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Discovering the Perception Differences of Stakeholders on the Sustainable and Innovative Stormwater Management Practices

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Abstract

The overarching aim of the present work is to explore the perception differences of stakeholders, i.e., municipalities (MN), water administrations (WS), non-governmental organizations (NGO), and universities (UN), playing vital roles in the decision mechanisms regarding one of the sustainable flood mitigation techniques, i.e., low impact development (LID) practices. As being rewarding alternative to conventional drainage techniques, four different LID strategies, i.e., green roof (GR), bioretention cells (BC), permeable pavement (PP), and infiltration trench (IT), and three of their combinations were adopted to the densely urbanized Ayamama River basin, Istanbul, Turkey. The performances of the LIDs were comprehensively evaluated based on three pillars of sustainability (i.e., social, economic, and environmental) using a hybrid multi-criteria decision-making (MCDM) framework containing the implementation of fuzzy analytical hierarchy process (fuzzy AHP) and the VIKOR (VIse KriterijumsaOptimiz acija I Kompromisno Resenje) for finding the weights of constraining criteria and prioritizing the LID scenarios, respectively. The major outcomes of this research showed that experts from MN, WS, and UN put forward the environmental dimension of sustainability, whereas respondents from NGO concentrated on the social aspect. Furthermore, MN and WS highlighted initial investment cost as the most determining criterion in optimal LID selection. On the other hand, criteria weights regarding the judgments of the experts attended from NGO revealed the significance of community resistance in specifying the optimal LID practices, while aesthetic appearance was the major concern of the academia. Hence, the present study, as an initial attempt, enabled critical standpoints for discovering perceptions of stakeholders.

Keywords Hydrologic modelling · Low impact development · Multi-criteria decision-making · Optimization · Sustainable drainage · Urban flooding

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1 Introduction

As one of the most destructive nature-induced disasters, floods have impacted 1.6 billion people between 2000 and 2019, resulting in economic damages of $651 billion and posing a threat to over 100,000 lives (Koç et al. 2021). In addition, urban floods exacerbate the risk to freshwater sources through intense pollution leading to various ecological problems. Traditional approaches to managing urban floods typically involve controlling surface flow disposal (Hua et al. 2020). However, increasing the capacity of existing systems and alleviating drainage load, exacerbated by the mounting pressure of climate change, using conventional techniques may offer limited sustainability, particularly in densely urbanized regions. Consequently, to mitigate surface runoff and prevent undesirable nature-induced phenomena in urban areas, more sustainable methods inspired by the nature (such as best management practices and low impact development strategies) have gained widespread acceptance in recent years.

Low impact development (LID) strategies facilitate the storage of excess water and groundwater recharge, aiming to minimize flood damage through various field design techniques (Tansar et al. 2022). The effectiveness of the LID practices depends on various factors, including investment and operational costs, compatibility/feasibility, and the specific regions where these practices are implemented (You et al. 2022). Accordingly, it is essential to establish a strategic assessment system that maximizes decision-support mechanisms, facilitating the incorporation of different policies and stakeholders. Hence, multi-criteria decision-making (MCDM) algorithms serve as rewarding and practical tools in managing such multi-dimensional problems. Several MCDM applications on the origin of integrated water resources management have recently been proposed by the research society. Among them, Piyumi et al. (2021) employed the analytical hierarchy process (AHP) technique to assess the performance of plot coverage regulations and various LID practices, such as rain barrels and green roofs, under different precipitation regimes, ensuring sustainability in urban design. Despite the existence of divergent LID formations, their effectiveness varies based on site-specific conditions. For instance, Su et al. (2022) examined the feasibility of bioretention cells, green roofs, permeable pavements, and the scenarios composed of their combinations at the university campus-scale considering surface type and vegetative cover. They utilized the commercial MIKE URBAN software for their hydrological simulations. On a watershed-scale, Ekmekcioğlu et al. (2021) employed the SWMM, calibrated by the PEST algorithm, to assess the impact of green roofs and permeable pavements on reducing pollutant concentrations and runoff volumes in the Ayamama basin which is the primary focus of this research. Notably, the Ayamama basin has been a subject of concern in recent decades due to extreme events. Such that, Nigussie and Altunkaynak (2019) modelled the impact of urbanization on flood risk in the Ayamama watershed using MIKE 21 FM. Gülbaz et al. (2019) simulated the September 2009 flooding incident with SWMM and generated flood hazard maps. Regarding the integration of hydrological simulations and MCDM techniques, Koc et al. (2021) conducted hydrological simulations with the SWMM and incorporated the results pertaining to the runoff and pollutant reductions into a decision framework to determine the optimal LID implementation scenario in the Ayamama River basin.

Water resource management entails complex policies, given its conflicted objectives and multi-dimensional problems (Nazari et al. 2023). Such multi-tiered problems directly affecting the communities and biodiversity require collaborations across multiple authorities for empowering the result-oriented fulfillment of the LID systems. Considering that in the vast majority of the regions, storm water management and its associated units are under the control of various departments accounting for a lack of coordination (Carlson et al. 2015), the constitution of an inter-jurisdictional network among the relevant decision/policy makers helps foster the marginal utility of the LID implementations. In addition, a sustainable adhibition of such practices requires buy-in through key stakeholders and an everlasting process for attaining expected outcomes. An integrated approach is crucial, and the evaluation of perceptions of different stakeholders helps manage complex problems. For instance, Ghodsi et al. (2016) incorporated perspectives of three main stakeholders (i.e., wastewater companies, local water companies, and municipalities) taking part in the decision-making process into determining the most suitable urban runoff management scenario. The researchers concluded that the pairwise voting results in the optimum scenario provided the highest runoff volume reductions and total suspended solid removal. In a similar vein, Gogate et al. (2017) assessed the sustainability performance of seven different LID scenarios, considering technical, economic, environmental, and social aspects. They utilized a variety of quantitative and qualitative criteria, revealing that the perceptions of the experts from both industry and academia predominantly focused on the social dimension of the sustainability.

