University of Central Lancashire UCLan

Central Lancashire Online Knowledge (CLoK)

Title	Effectiveness of Porous Concrete Pavements in Removing Total Suspended Solids from Urban Stormwater Runoff
Type	Article
URL	https://clok.uclan.ac.uk/id/eprint/55867/
DOI	https://doi.org/10.3808/jeil.202400152
Date	2025
Citation	Wijewickrama, D., Miguntanna, N., Siriwardhana, K. D., Kalaimathy, S. N., Kantamaneni, Komali and Rathnayake, U. (2025) Effectiveness of Porous Concrete Pavements in Removing Total Suspended Solids from Urban Stormwater Runoff. Journal of Environmental Informatics Letters, 13 (2). pp. 110-117. ISSN 2663-6859
Creators	Wijewickrama, D., Miguntanna, N., Siriwardhana, K. D., Kalaimathy, S. N., Kantamaneni, Komali and Rathnayake, U.

It is advisable to refer to the publisher's version if you intend to cite from the work. https://doi.org/10.3808/jeil.202400152

For information about Research at UCLan please go to http://www.uclan.ac.uk/research/

All outputs in CLoK are protected by Intellectual Property Rights law, including Copyright law. Copyright, IPR and Moral Rights for the works on this site are retained by the individual authors and/or other copyright owners. Terms and conditions for use of this material are defined in the http://clok.uclan.ac.uk/policies/

Journal of Environmental Informatics Letters 13(2) 110-117 (2025)

Journal of Environmental Informatics Letters

www.iseis.org/jeil

Effectiveness of Porous Concrete Pavements in Removing Total Suspended Solids from Urban Stormwater Runoff

D. Wijewickrama[1], N. Miguntanna[2], K. D. Siriwardhana[2], S. N. Kalaimathy[3], K. Kantamaneni[4], and U. Rathnayake[5 *]

[1] *Department of Civil Engineering, School of Engineering, SLTC Research University, Padukka 10500, Sri Lanka.*
[2] *Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, Malabe 10115, Sri Lanka.*
[3] *National Water Supply & Drainage Board (NWS&DB), Regional Support Center (Western North), Kadawatha 11850, Sri Lanka.*
[4] *School of Engineering, University of Central Lancashire, Preston PR1 2HE, United Kingdom.*
[5] *Department of Civil Engineering and Construction, Faculty of Engineering and Design, Atlantic Technological University, Sligo F91 YW50, Ireland.*

Received 05 Janurary 2024; revised 25 Janurary 2024; accepted 23 September 2024; published online 25 May 2025

ABSTRACT. This study investigates the effectiveness of total suspended solids removal in porous concrete pavement (PCP) with only changing aggregate size of the mix design and the thicknesses of the pervious concrete pavement specimen. The study used two different aggregate sizes, 10 ~ 14, and 14 ~ 19 mm, with a third mix percentage consisting of 50% of both aggregate sizes. Water content was maintained low in the mix designs since it influenced the porosity of the concrete and the water flow rate after solidifying the concrete. Slump tests were done to find the workability and all 3 mix designs' slump was near zero, and casted cubes were used to determine the compressive strength of each mix design. The results revealed that aggregate size had a direct impact on compressive strength, with smaller aggregate mix designs having higher strength. The study validated PCP's filtration properties as well as the percentage removal of total suspended solids. The removal efficiency was found to increase with the thickness of the PCP and the use of smaller aggregate sizes. Also, data revealed that where higher porosity facilitates improved filtration and reduces Total Suspended Solids (TSS) in storm water runoff. Furthermore, Infiltration data shows, where higher TSS Reduction Efficiency is associated with improved infiltration capacity, effectively mitigating the impact of stormwater runoff on water quality. According to the study, PCP is a better alternative for stormwater management systems and may be utilized for harvesting and cleaning purposes as non-portable water. The findings of this study might assist in determining the individual performance of each porous concrete pavement type and encourage wider use of these pavements to reduce the need for impermeable surfaces for stormwater management.

Keywords: mix designs, porous concrete pavements (PCP), stormwater management, total suspended solids (TSS)

1. Introduction

Many scientific studies have proved that the increasing level of urbanization is directly related to the excess stormwater runoff and pollutant levels of stormwater runoff. Urbanization leads to increased peak discharges and runoff volumes, decreased response time, increased frequency, and severity of flooding and a change in the characteristics of urban waterways from ephemeral to perennial streams (Fletcher et al., 2004). A study conducted in the United Kingdom shows, nearly 14 to 47% of front gardens across the United Kingdom which are at least 75% covered with impermeable paving and conversion of front gardens to impermeable cover has the potential to enhance urban flood risk (Kelly, 2018). In addition, urban stormwater runoff affects water quality, water quantity, habitat and biological resources, public health, and the aesthetic appearance of urban waterways. Most importantly, stormwater runoff creates a significant adverse impact on receiving water bodies due to addition of tons of pollutant loads from the runoff (Makepeace et al., 2009; Rathnayake and Tanyimboh, 2011; Rathnayake, 2015).

