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Integration of Sustainable Urban Drainage Systems (SUDSs) in Highway Projects in Small Island Developing States (SIDSs) for Improved Resilience to Flooding †

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Abstract

Sustainable Urban Drainage Systems (SUDSs) have recently emerged as an alternative to traditional drainage systems, offering better stormwater management and improved resilience in road infrastructure. However, their uptake is still slow in Small Island Developing States (SIDSs) such as Mauritius. The aim of this study was to understand the potential for integrating various SUDS in major road projects and identify existing barriers and potential enablers. Semi-structured interviews with 20 highway experts showed that for Mauritius, the most feasible solutions were swales, soakaways and infiltration trenches, due to their ease of implementation and lower costs. However, topography, soil infiltration and water table levels pose significant challenges. Other SUDS types, such as permeable paving areas, retention/detention ponds, infiltration basins and constructed wetlands were not considered favourably. Potential enablers identified included enhancing the local technical expertise on SUDS, developing adapted guidance documents and policies and the implementation of pilot projects as showcases for SUDS efficacy in managing stormwater. The study has contributed to identifying the most suitable SUDS components for implementation in road projects in Mauritius and pathways to increase their adoption.

Keywords: SUDS; road infrastructure; traditional drainage; swales; retention ponds; permeable paving; infiltration trenches; SIDS

1. Introduction

Road infrastructure is essential for societal development, with major highways acting as catalysts for trade activities, improved connectivity and greater accessibility [1–3]. However, with the advent of climate change, flooding has become a major threat to this critical infrastructure, leading to serious damage and economic losses [4,5]. It is therefore imperative that highways are made resilient to impacts of floods through appropriate stormwater management systems to enable them to perform and recover satisfactorily [6,7].

Sustainable Urban Drainage Systems (SUDSs) have emerged as viable nature-based alternatives to conventional drainage networks [8]. By mimicking natural hydrological processes, SUDSs have been found to lead to a decrease in runoff volume, attenuation of peak flows and improvement of runoff water quality [9,10]. These combined benefits help to improve urban areas' resilience to flood events. However, most studies have focused on the implementation of SUDSs in the context of urban planning with only a few studies focusing on SUDSs in highway infrastructure. Furthermore, these studies are mostly in

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large countries located in temperate regions [11–13]. Small Island Developing States (SIDSs) in subtropical areas encounter various challenges due to their inherent characteristics of small size, remoteness and lack of resources as well as frequent high-intensity rainfall and complex geological properties. These complexities lead to greater challenges in the implementation of SUDSs in small islands [14]. To date, little research has been undertaken in SIDSs to understand the slow adoption of SUDSs in road infrastructure projects.

This paper aims to bridge these gaps by investigating the following research questions pertaining to SUDS in highway infrastructure in SIDSs: (1) what are the SUDS measures that have high potential for integration; (2) what are the existing barriers to SUDS adoption and (3) what are the potential enablers for improving the uptake of SUDSs.

2. Literature Review

2.1. Types of Sustainable Urban Drainage Systems (SUDSs)

SUDSs consist of several solutions for managing stormwater; the commonly used ones applicable for integration in highway infrastructure are detailed in Table 1 [9,15].

Table 1. Type of SUDSs applicable for highway projects.

SUDS Type	Details
Soakaways	Shallow excavated areas with porous materials for stormwater runoff collection and infiltration
Swales	Shallow channels lined with vegetation to convey and filter stormwater and that allow soil infiltration
Permeable paving	Pavers or cellular blocks with spaces in-between that promote stormwater infiltration and filtering
Infiltration trench	Trenches excavated and filled with porous materials for stormwater capture and infiltration
Infiltration basin	Basins temporarily hold stormwater runoff, allowing infiltration and are usually dry between rainfall events
Detention ponds	Excavated basins temporarily hold stormwater runoff and release it gradually at controlled rates
Retention ponds	Ponds designed to capture and store stormwater, reducing peak flows to mitigate flooding downstream.
Constructed wetlands	Engineered systems to mimic natural wetlands and allow stormwater storage, treatment and infiltration.

2.2. Barriers and Enablers to SUDSs Implementation

Although SUDSs offer several benefits in terms of stormwater management, several barriers to their adoption have been identified and regrouped into five main categories:

- Technical constraints—lack of knowledge and experience in SUDSs, limited space availability and an absence of performance data through demonstration projects [10,16];
- Financial burden—high upfront costs due to larger land requirements and material resources [15,16] and increased maintenance budget [8,14];
- Organisational constraints—unclear institutional responsibilities, lack of stakeholder coordination and poor management perception [16,17];
- Lack of regulatory support—absence of local guidance documents, policies and legal frameworks [15,17] and lack of political leadership/will to implement SUDS [16];
- Individual factors—lack of awareness on SUDS and unwillingness to change from usual traditional drainage systems [8,16].