To address the imperative need for advance techniques capable of handling multi-tiered decision-making systems and considering the diverse perspectives of experts having substantial backgrounds in the relevant field, the present research formulated a hybrid MCDM framework, specifically the combination of the fuzzy AHP and VIKOR. A noteworthy methodological contribution of this research to the body of knowledge lies in being the initial attempt combining the corresponding MCDM techniques for the evaluation of optimal LID configurations. Furthermore, this study pioneers the exploration of perception differences among stakeholders pivotal in the decision mechanism within the sustainable urban drainage domain. Hence, it is anticipated to provide unprecedented insights into stakeholder perceptions, thereby offering valuable contributions to the advancement of strategies in this field.

2 Research Design

The current research undertook the hybrid implementation of hydrologic modelling and the integrated MCDM techniques to explore the impact of stakeholders' perspectives on the evaluation of LID strategies. Utilizing cost-effective nature that encompasses various paradigms through a participatory approach (Tabatabaee et al. 2022), focus group discussions (FGD) played a central role in constructing the decision-making framework. The fuzzy AHP method provided the importance levels of the criteria considered, while the VIKOR method not only prioritized the alternative LID configurations but also extracted the perception differences among stakeholders. The US EPA SWMM was employed to compute the contributions of LID techniques in terms of water quantity and water quality. The case study was conducted in the Ayamama basin, Istanbul, Turkey. Finally, the present study underscored the perception differences of the stakeholders regarding LID implementations under sustainability pillars, i.e., social, economic, and environmental. The corresponding steps followed throughout the study are illustrated in Fig. 1.

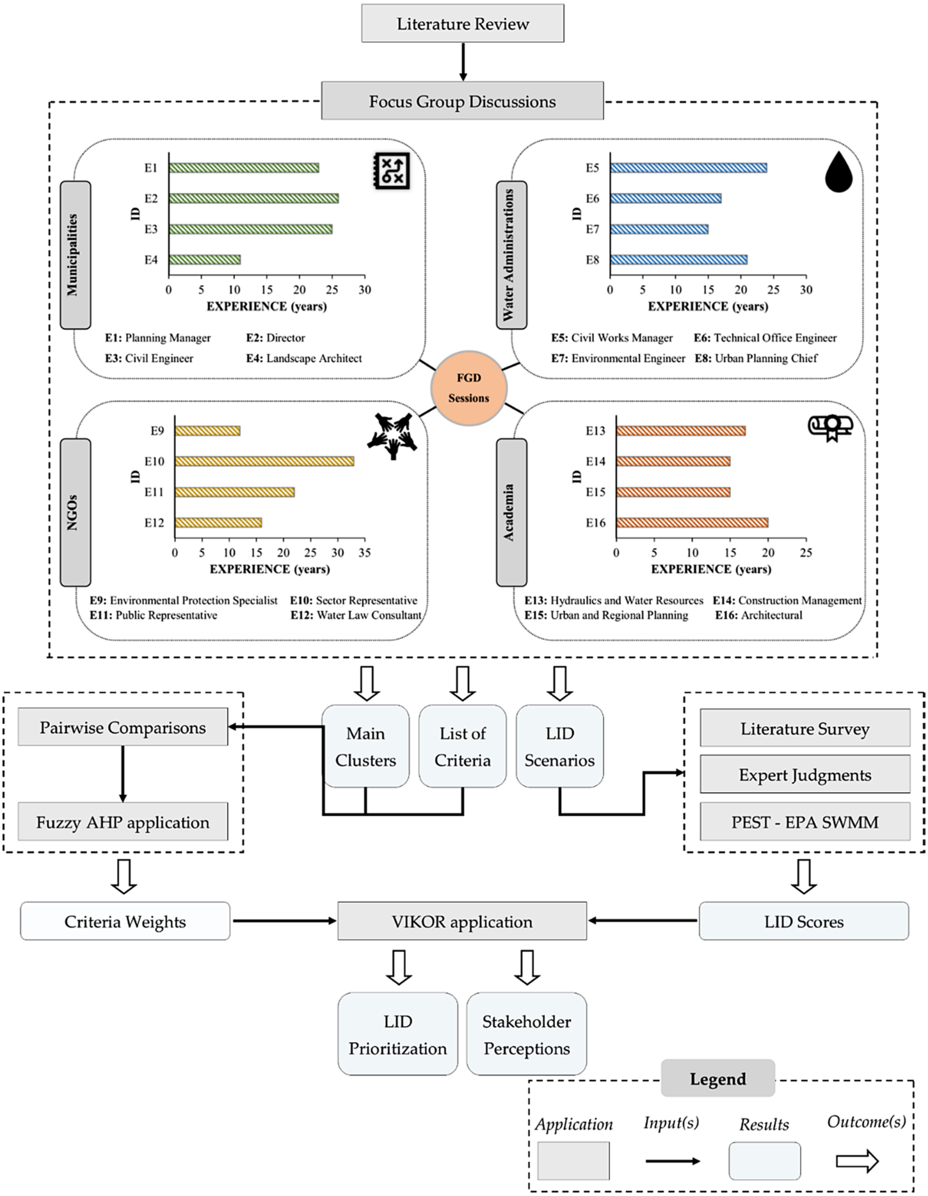

Fig. 1 Research flowchart

3 Study Area and Data

The Ayamama basin covering nearly 79 km² of surface area in total (Fig. 2), encountered serious flooding incidents in the past. The Ayamama River runs through six of the 39 districts of Istanbul, spanning a total length of 21 km and passing through 28 neighborhoods. The selection of the Ayamama basin as a focalized region is justified by the prevalence of