Water quality degradation poses particularly acute challenges in the Asian region, where many countries are experiencing rapid urbanization (Marcotullio, 2007; Jago-on et al., 2009). Porous pavement provides an innovative solution to these problems by creating a permeable surface that allows rainwater to percolate into the ground (Liu et al., 2009). This not only helps to recharge groundwater but also reduces total suspended solids (TSS) in stormwater runoff (Imran et al., 2013). Asian countries are increaseingly recognizing the importance of sustainable urban development practices, and the use of porous pavement is consistent with larger efforts to improve water resource management, preserve ecosystems, and promote resilience to the effects of climate change (Shade et al., 2020).

Sri Lanka, located in South Asia, faces its own set of water-quality challenges, with increased urbanization and industrial activity contributing to runoff pollution (Nuwanka and Gunathi-

* Corresponding author. Tel.: +353-899460732.
E-mail address: upaka.rathnayake@atu.ie (U. Rathnayake).

ISSN: 2663-6859 print/1684-8799 online
© 2025 ISEIS All rights reserved. doi:10.3808/jeil.202400152

laka, 2023; Siriwardhana et al., 2023). Implementing porous pavement in Sri Lanka's local context shows promise for improving water quality. The permeable nature of this pavement allows rainfall to infiltrate into the soil, reducing surface runoff and preventing total dissolved solids (TDS) from being transported directly into rivers and other bodies of water (Kayhanian et al., 2019). This approach is very valuable for Sri Lanka, which is frequently affected by floods (Herath et al., 2023). This approach is consistent with Sri Lanka's commitment to sustainable development and environmental conservation, providing a practical solution for mitigating the effects of urbanization on water resources and promoting a healthier and more resilient environment for its communities.

The ongoing urbanization and the growing public knowledge on the repercussions of the degradation of the water quality of receiving water bodies have heightened the public concern on the quality of the urban stormwater runoff. Consequently, urban stormwater runoff mitigation strategies are proposed on different scales by many entities. These mitigation techniques are also known as best management practices best management practice (BMPs). They include methods like infiltration with permeable pavement systems and rainwater storage tanks, which minimize peak flow while retaining some harmful elements (Freni et al., 2010; Qin, 2020).

To address these problems, designers, city planners, and stormwater management engineers across the world have begun exploring the effectiveness of the implementation of best management practices as a promising, cost-effective way to address the problem of increased stormwater runoff and decreased surface water quality that is associated with urbanization. In this context, the use of porous pavements has been increasingly recognized as a viable structural (BMPs) for stormwater management particularly in urban areas (Brattebo and Booth, 2003). The porous pavements let water infiltrate through the surface. Porous pavements can be designed for different places with various materials such as concrete, asphalt, and interlocking pavers. However, pervious concrete is relatively often used. Pervious concrete pavement consists of cement, water, and coarse aggregates. Importantly, the amount of fine aggregate is greatly reduced or eliminated, and the size distribution of coarse aggregate is maintained within a specified grading range. This not only supports the infiltration and but also the durability (Faisal et al., 2020).

Porous pavements made of pervious concrete trap pollutants contained in stormwater runoff and also can decrease stormwater runoff volume, increase groundwater recharge and enhance the quality of the stormwater runoff. Suspended solids are an important contaminant that must be eliminated from stormwater runoff because it acts as a carrier to many other pollutants such as heavy metals and nutrients. leading to impair aquatic habitats when ended up in the waterbodies (Baladès et al., 1995).

Porous Pavement Systems (PPS) are light load-bearing pavement constructions that are specifically intended to encourage rainwater infiltration via the top permeable layer and its underlying structure. PPSs are one of the most effective low-impact development (LID) strategies for improving the quality of stormwater runoff in urban areas. PPSs can enable stormwater harvesting by providing a catchment for collection and a place for water storage in the subgrade construction. PPSs can be used as a replacement for traditional impermeable surfaces on pathways, roadways, playgrounds, car parks, pedestrian spaces, and other locations. PPSs provide a firm surface as well as an irrigation and detention system, eliminating the need for additional detention space. This is especially essential in metropolitan areas where property prices are high and sites are relatively impermeable (Kuruppu et al., 2019).