Several enablers for SUDS adoption have also been identified in previous studies [16,17] and these include: (1) improving organisational readiness through support from top management for SUDS to reduce path dependency on traditional drainage systems; (2) improving stakeholder collaboration both among public and private sector actors; (3) reducing the skill gap through the provision of adequate personnel training to increase both technical knowledge and expertise; (4) using low-maintenance SUDS solutions to increase initial buy-in by stakeholders while at the same time providing demonstration projects and (5) creating the necessary regulatory environment with the provision of clear policies and guidance documents on SUDSs.

2.3. SUDS Application in Island Countries and Difficult Environments

SUDS application in small islands and regions with climatic, geological and topographical complexities remains limited; the sparse studies on this topic are listed in Table 2.

Table 2. SUDS application in difficult contexts and small island states.

Study and Year	Location	SUDS Type	Context	Findings
[18] 2025	Residential roads in Santa Cruz Island, Galapagos	Infiltration garden and permeable pavements	Tropical climate, flat terrain and moderate permeability	Cost effective, sustainable and visually appealing stormwater management solutions
[19] 2025	Residential area in Saltwater Creek, Cairns, Australia	Infiltration trench, retention areas and permeable pavements	Tropical climate, site with steep slopes and low permeability	Only retention-based systems performed well. Site-specific constraints need to be considered for optimum results
[20] 2026	Universiti Sains Campus, Penang, Malaysia	Constructed wetlands	Ponds with flat slopes in tropical climate	Effective, ecological solution for wastewater treatment but with odour and high maintenance issues

Studies [18–20] have emphasised that SUDS efficacy is context-sensitive and therefore more research needs to be done in difficult environments such as tropical climates and mountainous terrain to better understand their behaviour. Moreover, most pilot studies have been carried out in urban settings such as residential roads, with little attention given to SUDS application in major highway infrastructure. Lastly, recent review studies on SUDS implementation have highlighted the urgent need to focus on research on their application in small islands [21,22]. These findings indicate a clear need to carry out further research on SUDSs in highway projects in SIDSs to close the existing literature gaps and provide practical insights on feasible SUDS measures.

3. Materials and Methods

3.1. Study Context

Mauritius is a Small Island Developing State situated off the eastern coast of Africa in the Indian Ocean, as shown in Figure 1. The island is highly vulnerable to adverse climatic conditions, with several flash flood events recorded during the past decade causing significant damage to road infrastructure and leading to economic losses.

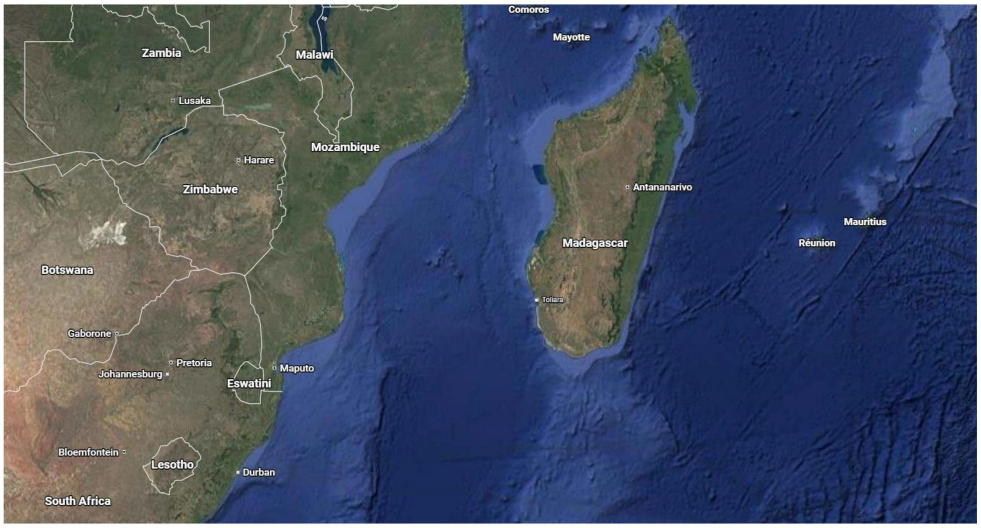


Figure 1. Google Map v26.34 image showing location of Mauritius in the Indian Ocean.