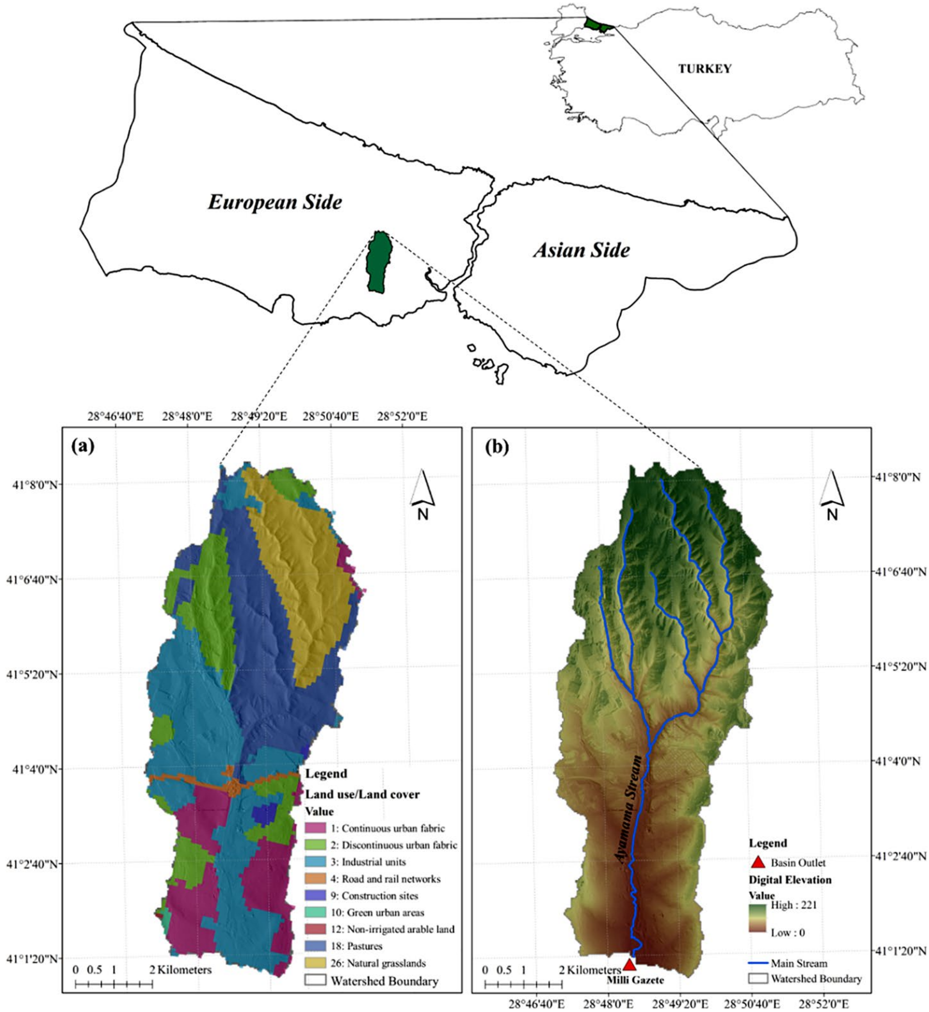

Fig. 2 Study area. **a** Land use/Land cover map. **b** Digital elevation map

impervious surfaces, including commercial, industrial, and residential areas as well as other strategic zones (e.g., military zones and educational facilities). Notably, the basin has experienced a set of flood events with the most severe events recorded in 1995, 2002, and 2005. The 1995 flood event resulted in losses exceeding 40 million US dollars, the 2009 event incurred losses exceeding 100 million US dollars and claimed 31 lives. Fig. 2a displays the land use/land cover map of the Ayamama River basin, derived from the CORINE dataset (2021). Additionally, Fig. 2b provides information on the elevation distribution throughout the basin, including the main stream of the Ayamama River and its main tributaries. Further details on the study region and hydro-meteorological conditions of the basin can be found in Ekmekcioğlu et al. (2021).

The Ayamama basin was meticulously divided into 41 sub-basins, taking into account the land use maps provided by Istanbul Metropolitan Municipality (BIMTAS 2020) and

CORINE dataset (2021), along with topographical elevations attained from the US Geological Survey Earth Explorer plug-in (USGS 2021) at a resolution of 30 m x 30 m. The stormwater sewer networks, sourced from the Istanbul Water and Sewerage Administration (ISKI), were also incorporated to identify the outlet locations of each sub-basin within storm sewer network. Furthermore, meteorological inputs, specifically precipitation and temperature data, were acquired from the Istanbul Metropolitan Municipality Disaster Coordination Center (AKOM) (2020).