Porous Concrete Pavement (PCP) is one of the most widely used permeable pavement systems in the world. Same as traditional concrete porous concrete also contains cement, aggregate, and water with different ratios. In 2010, American Concrete Institute published a report on pervious concrete referring to standard quantities and qualities of the materials (ACI, 2010). The amounts of cement and aggregates that should be used to make a pervious concrete pavement should be in the range of 270 ~ 415 and 1,190 ~ 1,480 kg/m^3, respectively. The acceptable range for the Aggregate/Cement ratio is between 4.0 and 5.5, while the acceptable range for the Water/Cement ratio is between 0.27 and 0.34. The suggested aggregate size range for the PCP is anywhere from 10 to 19 mm. Most PCP mixes have a cement concentration of between 270 and 415 kg/m^3, which is between 18 and 24% of the concrete mass (ACI, 2010).

The compressive strength of PCP was found to be greater when an aggregate of a smaller size was utilized, as reported by Yang and Jiang (2003). According to Pilon et al. (2019), PCP placed at Alcoa City showed PCP has the ability to remove different kinds of pollutants carried out with stormwater runoff such as TSS, nitrite, chemical oxygen demand (COD), zinc, pH, and polyaromatic hydrocarbons (PAH). Pervious concrete pavement is widely used in many countries such as the US and Japan since 1980s (Yang & Jiang, 2003) but not popular in the Asian region especially in Sri Lanka. However, there is a very high requirement for low cost and sustainable construction approaches in developing countries due to rapid urbanization. The main cities in Sri Lanka have been significantly urbanized over the reason years. Impervious layers have created additional surface runoff thus increasing the flood levels. In addition, the water quality of flood waters is drasticcally reduced due to pollutants readily available on impervious surfaces. Therefore, understating this research gap, this research presents the performance of PCP in eliminating total suspended solids while varying aggregate sizes for different concrete specimen sizes. Thus, the local conditions are attempted to be addressed by this research.

2. Materials and Methods

Experiments were carried out in several steps. First, a pervious concrete mix design was defined. Three different sizes of coarse aggregates were used (10 ~ 19 mm). The coarse aggregates were screened through sieves of 19, 14, and 10 mm. Then, collected remaining aggregate in 14 and 10 mm sieves and separately utilizes for two mix designs. Also 50% of retaining samples in 14 and 10 mm sieves were mixed to have the coarse aggregates for the 3rd mix design. Portland cement was used as the binder and

