable value to reflect the unique characteristics of different communities. a baseline value of 0.5 is established, meaning that, of all the knowledge external actors can share regarding NbS (suds), the community will retain only half (50%).

Result Realization Time = 4
Units: year
Document: the time required for the results of an implemented nature-based solutions (NbS) policy to be realized is typically around four years. this time frame reflects the average duration needed for the effects of the policy to become evident. for instance, if a new NbS policy is introduced to manage storm water through sustainable urban drainage systems (suds), it is expected to take approximately four years for its benefits—such as reduced flooding, improved water quality, and enhanced biodiversity—to materialize. this period allows for sufficient time to assess the policy's impact on environmental and community outcomes.

Social coherence = .9
Units: dmnl
Document: Social coherence is vital for the success of community initiatives like NbS (suds). communities that are divided by cultural or ethnic lines often encounter conflicts that hinder collaboration, while smaller, more homogeneous communities typically find it easier to succeed. as highlighted by cooney et al. (n.d.) and thakadu (2005), diverse communities may struggle to achieve consensus and cohesion, which can complicate unified efforts toward effective stormwater management and sustainable development.

Solidarity Adjustment Time = 2
Units: years

Document: The time it takes for changes in commitment to be realized is assumed to be 2 years.

Success_ratio = Success_Rate//Target Yearly Acknowledge Activities
Units: dmnl
Document: the success ratio reflects the effectiveness of the NbS (suds) initiatives, calculated as the proportion of successful activities to the target number of activities that were anticipated to be accomplished. this ratio serves as a key indicator of the project's performance and its capacity to deliver intended benefits for the community, such as improved storm water management and enhanced ecological resilience.

Target Benefits = 1
Units: dmnl/year
Document: The target value for the benefits that can be realized through the NbS (suds) initiatives is set at 1, or 100%. this indicates that stakeholders have assessed and communicated a thorough understanding of the potential benefits achievable through the initiatives. this target reflects the maximum expected positive impact the community can derive from effective storm water management practices.

Target Financial Capital = 1
Units: dmnl
Document: the target value of financial capital for the implementation of the NbS (suds) initiatives is set at 1, or 100%.

Target Investment = (Target Financial Capital-Financial Capital)/Time to Build Financial Capital + Depreciation of Financial Capital
Units: dmnl/year
Document: The target, or optimal, investment in financial capital for the NbS (suds) initiatives is calculated as the difference between the target value for financial capital and its current value, adjusted for the necessary time to secure the capital. the inclusion of the depreciation rate ensures that we account for the diminishing value of the financial resources over time, thereby avoiding a steady-state error in the investment calculations (see Sterman, 2000, pp. 671–2).

Target Knowledge and Skills = 1
Units: dmnl
Document: the maximum level of NbS (suds)-related knowledge the community can attain is set at 1, representing 100% of the relevant knowledge.

Target Political Capital in Community = 1
Units: dmnl
Document: The target value of political capital within the community is a key variable of interest, representing the decision-making criteria used by external actors to determine the level of political capital they intend to allocate to the community. this value influences how much authority and control the community will ultimately hold over the NbS (suds) initiatives.

Target Political Capital inside Community = Equilibrium Switch*1+ (1-Equilibrium Switch) *(Target Political Capital in Community)
Units: dmnl
Document: The value for the target political capital inside community is equal to the value assigned to the target political capital in community variable when the equilibrium switch is off (value of 0), but equal to 1 when the switch is on to ensure that no transferring of political capital takes place in or out of the community.

Target Yearly Acknowledge Activities = 1
Units: per year
Document: Each year, the community is assumed to have the potential to recognize 100% of the

activities associated with the nbs (suds) initiatives. this acknowledgment is crucial for fostering community engagement and ensuring that all aspects of the initiatives contribute to effective storm water management and overall community resilience.

Time for Community to get Legal Consent = 10
Units: years
Document: A community's effort to secure legal consent for NbS (suds) initiatives often progresses slowly. the pace at which various community contexts and programs achieve legal consent can vary significantly, but it is generally expected that this process will take at least 5 years. given the system's low sensitivity to this variable, there is no need to determine its value with high precision; instead, a general time frame is sufficient for modeling purposes.