4 LIDs and Stakeholder Association

4.1 LID Practices

LID practices aim to preserve, restore, and constitute sustainable spaces under various considerations, such as soils, vegetation, and rainwater harvesting (Pugliese et al. 2022). In this study, four stand-alone LID practices, i.e., green roofs (GR), bioretention cells (BC), infiltration trenches (IT), and permeable pavements (PP), and their three combinations, i.e., GR+BC, GR+BC+PP, and GR+BC+PP+IT, resulting in a total of seven scenarios were considered. This comprehensive evaluation is facilitated to explore the perception differences of stakeholders regarding these techniques. As one of the emerging building technologies, *green roofs* are prominent tools for mitigating the impacts of impervious land cover by reducing stormwater runoff (Matos et al. 2019). In addition to the significant stormwater runoff volume and peak discharge reductions leading up to 70%s and 80%s (Ekmekcioğlu et al. 2021), respectively, compared to the traditional rooftops, GRs further sustain the management of rainwater, augment esthetic appearance, and improve runoff water quality (Dadrasajirlou et al. 2023). Another LID technique under consideration in the current research is *bioretention cells*, which can be described as shallow landscape depressions designed to manage and treatment of the runoff from storm events. They are particularly effective in reducing urban pollutant and ensuring significant attenuation in both volume and rate of runoff to protect flood-susceptible areas (Gülbaz and Kazezyılmaz-Alhan 2018). This study also examined *infiltration trenches*, which are shallow excavation ditches intercepting runoff from upslope impervious areas. Similar to BCs, ITs provide temporary subsurface storage for stormwater runoff and enhance water-capturing capacity of the ground. In addition, *permeable pavements* that was used in this study are among the instrumental alternatives to traditional pavements, aiming to infiltrate surface water into native soil for runoff reduction. According to Ball and Rankin (2010), PPs can achieve a runoff reduction of up to 42%.

4.2 Stakeholders' role in the LID Selection Paradigm

4.2.1 Local and Metropolitan Municipalities

In this study, the perspectives of four experts with diverse backgrounds and roles in both local and municipal management of the city of Istanbul were considered. The major aim was to capture a comprehensive understanding of their perceptions regarding the implementation of LID techniques. Deliberately, two experts from the local municipality and two from the metropolitan municipality were included in the decision-making process. Each group comprised one civil engineer and one architect, chosen for their distinct but complementary expertise. Civil engineers were selected for their expected contribution of technical knowledge related to infrastructure design and construction, essential for assessing the engineering aspects of LID strategies. Simultaneously, architects were included due to their capacity to provide valuable insights into the aesthetic and design considerations of the region's conditions. This dual expertise ensures a well-rounded evaluation, where the feasibility of LID strategies is assessed not only from an engineering standpoint but also in consideration of the region's unique architectural and design requirements.

4.2.2 Water Administrations

In Istanbul, water administrations actively manage storm water, coordinating with local municipalities and addressing excess runoff disposal from settled areas. However, it is important to note that the service areas of water administrations are geographically limited to the jurisdiction of the municipalities that they are located in. Therefore, to enhance the comprehensiveness of this research, the perspectives of experts from the State Hydraulics Works (DSI) of Turkey were integrated as the DSI is responsible for planning, management, development and operation of all water resources and flood protection throughout the country. In this study, two experts from the DSI (to represent the general policy overviews regarding the effective use of water resources in the country) and two experts from Istanbul water and sewerage administration (ISKI) (to exhibit the approaches in water resources management in Istanbul) were determined. On the one hand, two environmental engineers from ISKI brought an in-depth understanding of the region's immediate environmental challenges, allowing them to focus on local nuances and specific issues within the community. This local expertise is crucial for tailoring LID practices to effectively address on-the-ground concerns. On the other hand, one civil engineer and one expert holding B. Sc. degrees in both civil engineering and architecture were included into the decision mechanism. The civil engineer's expertise was significant for evaluating broader engineering implications and tackling national-scale water management challenges. Meanwhile, the expert with dual degrees offers a distinctive skill set, integrating technical proficiency in civil engineering with a nuanced comprehension of aesthetic and design considerations derived from the architectural domain.

4.2.3 Non-governmental Organizations

Fisher (1998) emphasized the roles of NGOs in the socio-economic development of societies in various ways, citing two aspects directly related to the LID strategies: *developing communities through social change* and *fostering sustainable development within civil societies*. In many countries, NGOs play a pivotal role in contributing to water resources management activities currently facing severe threats related to environmental risks. This study explored the role of NGOs by incorporating the perspectives of four experts from different disciplines, aiming to reflect their standpoints in implementing sustainable solutions concerning both preserving water quantity and quality and alleviating the drastic impacts of flooding incidents. In this context, an environmental specialist, holding an M.Sc. degree in ecology, contributed by assessing the ecological impacts of LID practices. This ensured that the selected strategies are in alignment with environmental protection goals. Another expert, adept at facilitating operations in the private sector and engaging in volunteer activities, provided valuable insights into industry-specific challenges and needs. Furthermore, two additional experts played critical roles as a public representative and a water law consultant. The former, with a diverse background, focused on assessing community engagement in such practices. The latter, holding a Ph.D. degree in civil and environmental engineering, leveraged expertise in navigating potential regulatory hurdles and contributed to the development of legally sound strategies.

The experts selected from the NGOs were meticulously chosen to uphold the objectivity criterion in the LID evaluations. It is, therefore, ensured that their contributions to the evaluation are rooted in their professional knowledge and experience rather than political affiliations. This deliberate approach safeguards against any potential political bias, reinforcing the objectivity of the entire assessments. Each expert's unique background contributes to a comprehensive, unbiased assessment of LID practices, aligning with the commitments to a fair and objective decision-making process.