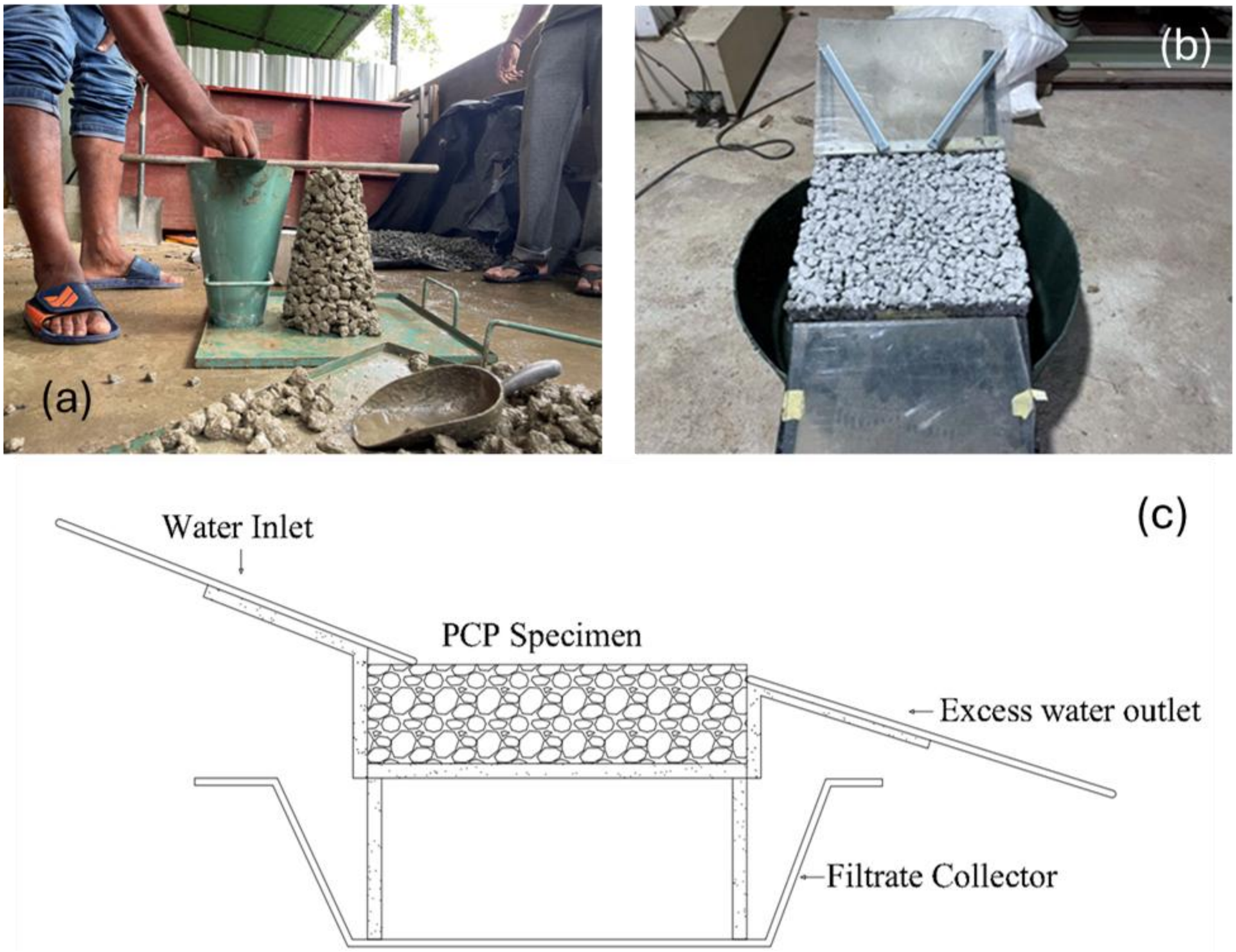

Figure 1. Experiments carried out. (a) Slump test for porous concrete; (b) Porous pavement for water quality test; (c) Porous pavement water quality test apparatus.

the cement concentration and coarse aggregate concentration were used at 350 and 1,400 kg/m^3 respectively. Water and cementitious ratio (Water/Cement) were kept at 0.3 for all three mix designs. The mixing and casting procedures involved using an auto sieve shaker and various sieves to separate the aggregates into different sizes and a mechanical mixer to mix the cement, gravel, and water. For each mix design, formwork dimensions of 300 by 300 mm were used, as well as depths of 80, 120, and 160 mm. Pervious concrete specimen size was selected considering the feasibility aspects of the design and construction in the lab. The mix design for pervious concrete pavement was obtained from previous studies (Nguyen et al., 2013; Yahia and Kabagire, 2014; Zhang et al., 2015; Chandrappa and Biligiri, 2016; Khankhaje et al., 2016; Faisal et al., 2020) and reports on pervious concrete such as American Concrete Institute ACI522R (ACI, 2010).

The slump test was carried out for the concrete mixtures as per the European standards BS EN 12350-2. The slump test checks the workability of the concrete mixture. Figure 1a shows a sample slump test carried out at the laboratory. The compres-sive strength was tested in accordance with BS EN 12390-3 to evaluate the strength of six cube samples (150 × 150 × 150 mm^3) for each mix design. Three samples were evaluated at 7 days, while the other three were tested at 28 days and the strength of each cube was calculated independently. The results were averaged from those three samples and the compressive strength of the concrete was calculated.

In this study, nine different experimental specimens with various thicknesses were cast to compare their efficiency in removing TSS. Pervious concrete pavement samples with thicknesses of 80, 120, and 160 mm were employed for wastewater treatment (Faisal et al., 2020). The sheet flow method (West et al., 2015) was chosen to collect stormwater runoff from the streets and water samples were collected during the first 5 ~ 10 minutes of the rain event because fresh runoff contains large amounts of TSS (first flush scenario). Samples were taken from 1st October to 1st November 2022 during second inter monsoon period in Sri Lanka. Figure 1 shows a pervious concrete pavement specimen and filtrate collection apparatus. The collected samples

Table 1. Compressive Strength of Cubes

After 7 days Mixed designs	Aggregate Size (mm)	Sample 1 (MPa)	Sample 2 (MPa)	Sample 3 (MPa)	Average (MPa)
MD1	10 ~ 14	15.12	14.60	14.04	14.59
MD2	14 ~ 19	10.64	9.98	10.08	10.24
MD3	10 ~ 19	12.66	11.71	11.93	12.10

Continued

After 28 days Mixed designs	Aggregate Size (mm)	Sample 1 (MPa)	Sample 2 (MPa)	Sample 3 (MPa)	Average (MPa)
MD1	10 ~ 14	19.33	19.00	18.78	19.04
MD2	14 ~ 19	15.36	16.66	15.84	15.95
MD3	10 ~ 19	17.54	17.09	16.81	17.15

were allowed to pass through the experimental setups and the filtrate was collected. Then laboratory tests were carried out to measure the TSS concentrations in both collected runoff samples and the filtrate from the aforementioned experimental setups. Subsequently, the percentage of suspended solids removal in each set-up was calculated.

