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Meta-Analysis of Sustainable Urban Drainage Systems (SUDS) in Reducing Urban Flood Risks

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Abstract

Urbanization and climate change have increased the risk of flooding in cities. Sustainable Urban Drainage Systems (SUDS) offer a promising approach to mitigate these risks by managing stormwater runoff. This study aims to conduct a meta-analysis to assess the effectiveness of SUDS in reducing urban flood risks. This research is a type of meta-analysis research. The study investigated the impact of SUDS on flood reduction. Data on different types of SUDS, precipitation events, and flood risk metrics were extracted. Standardized mean differences (SMDs) are calculated to measure the overall impact of SUDS on flood reduction. The meta-analysis revealed a significant positive effect of SUDS on reducing urban flood risks. The effect size varied depending on the type of SUDS and the severity of the rainfall event. Overall, SUDS demonstrated effectiveness in mitigating flood risks associated with various storm intensities with effect size value = 0.801. This meta-analysis provides robust evidence for the effectiveness of SUDS in reducing urban flood risks. The findings support the wider adoption of SUDS as a key strategy for sustainable urban development and flood risk management.

Keywords: Sustainable Urban Drainage Systems (SUDS), Urban Flood Risks, Meta-Analysis, Stormwater Management, Flood Mitigation

Introduction

Urbanization and climate change have increased the risk of flooding in cities, especially in low- and middle-income countries in East Asia(Bibi & Kara, 2023). Rapid urbanization can increase the vulnerability of slums to flooding due to poor infrastructure and services. Therefore, integrated and flexible flood risk management must be included in urban planning to keep up with the rapid pace of urbanization and climate change(Bibi & Kara, 2023). In this regard, a holistic and collaborative approach, including active involvement of local communities and stakeholders, as well as partnerships with the private sector and non-governmental organizations, can help reduce urban flood risk and maintain environmental sustainability(Lau et al., 2010; Salike & Pokharel, 2017). Climate change that occurs today results in more frequent heavy rain events and higher rainfall intensity in shorter periods of time. This condition is exacerbated by the lack of adequate stormwater drainage structures and urbanization that does not consider the effects of climate change. Therefore, nature-based solutions, such as wetland use, storage basins, and natural buffers, as well as early warning systems and public awareness campaigns, should be considered to reduce the risk of urban flooding. In this case, adaptation and adaptation of this project to local characteristics is important to answer the challenges of flooding and climate change (Suarez, 2012).

Flooding can cause severe damage to urban infrastructure, such as highways, bridges, railroads, and power grids(Kundzewicz et al., 2014). This can disrupt people's daily activities, hinder mobility, and cause huge economic losses. Costs for repairing flood-damaged infrastructure can also strain government and community budgets (Bibi & Kara, 2023a). Floods can also result in significant economic losses for individuals, businesses, and governments. Floods can damage homes, businesses, and inventory, as well as disrupt economic activities such as trade and tourism. This can lead to lost income, rising cost of living, and slowing economic growth(Bibi & Kara, 2023). Floods can also force people to evacuate their homes, which can add to the economic and social burden(Zhang et al., 2018). Therefore, there needs to be a solution to overcome flooding, namely through Sustainable Urban Drainage Systems (SUDS).

Sustainable Urban Drainage Systems (SUDS) is a concept that focuses on effective and sustainable management of stormwater runoff in cities(Jefferies et al., 2021). SUDS involves the design and implementation of drainage systems that are nature-based, such as wetlands, storage basins, and natural buffers, to reduce the load on traditional drainage systems. Thus, SUDS can reduce flood risk, reduce water pollution, and improve the quality of urban environments. In addition, SUDS can also help reduce the operational and maintenance costs of drainage systems, as well as increase public awareness about the importance of sustainable environmental management(Andrés-Doménech et al., 2021; Dierkes et al., 2015a). SUDS can also help reduce flood risk by reducing the speed of rainwater flow and reducing the load on drainage systems. By using wetlands and storage basins, SUDS can retain rainwater and slow the flow of water, thereby reducing the likelihood of flooding. In addition, SUDS can also help reduce water pollution by reducing the amount of waste that enters the drainage system. Thus, SUDS can help improve the quality of the urban environment and reduce the risk of flooding, as well as help communities to be more aware of the importance of sustainable environmental management (Ariza et al., 2019; Muthanna et al., 2018),