4.2.4 Academia

Although academics may not be considered a load-bearing column in addressing nature-induced challenges, they create an active zone between the institutions taking the strategic course of actions and the public directly affected by the consequences. With technical support based on in-depth knowledge of the physics and dynamics of the corresponding actions, academia plays an essential role. To enhance the assessment of sustainable water management practices, the judgments of four academic experts from diverse disciplines were considered in this research. The first expert, an associate professor in hydraulics and water resources department, is a civil engineer with specialized insights into the technical aspects of stormwater management, flood control, and water resource sustainability within the LID framework. The second, an associate professor in construction management department and a civil engineer contributed important insights into project management, construction logistics, and feasibility of executing LID strategies in real-world construction scenarios. The third, a professor in urban and regional planning department, provided a planning-oriented perspective to evaluate whether LID practices align with urban and regional planning goals, including considerations for land use, zoning, and community development. The last expert, also a professor in the department of interior architecture, played a crucial role in assessing whether LID strategies are not only functional but also aesthetically harmonious with the built environment, enhancing the overall sustainability and acceptance of LID practices.

5 Materials and Methods

This section presents an overview regarding the MCDM approaches (i.e., focus group discussions, fuzzy AHP, and VIKOR) and the numerical techniques (i.e., US EPA SWMM and PEST) utilized for attaining quantitative and qualitative reductions provided by the LIDs as presented in the following sub-sections.

5.1 Hydrological Model Implementation

The EPA SWMM is a versatile tool that allows users to perform dynamic hydraulic-hydrologic simulations, water quality analysis, low impact development (LID) strategies, among other tasks. The model treats each sub-catchment as a non-linear reservoir, and the computation of overland flow for each sub-catchment is based on the the conservation of mass and momentum laws in rainfall-runoff modelling. The SWMM introduces alternative modelling approaches, including steady flow, kinematic wave, and dynamic wave routing, adopting the Saint-Venant equations for flow routing. Demonstrated as a practical and efficient tool, SWMM is particularly useful for investigating the applicability of the LID techniques. Accordingly, via the EPA SWMM, LID control options encompassing a set of vertical layers with divergent attributes can be assigned on a per-unit-area-basis. In this research, Horton's infiltration approach was adopted as an infiltration model due to its practicality for relatively smaller regions, while dynamic wave routing was chosen for its consistent outcomes (Koc et al. 2021). It is noteworthy that the hyperparameters of the SWMM were tuned using the Parameter EStimation Tool (PEST) (Doherty et al. 1994) with the consideration of Nash-Sutcliffe Efficiency (NSE) (1970) metric as an objective function.

5.2 MCDM Application

The conventional AHP lacks has been critiqued for lacking a holistic representation of the inherent uncertainty of the human decision making, leading to biased outcomes and zero-weight problems in some scenarios. To tackle the corresponding limitation, Chang (1996) introduced the concept of extent analysis, allowing the incorporation of the fuzzy set theory (Zadeh 1965) into the AHP. Pairwise comparisons are utilized to assess the decision criteria, and a practical triangular fuzzy-AHP is employed to determine the criteria weights. The consistency ratio (CR) is then computed to ensure the reliability of the experts' judgments. Linguistic variables are transformed into their fuzzy equivalents in the following step. To achieve this, the reciprocal of linguistic variables, i.e., l_{ij}, m_{ij}, and u_{ij} denoting the lower, mean, and upper width of the pairwise judgments, respectively, are identified with regard to each criterion (criterion i) compared to its counterparts (criterion y). Finally, Chang's extent analysis is implemented to handle the vagueness inherent in the judgments.

To prioritize the LID alternatives and extract perception differences, the VIKOR technique, designed for ranking a set of alternatives under conflicting criteria, was employed. This approach has uncertain by simultaneously considering the closeness to the positive and negative ideal solutions, without requiring additional data transformation (Huang 2022). The VIKOR procedure involves determining the best vector and worst vector among the decision criteria. Subsequently, the maximum group utility and the minimum of the individual regret are computed. Finally, VIKOR index (Q) values leading to the finalized ranking, are determined for each decision layer. In VIKOR, the lowest Q value indicates the best alternative, while the highest Q value indicates the opposite.

6 Results and Discussion

6.1 LID Simulation Results

To conduct LID simulations, the present study first carried out a sensitivity analysis to explore the parameters that have the utmost impact on the model using the PEST. Associatively, *N-Imperv*, *N-Perv*, *pctzero*, *maxrate* and *minrate* on the Horton infiltration curve (HIC), *decay*, *drytime*, and *roughness* were found as the sensitive parameters. Using the corresponding sensitive parameters, optimization was performed and the SWMM model was configured with respect to the Ayamama basin. As a result, an NSE value of 0.81, which is statistically acceptable according to Moriasi et al. (2007), was obtained. For investigating the performances of the LID scenarios, the alternating block method (ABM) was utilized to synthetically generate 10-year return period storm events by means of the depth-duration curves. In this regard, seven different LID scenarios (including four standalones, i.e., GR, BC, IT, and PP, and three combinations, i.e., GR+BC, GR+BC+PP, and GR+BC+PP+IT) were tested (Fig. 3a). This research initially evaluated the performance of the non-LID strategy, and subsequently, volume and peak reductions are attained through the implementation of seven scenarios (Fig. 3b). As shown in the figure, the GR technique outperformed its counterparts in terms of both volume and peak flow reductions among stand-alone LIDs. One can further observe that the corresponding reductions increase when the combination scenarios are implemented. Specifically, the scenario containing all LIDs exhibited the highest volume and peak flow reductions at 60.81% and 51.04%, respectively.