The TSS of both the initial and filtrate samples was analyzed according to the ASTM D5907-18 standards. First, 100 ml of sample (V) was filtered through a pre-weighted glass fiber filter paper (W_i). Then, filter paper with the residual was oven dried for a duration of 1 hour at 105 °C degrees temperature. Next, the weight of the oven-dried filter paper was measured (W_f). Finally, the TSS concentration was calculated as shown in Equation 1:

$$TSS\ concentration = \left(\frac{W_i - W_f}{V}\right) \times 100\% \quad (1)$$

Porosity in porous concrete specimens was determined using the water displacement method. This standardised method is widely used to measure a material's void space or pore volume, which is critical for understanding permeable concrete′s ability to allow water to pass through. The process began by immersing each concrete specimen in water and recording its initial water level. The specimen was then carefully removed, and any remaining voids were filled by immersing it in water again. The change in water level represented the volume of water displaced by the specimen's pores, which was used to calculate porosity.

The general formula for porosity (P) is given by:

$$Porosity(P) = \left(\frac{Vt}{Vv}\right) \quad (2)$$

where P represents the porosity, Vv denotes the volume of voids or the volume of water displaced by the material, and Vt represents the total volume of the material.

Infiltration in porous concrete specimens was evaluated using the standard ASTM C1701 test method. In this procedure, a predetermined volume of water is poured into a specific ring, and the time it takes for the water to penetrate the concrete specimen is meticulously recorded. This direct measurement of infiltration rate provides critical information about the material′s ability to absorb and allows the passage of water. The results are commonly reported as a coefficient of permeability, which is based on Darcy's law, which relates flow velocity to hydraulic gradient and material properties. This infiltration test is a fundamenttal assessment tool for understanding the permeability characteristics of concrete, providing useful data for stormwater management and sustainable urban development. The general formula for Infiltration (Q) is given by:

$$Infiltration(Q) = KiA \quad (3)$$

where: this equation allows the calculation of the hydraulic gradient (i) based on the measured flow rate (Q), the cross-sectional area (A), and the coefficient of permeability (K) for the permeable concrete specimen.

3. Results and Discussion

3.1. Slump Test Results

Mix proportions of pervious concrete pavements have a 0.3 water/cement ratio, with low water content. An excessive amount of water may drain the cement paste and then clog pores. Water concentration directly affects the strength and void structure of pervious concrete (ACI, 2010). It is also recommended in ACI-522R to keep the water/cement ratio between 0.26 and 0.45 and the zero slump (ACI, 2010). The slump test provides almost perfect slumps (as shown in Figure 1 a) for all samples.

3.2. Compressive Strength of Cubes

The water-cured pervious concrete cubes were tested for their compressive strength at the ages of 7 and 28 days. The results for both scenarios are shown in Table 1. Mixed design 1 (MD1) has the highest compressive strength at 7 days, at 14.59 MPa, representing 76.62% of the 28^{th}-day strength of 19.04 MPa. This is interesting and comparable with the literature. Cited examples showed compressive strength of porous concrete between 2.8 to 28 MPa with an average value of 17 MPa (ACI, 2010;

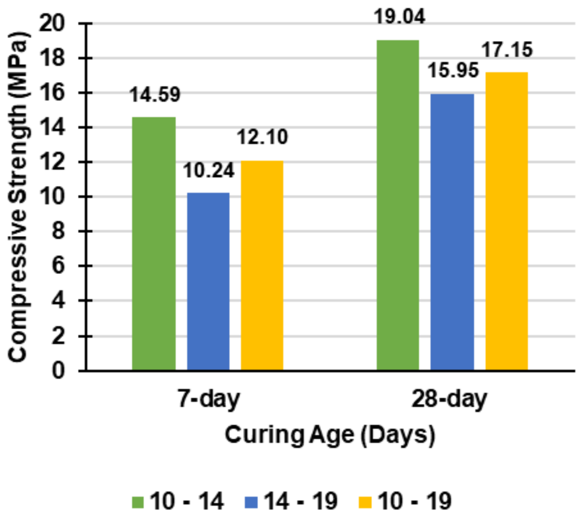

Figure 2. Influence of gravel size on compressive strength.

Faisal et al., 2020). The compressive strength of Mixed design 2 (MD2) was 10.24 MPa after 7 days, or 64.2% of 15.95 MPa at the 28th-day compressive strength while Mixed design 3 (MD3) had 12.10 MPa (after 28 days, it was 17.15 MPa). It is important to note that the compressive strength of all the mixed designs was less than 20 MPa due to pervious concrete mix designs which do not contain fine aggregates but with a high void ratio.

Pervious concrete had mostly uniform coarse aggregates and no fine aggregates. Usually, in ordinary concrete, fine aggregate increases the compressive strength and density of the concrete. Therefore, this is a negative factor for the pervious concrete compressive strength. Mixture proportion and compaction effort during the placement also directly affected the compressive strength. The effect of coarse aggregate size on compressive strength is graphically shown in Figure 2.