3.2. Study Approach

Qualitative methods were selected for this study as they offer powerful tools for research in terms of generating insights on complex situations from individuals' beliefs and perspectives based on their experiences [23]. Semi-structured interviews were carried out with twenty highway experts working in Mauritius. The participants were selected using a non-probability purposive sampling and consisted of highway engineers and project managers. All experts had a civil engineering background, with five having at least 10 years' experience while the rest had worked in the road infrastructure sector for more than 20 years. Eight interviewees were from the national agencies responsible for highway and stormwater drainage construction while twelve worked in private civil engineering consultancy firms. Permission was sought from participants prior to the interviews and they were informed that data collected would be kept strictly confidential. The interview questionnaire consisted of three main sections: (a) demographic information of participants; (b) ease of implementation of various SUDS type using a 5-point Likert scale ranging from 1 (Very Difficult) to 5 (Very Easy) and (c) open-ended questions on existing barriers and potential enablers for SUDS integration in road projects. Data saturation for the open-ended section was achieved after 14 interviews based on a content analysis carried out for codes identified. However, the data collection was carried out for all 20 experts who had agreed to participate in the interview.

3.3. Data Analysis

For identifying the most feasible SUDSs, the relative importance index (RII) was used to rank the eight selected measures. Thematic analysis is a widely used approach for analysing interview transcripts and was therefore adopted for this study [24,25]. This approach consists of the following main steps to analyse qualitative data: (a) transcription of interviews, data familiarisation and selection of relevant quotations; (b) selection of keywords; (c) coding; (d) theme development and (e) interpretation of codes and themes. The final outcomes answering the research questions were then validated with interviewees to ensure reliability and robustness of data analysis and interpretation.

4. Results and Discussion

4.1. SUDS Components for Integration in Highway Projects

Table 3 provides ratings from participants on the ease of implementation of different SUDS measures in highway projects.

Table 3. Ease of implementation of SUDSs in highway projects.

SUDS Type	Very Difficult	Difficult	Neutral	Easy	Very Easy	RII	Rank
Soakaways	0	1	3	10	6	0.81	1
Swales	1	4	3	9	3	0.69	3
Permeable paving	5	5	4	6	0	0.51	6
Infiltration trench	0	2	3	11	4	0.77	2
Infiltration basin	2	8	3	5	2	0.57	5
Detention ponds	2	8	3	4	3	0.58	4
Retention ponds	3	10	2	5	0	0.49	7
Constructed wetlands	10	7	3	0	0	0.33	8

According to the semi-structured interviews carried out, soakaways, infiltration trenches and swales were considered easy to implement as part of road projects. Permeable paving, although effective for reducing runoff in temperate climates [11], was not favourably considered for integration in major highways due to its shorter service life and high maintenance requirements in line with findings from previous studies [15,26]. Other SUDS measures such as infiltration basins/ponds and detention ponds were viewed as relatively easy to construct but were not highly rated for integration in highway projects due to the large space requirements for these solutions and their technical complexity, as highlighted in earlier studies [10,16]. Constructed wetlands were considered to be the least feasible for integration by most experts due to their complexity of implementation and long-term maintenance management, in line with earlier findings [27].

4.2. Barriers for SUDS Integration in Highway Projects

The barriers are organised around five major themes, namely technical, financial, regulatory, organisational and individual, as discussed in the subsections below.

4.2.1. Technical Barriers

Several interviewees pointed out technical issues as the main barrier to SUDS implementation in highway projects. While technical issues related to design, construction and maintenance are similar to previous findings [10,16], it was found that in SIDSs, there are other constraints such as lack of information on soil properties, steep slopes and high rainfall intensity which also need to be considered carefully when implementing SUDSs.

> "Before selecting SUDS, there is a need to have detailed information on soil properties, position of the water table and the existing topography. These are often not available due to restricted site investigations . . ." [Participant 3]

> "Although swales and infiltration trenches are easy to construct, precautionary measures such as lining on high slopes to prevent erosion during frequent high-intensity rainfall. . ." [Participant 10]

4.2.2. Financial Barriers

Another major barrier pointed out by many participants related to the financial aspects of SUDS implementation. Higher initial implementation costs in terms of materials and land resources required as well greater maintenance budgets have been identified by interviewees, in line with other studies [8,14–16].

> "SUDS require significantly more land compared to traditional drainage systems and in Mauritius, with the land scarcity issue, this increases the project costs through expensive land acquisition. . ." [Participant 1]

> "More maintenance is required for SUDS as they are prone to silting and overgrown vegetation during the rainy season and therefore a higher budget . . ." [Participant 5]

4.2.3. Regulatory Barriers

Interview participants also referred to various regulatory barriers such as the absence of existing guidelines and clear policies for SUDS implementation in the local context, as well as the lack of a legal framework as highlighted in the extracts below. While there is a need to improve the regulatory framework and develop locally adapted guidelines, as highlighted by other studies [15,17], it was noted that interviewees did not point to the lack of political will as a barrier, in line with the study by Ortega et al. [16]. This may be explained by the fact that there is a strong political leadership in Mauritius that is encouraging the move towards more sustainable and resilient infrastructure.