For water quality assessments, the building and wash-off parameters of the LID implementations were determined through a literature survey due to lack of water quality measurement within the Ayamama basin. Maximum possible build-up and rate constants in urban areas for total suspended solid (TSS) were specified as 15 g/m^2 and 0.4, respectively (Bonhomme and Petrucci 2017). The wash-off coefficient and runoff exponent were determined as 0.05 and 0.75, respectively (Avellaneda et al. 2009). Water quality improvements were quantified using the computed pollutant reductions (Fig. 3c). The figure illustrates that, among stand-alone LIDs, the adoption of BCs resulted in the highest TSS reduction (42.87%) and total nitrate (TN) reduction (31.66%), while GRs performed better in terms of chemical oxygen demand (COD) (39.73%) and total phosphorus (TP) (32.26%) reductions with slight differences. In the case of combination scenarios, adding an extra LID option consistently increased pollutant reductions (Fig. 3c). Similar to the volume and peak flow reductions, the highest pollutant reductions were achieved through the application of all LIDs, i.e., GR+BC+PP+IT, with 50.76%, 45.11%, 42.23%, and 40.55% for TSS, COD, TN, and TP reductions, respectively.

6.2 MCDM Application Results

Table 1 exhibits the results attained through the fuzzy AHP analysis. The environmental dimension emerges as the major concern based on the overall evaluations of all stakeholders, carrying a weight of 43.74%. Likewise, all stakeholders, except those from the NGOs, emphasized the environmental aspect. However, significant perception differences are observed regarding the economic and social dimensions. The experts from municipalities and water administrations assigned higher importance to the economic facet, with weights

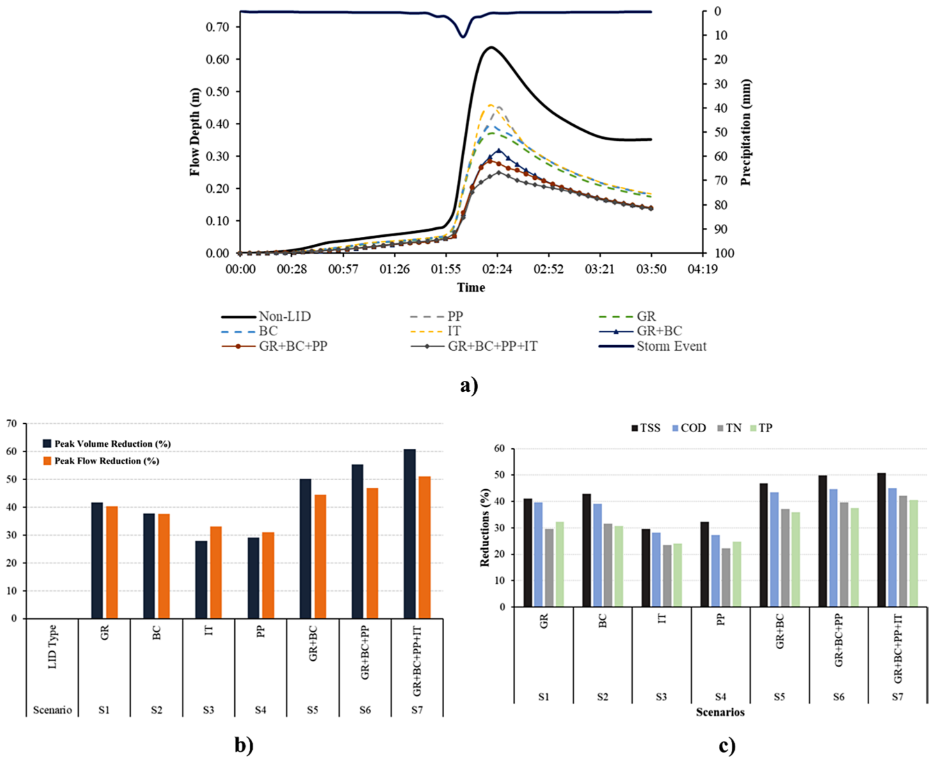

Fig. 3 Summary of the hydrological simulations: **a)** Hydrograph estimations, **b)** Quantitative reductions, **c)** Qualitative reductions

of 38.10% and 39.12%, respectively. This outcome can be attributed to the fact that municipalities and their associations are responsible for regulating investment plans and addressing water-related issues at the local level (Tinoco et al. 2022). On the contrary, the experts representing the NGOs and universities underestimated the economic dimension, assigning weights of 10.43% and 29.87%, respectively. Instead, they focused more on the social facet, with weights of 47.34% (for NGOs) and 33.99% (for UN). This result aligns with one of the major concerns of NGOs, particularly the social impact of the potentially adopted technologies, which also focal point for regional scholars (Shah et al. 2021).