As can be seen in Figure 2, the particle size of gravel had a substantial impact on the compressive strength of the pervious concrete pavements. It is clear that the mixtures consisting of smaller aggregates were able to create stronger results than those consisting of larger aggregates. This mimics the relative strength enhancement with fine aggregates. After 28 days, the compressive strength of the smaller gravel size 10 ~ 14 mm sample is 19.04 MPa, which is 1.2 times that of the 14 ~ 19 mm sample and 1.11 times that of the composite sample of both aggregate sizes.

By looking at the samples in Figure 1, it can be felt that the porous concrete might have some adverse impacts on load bearing. However, the compressive strength tests showcased that they are still capable of handling significant loads. However, it is recommended to include more tests and then to see the practicality of them in the usage of roads. Nevertheless, the porous concrete tested here is capable of handling loads from pedestrians.

3.3. Removal Percentage TSS

Figure 3 depicts the removal percentage of total suspended solids based on the thickness of the sample and used coarse aggregate size. As it is expected higher removal efficiencies can be seen in the samples which have higher thickness (160 mm). Higher efficiencies can be observed in all three coarse aggregate sizes while increasing with thickness. In this study, only concrete specimens were used for stormwater treatment, without additional layers, to precisely determine TSS removal efficacy with regard to pervious concrete pavements specimen thickness and mix proportion.

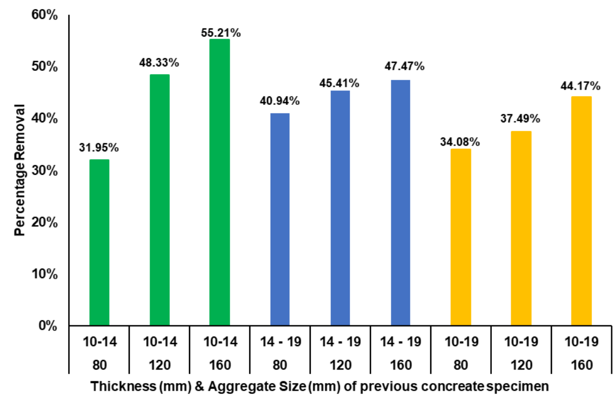

Figure 3. Percentage removal of TSS

The size of the coarse aggregate also significantly affects the removal efficiency, as seen in Figure 3. Most of the time, designs with smaller coarse particles (10 ~ 14 mm) exhibit higher removal efficiency. This is due to the result of smaller aggregate particles in the concrete mix interlock more efficiently than larger coarse aggregates. Most of the relevant research was conducted through field installations and laboratory experiments involving porous materials, including the subgrade layer. When utilizing porous pavement in combination with gravel or porous sub-layers, it exhibits a removal efficiency ranging from 79 to 100%. However, when using only porous pavement material, the removal efficiency ranges from 11 to 52%, as indicated in Table 2. Within this study, the experimental setup resulted in a removal efficiency of 31 to 55%, considering varying coarse aggregate sizes and pavement thicknesses.

Because of the rapid urbanization in Sri Lanka, utilizing porous concrete pavement for pathways, parking areas, and light weight surfaces becomes a cost-effective approach. Furthermore, given the changing climate and increasing development projects the reduction of pollutants from stormwater runoff can be achieved by using porous pavements. Moreover, the efficiency of removing water pollutants can be enhanced by implementing field installations with both porous pavement and porous sublayers. Moreover, at the forefront of water scarcity the treat-ment of stormwater runoff through porous pavement systems will also enable approaches for stormwater harvesting by providing a catchment for collection and a place for water storage in the pavement subgrade level.

3.4. TSS Reduction Efficiency versus Porosity

Figure 4 illustrates the graphical correlation between TSS

Table 2. Removal Efficiency of TSS

Reference	Porous Pavement Type	Removal Efficiency of TSS (%)
Brown et al., 2009	UNI EcoStone and porous asphalt	90 ~ 96
Koupai et al., 2016	Porous concrete	11 ~ 53
Li et al., 2017	Porous asphalt, porous concrete	90
Kamali et al., 2017	Permeable pavement	100
Teymouri et al., 2020	Porous concrete	37 ~ 40
Zheng et al., 2022	Permeable pavements	91
Sambito et al., 2021	Porous paver, pervious concrete, porous asphalt	79
Yong et al., 2021	Porous asphalt, permapave, modular hydrapave	100

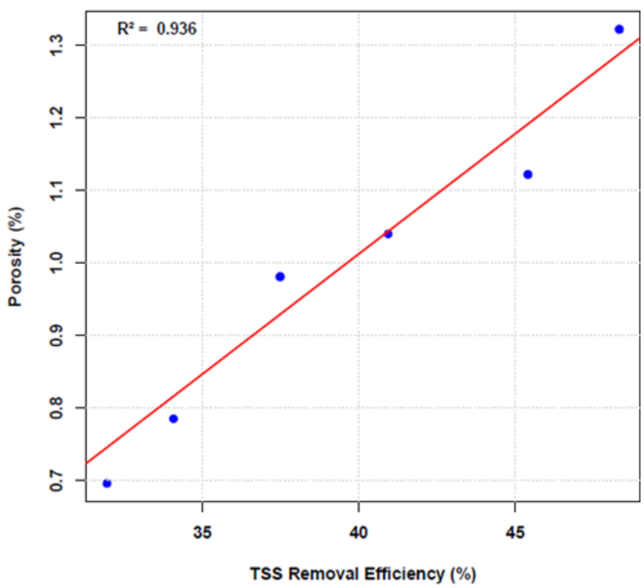

Figure 4. Percentage removal of TSS versus Porosity.