> "Existing international design documents cannot be used. There is a need to have guidelines developed for the island given its specificities . . ." [Participant 7]

> "To increase SUDS adoption, laws need to be put in place to ensure that designers are considering these solutions during the initial project stages. . ." [Participant 16]

4.2.4. Organisational Barriers

Lack of top management support for SUDS implementation and absence of stakeholder coordination were identified as major organisational issues and this concurs with findings from previous studies [16,17]. Interviewees also strongly pointed to the need for adoption of SUDSs during the early project lifecycle stages to ensure that the required space is acquired for SUDS implementation.

> "It has not yet been proven that SUDS will solve the issue of flooding fully. Therefore, management is sometimes very reluctant to adopt this measure and prefer the traditional drainage systems that they know will perform satisfactorily. . ." [Participant 2]

> "Projects are often carried out in silos by organisations, with early designs not incorporating SUDS measures. Once the land acquisition process has been completed, there is little room to incorporate SUDS due to the larger land requirements. . ." [Participant 14]

4.2.5. Individual Barriers

Several interviewees pointed out individual barriers as being a major hindrance to SUDS integration. Challenges pertain to lack of trust in the performance of SUDSs as well as the path dependency of using traditional drainage systems, as highlighted in the extracts below. These align with findings from previous studies [8,16] that found that resistance to change is a major issue when needing to adopt new practices.

> "Design of SUDS is different to traditional stormwater systems. Training is required to build up the skills for designing and implementing SUDS. . ." [Participant 4]

> "There are very few projects that have been successfully implemented and demonstrated that they are performing better than the traditional systems. These could have been used for reference purposes to increase trust in SUDS. . ." [Participant 12]

> "There is better acceptance of traditional drainage systems since this has always been used and there is resistance to change to new and untried solutions..." [Participant 11]

4.3. Enablers for SUDS Integration in Highway Projects

Several interviewees pointed out that it is essential that professionals working in the road infrastructure sector be made aware of the potential SUDS measures that can be integrated in highway projects. Moreover, information should also be provided on successfully implemented SUDS projects or components to increase trust in their efficacy.

> "It will help to increase SUDS adoption if we can show that the SUDS measures are working efficiently through small scale pilot projects ..." [Participant 3]

> "Suppliers of sustainable drainage solutions need to market their products with the highway authorities and local consultancy firms to increase awareness..." [Participant 5]

Another essential requirement is the provision of training to personnel to ensure that they are familiar with the design, implementation and maintenance of SUDS measures.

> "Clients and consultants need to be trained in SUDS so that these measures can be adopted during the early project phases such as during planning ..." [Participant 9]

> "During the construction phase, health and safety issues arise due to bulk earthworks required for ponds and site personnel should also be trained to cope ..." [Participant 13]

Interviewees also identified the need to have cost–benefit analysis carried out to identify the potential long-term advantages of using SUDSs despite their higher upfront costs.

> "We have to show that this type of drainage has more benefits even though it costs more. Cost–benefit analysis taking into account both direct and indirect benefits should be made for these new measures ..." [Participant 1]

Another enabler related to cost aspect is the need to develop maintenance schedule to be able to ascertain the costs associated with various types of drainage systems.

> "Maintenance of the existing traditional drainage system is done infrequently and therefore the cost may appear to be low compared to maintenance budget for SUDS. There is a need to have a clearly defined maintenance plan for both systems before assessing the costs..." [Participant 13]

To overcome the regulatory barriers, interviewees were of the view that there is a need for country-specific guidelines to be developed while simultaneously having a dedicated agency with the required personnel to closely monitor the performance of SUDS and collect data for dissemination to all industry stakeholders.

> "Mauritius has specific characteristics in terms of varying soil infiltration rates, difficult topography in some regions, high water table and high intensity rainfall. We need to have guidelines on SUDS developed considering all these parameters..." [Participant 4]

> "The drainage authority needs to have a team which is well versed in SUDS to carry out monitoring of these implemented projects to capture information with respect to their performance and disseminate it to all relevant stakeholders..." [Participant 10]

Finally, collaboration among key stakeholders to adopt a holistic approach was considered essential by most interviewees to ensure the adoption of SUDS.

> "Coordination amongst stakeholders during early project lifecycle is needed to break the fragmented approach and ensure that a holistic approach is being adopted when implementing the highway infrastructure. . .." [Participant 6]

5. Conclusions

This study identified that soakaways, infiltration trenches and swales were the most feasible SUDS measures for implementation in highway projects. The results have also shown that the barriers for SUDS adoption revolve mainly around technical, financial, regulatory and organisational themes. Future research should focus on demonstration projects and cost benefit analyses to increase the trust of all stakeholders in SUDSs. The findings of this study may be particularly useful for national agencies in Small Island Developing States to develop training programmes, policy documents, financial incentives and regulatory frameworks that will overcome existing barriers and thus offer potential pathways for greater adoption of SUDS in road projects.

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Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the author on request.

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