Table 1 further reveals the sub-criteria weights obtained through the fuzzy AHP, reflecting the separate judgments of the stakeholders and their overall evaluations. For instance, MN pointed out the top three criteria as the initial investment cost (0.099), return period of a LID (0.0964), and operation feasibility (0.0952). Mirroring the experts from MN, WS considered the initial investment cost as the most important criterion with a weight of 0.1444. However, they ranked groundwater recharge potential (0.1412) and peak runoff reduction (0.1338) as the second and third most significant criteria, respectively. In addition to the economic concerns, focusing on these two factors by the experts from WS is reasonable since technical issues in the field are among their primary concerns. Regarding the social dimension of sustainability, NGOs highlighted community resistance (0.2634) and aesthetic (0.1890) as the first and third most influential criteria. Experts from academia also

Table 1 Criteria weights computed by the judgments of the stakeholders

Main criteria	Weights					Sub-criteria	Weights					Ranks				
	MN	WS	NGO	UN	ALL		MN	WS	NGO	UN	ALL	MN	WS	NGO	UN	ALL
Social	0.1356	0.1473	0.4734	0.3399	0.2698	Aesthetic (C1)	0.0344	0.0247	0.1890	0.1985	0.0957	12	12	3	1	2
						Community resistance (land acquisition, people's satisfaction, etc.) (C2)	0.0663	0.1030	0.2634	0.0691	0.1218	9	5	1	7	1
						Employment probability during operation (C3)	0.0349	0.0196	0.0210	0.0723	0.0523	11	13	9	6	12
Economic	0.3810	0.3912	0.1042	0.2987	0.2928	Initial investment cost (C4)	0.0990	0.1444	0.0035	0.1267	0.0806	1	1	15	2	5
						Operation cost (C5)	0.0905	0.0877	0.0280	0.0296	0.0626	5	6	7	13	10
						Operation feasibility (including periodic maintenance, design feasibility, etc.) (C6)	0.0952	0.1330	0.0659	0.0408	0.0890	3	4	6	10	3
						LID return period (C7)	0.0964	0.0261	0.0068	0.1016	0.0606	2	11	10	3	11
Environmental	0.4833	0.4614	0.4225	0.3613	0.4374	Volume reduction (C8)	0.0951	0.0593	0.0878	0.0339	0.0646	4	7	5	11	9
						Peak runoff reduction (C9)	0.0421	0.1338	0.1982	0.0444	0.0815	10	3	2	9	4
						Total suspended solids (TSS) (10)	0.0334	0.0148	0.0049	0.0775	0.0388	13	15	11	5	13
						Chemical oxygen demand (COD) (C11)	0.0334	0.0191	0.0049	0.0333	0.0273	13	14	11	12	14
						Total nitrogen (TN) (C12)	0.0151	0.0272	0.0049	0.0045	0.0129	16	9	11	15	16
						Total phosphorus (TP) (C13)	0.0232	0.0272	0.0049	0.0005	0.0149	15	9	11	16	15
						Impact on flora/fauna (ecological function) (C14)	0.0861	0.0283	0.0001	0.0849	0.0656	6	8	16	4	8
						Groundwater recharge potential (C15)	0.0688	0.1412	0.0250	0.0243	0.0656	8	2	8	14	7
						Greenhouse gas emission (C16)	0.0861	0.0107	0.0919	0.0581	0.0663	6	16	4	8	6

concentrated on the aesthetic appearance of the LIDs with the highest weight (0.1985). In contrast the other expert groups, they emphasized two criteria, i.e., initial investment cost and LID return period, regarding the economic aspect with weights of 0.0806 and 0.0606, respectively.

As a result, the prioritization of the seven LID scenarios were conducted in accordance with the VIKOR index (Q_i) values (Table 2). It is essential to note that the lower the Q_i, the more suitable to implement the LID practices in a comprehensive decision-making procedure. Hence, the overall assessments covering the divergent opinions of all stakeholders illustrated that the most suitable LID scenario for the Ayamama basin is the combination of GR and BC as it holds the lowest Q_i value (0.0000). Following this, the stand-alone GR (0.1107) and the combination of GR, BC, and PP (0.1850) were ranked as favourable alternatives. Besides, one can further conclude that different stakeholders put forward different LID scenarios. For instance, MN primarily focused on the application of stand-alone BC and GR techniques (Table 2). Similarly, experts from WS highlighted that implementing BC is the most suitable alternative for the focalized region. The NGO and UN, on the other hand, approached the LID scenarios from different aspects; such that the combination of GR, BC, and PP and the stand-alone GR were found as the best alternative as a result of their judgments, respectively. The results attained indicated that, among stand-alone LID alternatives, the GR and BC stand out, while combining GR and BC emerged as the most rewarding alternative in the overall assessments.

Furthermore, the outcomes of the current research regarding each pillar of the sustainability rationale were extracted to boost the diverse views of the stakeholders. In terms of the social context, all stakeholders exept the UN regarded the GR as the most prevailing alternative, as depicted in Table 3. On the other hand, the stakeholders generally underestimated the social contributions of IT, PP, and BC to sustainable LID practices. Besides, all stakeholders found IT as the most economically feasible solution, followed by BC, GR, and PP. As expected, the inclusion of an additional LID technique increases costs (i.e., operational and maintenance), and hence, all stakeholders agreed that the combination of all LIDs (GR+BC+PP+IT) is the least suitable alternative in terms of economical facet. Contrary to the economic aspect, implementing the combined LIDs augments the benefits within the environmental dimension. Therefore, the combination scenarios outperformed the stand-alone LID applications. What is striking about these results is that the most environmentally friendly solution is achieved by combining only GR and BC, rather than introducing all LIDs together. This is due to the fact that IT and PP are less functional in terms of ecology providing limited contributions to the flora and fauna and potentially leading to a significant amount of green gas emission compared to GR and BC.