reduction efficiency with porosity. Plotting the data and fitting a best-fit line reveals a clear and consistent pattern, indicating a positive linear relationship between TSS Reduction Efficiency and Porosity. The upward trend suggests that as the percentage of porosity in pavement materials increases, correspondingly rises the TSS Reduction Efficiency. This observation is consistent with the expected behaviour of porous pavements, where increased porosity allows for better filtration and a reduction in TSS from storm water runoff.

The best-fit line's straight-line nature emphasises the relationship's strength and linearity. The *R*-squared value of 0.936, which represents the proportion of variance explained by the model, indicates a high level of predictability in TSS Reduction Efficiency Based on Porosity. This strong correlation has practical consequences for stormwater management and sustainable urban development. According to the findings, strategically implementing porous pavements with higher porosity can be an effective strategy for improving TSS Reduction Efficiency, contributing to better water quality and a lower environmental impact. Overall, the dataset sheds light on the potential of porous pavements as a long-term solution for reducing the negative effects of urban runoff on water quality.

3.5. TSS Reduction Efficiency vs Porosity

Figure 5 illustrates the graphical correlation between TSS reduction efficiency with Infiltration. After plotting the data and fitting a best-fit line, a clear and consistent upward trend appears, indicating a positive linear correlation. As TSS Reduction Efficiency increases, it also increases Infiltration Rate, implying that TSS removal efficiency is directly proportional to pavement materials' ability to facilitate water infiltration.

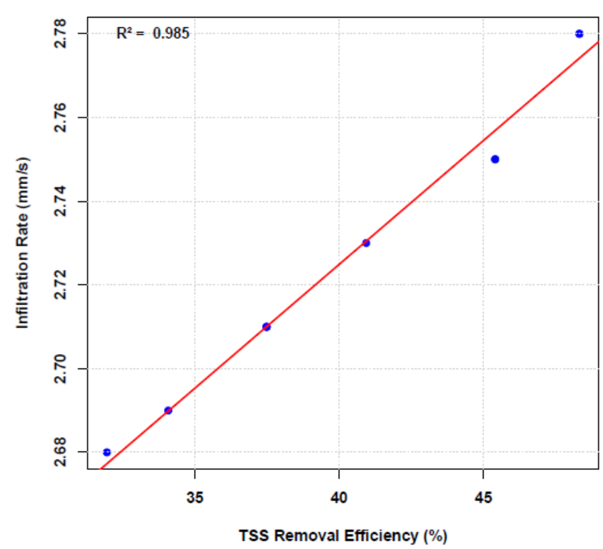

Figure 5. Percentage removal of TSS versus Infiltration.

The best-fit line's straightness highlights the strong and linear relationship between TSS Reduction Efficiency and Infiltration Rate. The high *R*-squared value of 0.984 validates the linear model's reliability and accuracy, indicating that changes in TSS Reduction Efficiency can explain a significant portion of the variability in Infiltration Rate. This strong correlation has important implications for stormwater management and urban planning, implying that improving TSS Reduction Efficiency via permeable surfaces can result in more effective water infiltration, ultimately contributing to improved environmental sustainability. The dataset provides valuable insights into potential of porous pavements to address water quality issues associated with urban runoff.

Porous pavement technologies are still relatively new in Sri Lanka, and their use is not yet widespread. However, some pilot projects can be seen in the capital of Sri Lanka which are being monitored. Nevertheless, most of the pavements in Sri Lanka are impervious, and a significant impact on the water cycle can be observed during stormy days. In addition, some of the pavements are constructed with interlock bricks. The idea of these interlock bricks is to enhance the infiltration of stormwater runoff. However, poor maintenance practices led these interlock-bricked pavements to act as impervious layers. Therefore, the idea of infiltration is not properly practiced. Thus, porous pavements have a promising future in Sri Lanka. It requires further attention from the authorities before developing relevant policies.

However, the developing countries have different priorities. Therefore, it is a bit difficult to enhance the required budget to implement the porous concrete into the pavements. The authorities have to convince the government and various other funding agencies in development projects to implement such stormwater management systems in the urbanizing environment. Thus, a proper planning strategy is required for a longer time, starting with little and then moving into more sustainable approaches.