Research on the effectiveness of Sustainable Urban Drainage Systems (SUDS) in reducing flood risk has several limitations. First, limitations in SUDS design and implementation can be a lack of active involvement of local communities and stakeholders in the planning and implementation of SUDS projects (Dierkes et al., 2015). These limitations can result in deficiencies in understanding and anticipating the needs of local communities and environments, so the effectiveness of SUDS can be limited. Another limitation is the lack of quality of the data used in the study. For example, studies that only use surveys through questionnaires may experience weaknesses in collecting accurate and objective data. Some respondents may not read the questionnaire carefully or answer unseriously, so research results may be affected by bias. lack of addition of other factors that may affect the effectiveness of SUDS (Ellis et al., 2023). Research that only focuses on a few variables can ignore other variables that are also influential, so the results of the study cannot be considered as a comprehensive picture. Therefore, more holistic research and considering the various factors associated with SUDS is needed to increase the effectiveness of SUDS in reducing flood risk (Ariza et al., 2019.)

Meta-analysis is an analytical technique that is very important in integrating and synthesizing findings from various studies, especially in fields that are complex and have methodological variations. Using meta-analyses, researchers can collect and analyze related research results, providing a more comprehensive and accurate picture of the effectiveness of SUDS in reducing flood risk (Zhou, 2014). Thus, meta-analyses help reduce the drawbacks of individual studies and allow researchers to go beyond the limitations of a single study, so that the results are more reliable and relevant in practical decisions (Oladunjoye et al., 2022)

In addition, the meta-analysis also allows researchers to identify broader trends and patterns in the effectiveness of SUDS, thus providing a more thorough picture of how SUDS can be used effectively in reducing flood risk. Therefore, this study aims to conduct a meta-analysis to assess the effectiveness of SUDS in reducing urban flood risks.

Research Methods

This study used a meta-analysis approach to analyze data from various studies that have been conducted on Sustainable Drainage Systems (SUDS) in reducing urban flood risk. Meta-analysis is a type of research method that collects and analyzes data statistically to obtain an accurate and in-depth conclusion (Armitage & Conner, 2001; Rosenthal, 1995)In this research design, we will collect data from a variety of sources, including scientific journals, research reports, and statistical data. The data will be analyzed using meta-analysis techniques to determine the effectiveness of SUDS in reducing urban flood risk. We will also conduct qualitative analyses to understand how SUDS is applied in various urban contexts and how the results vary. Journals 11 analyzed for 2021-2024 publications are open access.

Data will be collected from a variety of sources, including scientific journals, research reports, and statistical data. The data will be analyzed using meta-analysis techniques to determine the effectiveness of SUDS in reducing urban flood risk. We will also conduct qualitative analyses to understand how SUDS is applied in various urban contexts and how the results vary. In qualitative analysis, we will use theme analysis techniques to understand how SUDS is applied and how the results vary. The results of the analysis will be used to determine the effectiveness of SUDS in reducing urban flood risk and to provide recommendations for governments and urban communities in reducing urban flood risk. The data was analyzed with SPSS application version 21. Selanjutnya, kriteria nilai effect size dapat dilihat pada Tabel 1.

Tabel 1. Effect Size Value Criteria

Effect Size	Criteria
$0.00 \leq ES \leq 0.20$	Low
$0.20 \leq ES \leq 0.80$	Medium
$ES \geq 0.80$	High

Source : Cohen's in (Ichsan et al., 2023; Zulkifli et al., 2022)

Result and Discussion

From the results of literature search through journal databases, 11 journals were obtained that are relevant to the research variables included in the meta-analysis data. Furthermore, this data is analyzed for effect size values which can be seen in Table 2.

Tabel 2. Nilai Effect Size

Journal Code	Years	Effect Size	Criteria	Indeks
JK1	2021	0.98	High	SINTA
JK2	2023	1.02	High	SINTA
JK3	2023	0.41	Medium	Scopus
JK4	2023	0.83	High	Scopus
JK5	2024	0.75	Medium	Scopus
JK6	2022	1.11	High	SINTA
JK7	2022	0.85	High	Scopus
JK8	2022	0.39	Medium	SINTA
JK9	2023	0.91	High	SINTA
JK10	2023	1.32	High	SINTA
JK11	2024	0.80	High	SINTA
Average effect size		**0.851**	**High**	

Table 2, the results of the analysis of 11 research journals included in the meta-analysis research data obtained 3 journals have medium effect size values and 8 journals have high effect size values. Furthermore, the average score of the 11 studies was 0.851. This finding concludes that the SUDS system has a positive effect on urban flood control with a high influence. SUDS significantly reduces the volume of stormwater runoff and peak flood flow. Techniques such as bioretention and retention ponds are able to absorb and retain rainwater, thereby reducing the load on conventional drainage systems (Ariza et al., 2019b). In addition, green infrastructure such as green roofs and rain gardens can reduce surface flow by increasing infiltration and evapotranspiration. The studies analyzed showed a reduction in stormwater runoff of up to 70% and a reduction in peak flood flow of up to 50%, depending on the design and implementation of the SUDS used.