7 Conclusions

The fundamental objective of the present research is to delve into the perspectives of the stakeholders who, as decision-making authorities, play a pivotal role in shaping sustainable water resources management practices. To realize this overarching goal, the judgments of the experts from different disciplines were attained through surveys and examined separately with the fuzzy AHP-VIKOR framework. The results unveiled a nuance landscape, showcasing both similarities and distinctions in the perceived importance of criteria affect-

Table 2 Results of VIKOR analysis by stakeholders in terms of Q_i values

Stakeholders / LID scenarios	GR	BC	IT	PP	GR+BC	GR+BC+PP	GR+BC+PP+IT
MN	0.1683	0.0156	0.6858	0.9588	0.2018	0.6037	0.6327
WS	0.7389	0.0253	0.6408	0.9031	0.2430	0.5236	0.5101
NGO	0.0221	0.5990	1.0000	0.7230	0.0111	0.0085	0.1268
UN	0.0844	0.4221	0.7190	1.0000	0.1090	0.2388	0.2184
ALL	0.1107	0.3894	0.8860	0.7706	0.0000	0.1850	0.2604

ing the selection of LID strategies and the identification of the optimum LID scenario for the Ayamama River basin. For instance, experts from MN, WS, and UN put forward the environmental dimension of sustainability. In contrast, respondents from NGOs placed a stronger emphasis on the social aspect. Furthermore, the economic pillar emerged as more prominent for MN and WS, while NGO and UN deemed it less significant compared to the social and environmental facets. Considering the comprehensive insights gleaned through the VIKOR approach, the recommendations diverged among stakeholder groups. In this vein, MN and WS advocated for the implementation of stand-alone BC, citing its economic feasibility and augmented environmental benefits. On the other hand, NGOs and UN highlighted the combined use of GR, BC, and PP and exclusive use of, respectively, as the preferred LID scenarios.

This research serves as the pioneering endeavour in the relevant literature, undertaking the inceptive exploration of divergent stakeholder preferences within the context of LID techniques, elucidating unprecedented insights into perception differences crucial for advancing sustainable urban water management strategies. Despite the novel approach with an innovative MCDM framework, it is still not free of limitations. To exemplify, further hydrological simulations can be conducted with other infiltration techniques and different optimization techniques, such as meta-heuristics. Regarding the decision-making facet, taking the interrelationships among the criteria into account could be a valuable research direction in follow-up attempts. Subjecting the judgments of the experts to the fuzzy set theory for prioritization through the fuzzified version of the VIKOR (i.e., fuzzy VIKOR) can further help deal with the vagueness and uncertainties in decision-making processes.

Overall, this study provided significant insights for optimal LID selections based on core dimensions of sustainability and provided encouraging solutions regarding social, economic, and environmental aspects. Hence, as an initial attempt, the current work enabled critical standpoints for specifying necessary actions, and managing the modern stormwater management practices, and is expected to assist in decision authorities for assessing different sustainable drainage alternatives comprehensively.

Table 3 LID performances with respect to sustainability pillars

Dimension		VIKOR index (Q_j)					Rank				
	Strategies	MN	WS	NGO	UN	ALL	MN	WS	NGO	UN	ALL
Social	GR	0.0032	0.0000	0.0000	0.2877	0.0158	**1**	**1**	**1**	4	**1**
	BC	0.6746	0.7231	0.6878	0.7097	0.6765	6	6	6	5	5
	IT	1.0000	1.0000	1.0000	0.9300	1.0000	7	7	7	6	7
	PP	0.4986	0.4103	0.6161	0.9849	0.6997	5	5	5	7	6
	GR+BC	0.0926	0.2618	0.1540	0.1319	0.0963	3	3	3	3	3
	GR+BC+PP	0.0607	0.2445	0.1147	0.0224	0.0555	2	2	2	**1**	2
	GR+BC+PP+IT	0.1899	0.3810	0.2566	0.0313	0.1820	4	4	4	2	4
Economic	GR	0.4643	0.4055	0.4876	0.4031	0.4438	3	4	4	3	3
	BC	0.1639	0.2379	0.0025	0.3181	0.1782	2	3	**1**	2	2
	IT	0.0000	0.0028	0.0147	0.0000	0.0000	**1**	**1**	2	**1**	**1**
	PP	0.6554	0.0659	0.0938	0.6619	0.4462	4	2	3	4	4
	GR+BC	0.6987	0.7273	0.6265	0.7523	0.6648	5	5	5	5	5
	GR+BC+PP	0.9385	0.9307	0.8582	0.9825	0.8826	6	6	6	6	6
	GR+BC+PP+IT	1.0000	1.0000	1.0000	1.0000	1.0000	7	7	7	7	7
Environmental	GR	0.5169	0.8647	0.3375	0.3260	0.5966	5	6	4	5	5
	BC	0.4911	0.6081	0.5130	0.3135	0.4851	4	4	5	4	4
	IT	0.9005	0.8588	0.8100	0.8640	0.8317	6	5	6	6	6
	PP	0.9763	0.9718	1.0000	1.0000	1.0000	7	7	7	7	7
	GR+BC	0.0371	0.2671	0.0701	0.0247	0.0597	**1**	3	**1**	**1**	**1**
	GR+BC+PP	0.3764	0.1418	0.1342	0.2720	0.3246	2	2	3	2	2
	GR+BC+PP+IT	0.4294	0.0000	0.1008	0.3041	0.3607	3	**1**	2	3	3

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Data Availability The data are available from the corresponding author upon reasonable request.

Declarations

Ethical Approval The submitted work is original and has not been published elsewhere in any form or language.

Consent to Participate Not Applicable.

Consent to Publish The author of the submitted manuscript agrees to publish in Water Resources Management Journal.

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