Time to build Financial capital = 5
Units: years
Document: The time required for acquiring financial capital for the NbS (suds) initiative is assumed to be 5 years. since the specific type of financial capital is not defined, this average value is used, similar to the approach taken with the variable "lifetime of financial capital." for instance, this time frame may apply to securing long-term funding sources, such as grants for green infrastructure projects, while obtaining financing for smaller initiatives, like operational budgets for ongoing maintenance, could be achieved more quickly. conversely, larger funding arrangements, such as loans for significant capital investments, may take longer to finalize, potentially extending beyond the average of 5 years.

Time to Phase Out = Normal Implementation Time + Result Realization Time
Units: year
Document: The time it takes for NbS (suds) activities to phase out is defined as the sum of the normal implementation time and the time required to realize results. If an acknowledged activity is not implemented within this maximum timeframe, it will be discarded from the community's agenda. This ensures that only feasible and timely initiatives remain under consideration, allowing the community to focus on actionable projects.

Time to Realize Political Capital Transfer and Benefits = 1
Units: year
Document: the time frame for the community to observe changes in political capital and benefits from the NbS (suds) initiative is estimated to be one year.

Time to Transfer Political Capital = Normal Time to Transfer Political Capital*Effect of Capital Coverage on Time to Transfer Political Capital
Units: years
Document: the adjusted time required to transfer political capital is based on the standard time frame for such transfers, modified by the influence of capital coverage. This adjustment illustrates how the community's levels of social, human, and financial capital can enhance or impede the efficiency and speed of the political capital transfer process

Traditional Knowledge in Community = .3
Units: dmnl
Document: this highlights the community's existing knowledge and skills in managing nature-based solutions (NbS) and sustainable urban drainage systems (suds) for effective stormwater management. The community's expertise is essential for the successful planning, implementation, and maintenance of NbS (suds) initiatives, allowing them to utilize natural processes to tackle urban drainage challenges effectively.

Weight of financial capital = (1-Weight of Social Capital)/2
Units: dmnl
Document: for the sake of simplicity, the weight of financial capital is assumed to be equal to that of

human capital. Given that the total weight of all three types of capital—social capital, human capital, and financial capital—cannot exceed 1, the weight of financial capital is defined as half of the difference between 1 and the weight of human capital. This approach ensures a balanced representation of both financial and human capital in the overall evaluation of the community's capacity for the nbs (suds) initiatives.

Weight of Human Capital = (1-Weight of Social Capital)/2
Units: dmnl
Document: to simplify the model, the weight assigned to human capital is assumed to be equal to that of financial capital. Since the total weight of all three types of capital—social capital, human capital, and financial capital—cannot exceed 1, the weight of human capital is calculated as half of the remaining value after accounting for the weight of social capital. This ensures that all three forms of capital are appropriately balanced in their contributions to the overall assessment of community capacity for the NbS (SUDS) initiatives.

Weight of Social Capital = 0.9
Units: dmnl
Document: in the context of community-led NbS (suds) initiatives, the weight or significance of social capital is assumed to be slightly higher than that of the other forms of capital, namely human capital and financial capital. This reflects the understanding that strong social networks and community cohesion play a crucial role in the success of these initiatives, facilitating collaboration, knowledge sharing, and collective action among community members.

Wellbeing Index = (Environmental Capital +Human Capital +Financial Capital +Political Capital In The Community + Social Capital + Success Ratio)/6
Units: Dmnl
Document: The wellbeing index is a comprehensive measure of a community’s overall quality of life, incorporating social, economic, environmental, cultural, and political conditions that individuals and communities identify as essential for flourishing and realizing potential (wiseman & brasher, 2008). Traditional wellbeing indices typically emphasize social, economic, and health aspects, with environmental and political factors being less represented (kim & lee, 2014). However, these underrepresented components are increasingly recognized as critical, especially considering the significant impact of natural resources and ecosystems on human wellbeing (who, 2005) and the growing importance of community participation and governance in wellbeing outcomes (cuthill, 2003).in this index, we evaluate wellbeing by integrating all forms of community capital: political, social, human, financial, and environmental. We measure financial capital by the initiative's benefits (using the success ratio as a proxy) and political capital by community involvement in decision-making and ownership of the NbS (suds) initiative. Social cohesion, particularly through collaboration on shared goals, also plays a key role in community wellbeing (pretty, 2003; see also kim & lee, 2014). Each factor is treated as equally important, collectively supporting a balanced and sustainable approach to community resilience and quality of life.