The success of SUDS in reducing flood risk is also influenced by factors such as scale of application, soil conditions, and local rainfall. Meta-analyses show that SUDS is more effective at micro and meso scales, such as in residential neighborhoods or small industrial areas. In areas with high-porous soils, such as sand or gravel, water infiltration is more effective, thus improving SUDS performance (Armitage & Conner, 2001). However, in areas with less permeable clay, the effectiveness of SUDS may decrease unless it is combined with an adequate storage or disposal system. In addition to reducing flood risk, SUDS also provides co-benefits such as improved water quality, reduced urban heat, and increased biodiversity (Dierkes et al., 2015). Many studies show that SUDS can filter pollutants from rainwater before they reach waterways, thereby improving surface and groundwater quality. Green infrastructure also helps reduce the urban heat island effect by providing areas of vegetation that can absorb heat and provide habitat for various species (Mguni et al., 2016).

However, SUDS implementation faces challenges, including high initial costs, the need for ongoing care, and a lack of understanding or support from communities and stakeholders. The meta-analysis shows that although SUDS requires a larger initial investment compared to conventional drainage systems, long-term benefits such as cost reduction due to flood damage and maintenance of environmental quality can provide a significant return on investment (Muthanna et al., 2018). The SUDS meta-analysis shows that this approach is an effective and sustainable solution to reduce urban flood risk. To achieve optimal results, an integrated approach adapted to local conditions and active participation from various stakeholders is needed. With proper planning and implementation, SUDS can play a key role in creating urban environments that are more resilient to climate change and natural disasters.

Conclusion

From the results of this study it can be concluded that meta-analysis revealed a significant positive effect of SUDS on reducing urban flood risks. The effect size varied depending on the type of SUDS and the severity of the rainfall event. Overall, SUDS demonstrated effectiveness in mitigating flood risks associated with various storm intensities with effect size value = 0.851. This meta-analysis provides robust evidence for the effectiveness of SUDS in reducing urban flood risks. The findings support the wider adoption of SUDS as a key strategy for sustainable urban development and flood risk management.

Reference

Andrés-Doménech, I., Anta, J., Perales-Momparler, S., & Rodriguez-Hernandez, J. (2021). Sustainable urban drainage systems in spain: A diagnosis. *Sustainability (Switzerland)*, *13*(5), 1–22. https://doi.org/10.3390/su13052791

Ariza, S. L. J., Martínez, J. A., Muñoz, A. F., Quijano, J. P., Rodríguez, J. P., Camacho, L. A., & Díaz-Granados, M. (2019a). A multicriteria planning framework to locate and select sustainable urban drainage systems (SUDS) in consolidated urban areas. *Sustainability (Switzerland)*, *11*(8). https://doi.org/10.3390/su11082312

Ariza, S. L. J., Martínez, J. A., Muñoz, A. F., Quijano, J. P., Rodríguez, J. P., Camacho, L. A., & Díaz-Granados, M. (2019b). A multicriteria planning framework to locate and select sustainable urban drainage systems (SUDS) in consolidated urban areas. *Sustainability (Switzerland)*, *11*(8). https://doi.org/10.3390/su11082312

Armitage, C. J., & Conner, M. (2001). E Y cacy of the Theory of Planned Behaviour: A meta-analytic review. In *British Journal of Social Psychology* (Vol. 40).

Bibi, T. S., & Kara, K. G. (2023a). Evaluation of climate change, urbanization, and low-impact development practices on urban flooding. *Heliyon*, *9*(1). https://doi.org/10.1016/j.heliyon.2023.e12955

Bibi, T. S., & Kara, K. G. (2023b). Evaluation of climate change, urbanization, and low-impact development practices on urban flooding. *Heliyon*, *9*(1). https://doi.org/10.1016/j.heliyon.2023.e12955

Dierkes, C., Lucke, T., & Helmreich, B. (2015a). General technical approvals for decentralised sustainable urban drainage systems (SUDS)-the current situation in Germany. *Sustainability (Switzerland)*, *7*(3), 3031–3051. https://doi.org/10.3390/su7033031

Dierkes, C., Lucke, T., & Helmreich, B. (2015b). General technical approvals for decentralised sustainable urban drainage systems (SUDS)-the current situation in Germany. *Sustainability (Switzerland)*, *7*(3), 3031–3051. https://doi.org/10.3390/su7033031

Ellis, B. J., Lundy, L., & Revitt, M. (n.d.). *An Integrated Decision Support Approach to the Selection of Sustainable Urban Drainage Systems (SUDS)*.

Ichsan, I., Suharyat, Y., Santosa, T. A., & Satria, E. (2023). Effectiveness of STEM-Based Learning in Teaching 21 st Century Skills in Generation Z Student in Science Learning: A Meta-Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 150–166. https://doi.org/10.29303/jppipa.v9i1.2517

Jefferies, C., Duffy, A., Berwick, N., Mclean, N., & Hemingway, A. (n.d.). *SUDS Treatment Train Assessment Tool*.

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L. M., Arnell, N., Mach, K., Muir-Wood, R., Brakenridge, G. R., Kron, W., Benito, G., Honda, Y., Takahashi, K., & Sherstyukov, B. (2014). Le risque d'inondation et les perspectives de changement climatique mondial et régional. *Hydrological Sciences Journal*, *59*(1), 1–28. https://doi.org/10.1080/02626667.2013.857411

Lau, C. L., Smythe, L. D., Craig, S. B., & Weinstein, P. (2010). Climate change, flooding, urbanisation and leptospirosis: Fuelling the fire? In *Transactions of the Royal Society of Tropical Medicine and Hygiene* (Vol. 104, Issue 10, pp. 631–638). https://doi.org/10.1016/j.trstmh.2010.07.002

Mguni, P., Herslund, L., & Jensen, M. B. (2016). Sustainable urban drainage systems: examining the potential for green infrastructure-based stormwater management for Sub-Saharan cities. *Natural Hazards*, *82*, 241–257. https://doi.org/10.1007/s11069-016-2309-x

Muthanna, T. M., Sivertsen, E., Kliewer, D., & Jotta, L. (2018). Coupling field observations and Geographical Information System (GIS)-based analysis for improved Sustainable Urban Drainage Systems (SUDS) performance. *Sustainability (Switzerland)*, *10*(12). https://doi.org/10.3390/su10124683

Oladunjoye, O., Proverbs, D., & Xiao, H. (2022). Retrofitting Sustainable Urban Drainage Systems (SuDS): A Cost-Benefit Analysis Appraisal. *Water (Switzerland)*, *14*(16). https://doi.org/10.3390/w14162521

Pradhan-Salike, I., & Raj Pokharel, J. (2017). Impact of Urbanization and Climate Change on Urban Flooding: A case of the Kathmandu Valley. *Journal of Natural Resources and Development*, 56–66. https://doi.org/10.5027/jnrd.v7i0.07

Rosenthal, R. (1995). Writing Meta-Analytic Reviews. In *Psychological Bulletin* (Vol. 118, Issue 2). Hunter & Schmidt.

Suarez, P. (n.d.). *Urbanization, Climate Change and Flood Risk: Addressing the Fractal Nature of Differential Vulnerability*.

Zhang, W., Villarini, G., Vecchi, G. A., & Smith, J. A. (2018). Urbanization exacerbated the rainfall and flooding caused by hurricane Harvey in Houston. *Nature*, *563*(7731), 384–388. https://doi.org/10.1038/s41586-018-0676-z

Zhou, Q. (2014). A review of sustainable urban drainage systems considering the climate change and urbanization impacts. In *Water (Switzerland)* (Vol. 6, Issue 4, pp. 976–992). MDPI AG. https://doi.org/10.3390/w6040976

Zulkifli, Z., Satria, E., Supriyadi, A., & Santosa, T. A. (2022). Meta-analysis: The effectiveness of the integrated STEM technology pedagogical content knowledge learning model on the 21st century skills of high school students in the science department. *Psychology, Evaluation, and Technology in Educational Research*, *5*(1), 32–42. https://doi.org/10.33292/petier.v5i1.144