4. Conclusions

Rapid urbanization together with the growth of population have already created a significant stress on our water environment due to the increase of demand for safe water and sanitation and also the increase level of water pollution caused by various anthropogenic activities. In this context design and application of various water sensitive urban design (WSUD) has increasingly recognized as a viable approach to safeguard the water environment and reducing the cost of water treatment by reducing the amount of pollutant loads added to water bodies particularly due to non-point sources which primarily include urban stormwater runoff. In this context design of sustainable and low-cost WSUD approaches are of crucial importance particularly in terms of feasibility in adaptation. Consequently, porous concrete pavements provided a superior option for stormwater management systems in urban areas and may be employed in light load locations such as walkways and parking lots. Experimental analysis showcases significant Total suspended solid removal efficiencies in all three tested previous concrete samples. Out of them, mix design 1 (10 ~ 14 mm) showcases the best performance. The removal efficiency increases with the thickness of the samples. Furthermore, the porosity data show a positive linear correlation between TSS Reduction Efficiency and Porosity, emphasising the importance of increased porosity in improving filtration and reducing TSS from stormwater runoff. Similarly, the infiltration data show a positive linear correlation between TSS Reduction Efficiency and Infiltration Rate, indicating that effective TSS removal is directly related to the pavement's ability to facilitate water infiltration. However, the extended field level analysis is required to generate a sound conclusion. In addition, an economic analysis must be carried out to understand the practical application of the tested mixed design. Moreover, the application of modified porous pavements with the use of various materials such as recycled waste materials and various layer arrangements and mix designs is being investigated to further enhance the objective of porous pavement systems. The outcomes of this research directly provide an initiative to these efforts. Furthermore, it can be recommended further investigation of the potential use of the harvested stormwater from previous concrete pavements for non-potable use.

References

ACI. (2010). *522R-10: Report on Pervious Concrete*. American Concrete Institute Vol. 10.

Baladès, J.D., Legret, M. and Madiec, H. (1995). Permeable pavements: Pollution management tools. *Water Science and Technology*, 32(1), 49-56. https://doi.org/10.1016/0273-1223(95)00537-W

Brattebo, B.O. and Booth, D.B. (2003). Long-term stormwater quantity and quality performance of permeable pavement systems. *Water Research*, 37(18), 4369-4376. https://doi.org/10.1016/S0043-1354 (03)00410-X

Brown, C., Chu, A., van Duin, B. and Valeo, C. (2009). Characteristics of sediment removal in two types of permeable pavement. *Water Quality Research Journal*, 44(1), 59-70. https://doi.org/10.2166/wqrj.2009.007

Chandrappa, A.K. and Biligiri, K.P. (2016). Comprehensive investigation of permeability characteristics of pervious concrete: A hydrodynamic approach. *Construction and Building Materials*, 123, 627-637. https://doi.org/10.1016/J.CONBUILDMAT.2016.07.035

Faisal, G.H., Jaeel, A.J. and Al-Gasham, T.S. (2020). BOD and COD reduction using porous concrete pavements. *Case Studies in Construction Materials*, 13, e00396. https://doi.org/10.1016/j.cscm.2020.e00396

Fletcher, T., Monash University. Cooperative Research Centre for Catchment Hydrology (2004). *Stormwater flow and quality and the effecttiveness of non-proprie-tary stormwater treatment measures: A review and gap analysis*. CRC for Catchment Hydrology Australia.

Freni, G., Mannina, G. and Viviani, G. (2010). Urban stormwater quality management: centralized versus source control. Journal of *Water Resources Planning and Management*, 136(2), 268-278. https://doi.org/10.1061/(ASCE)0733-9496(2010)136:2(268)

Herath, R.D., Pawar, U., Aththanayake, D.M., Siriwardhana, K.D., Jayaneththi, D.I., Palliyaguru, C., Gunathilake, M.B. and Rathnayake, U. (2023). Rainfall-runoff-inundation (RRI) model for Kalu River, Sri Lanka. *Modeling Earth Systems and Environment*, 10, 1825-1839. https://doi.org/10.1007/s40808-023-01877-1

Imran, H.M., Akib, S. and Karim, M.R. (2013). Permeable pavement and stormwater management systems: a Review. *Environmental Technology*, 34(18), 2649-2656. https://doi.org/10.1080/09593330.2013.782573

Jago-on, K.A., Kaneko, S., Fujikura, R., Fujiwara, A., Imai, T., Matsumoto, T., Zhang, J., Tanikawa, H., Tanaka, K., Lee, B. and Taniguchi, M. (2009). Urbanization and subsurface environmental issues: An attempt at DPSIR model application in Asian cities. *Science of The Total Environment*, 407(9), 3089-3104. https://doi.org/10.1016/j.scitotenv.2008.08.004

Kamali, M., Delkash, M. and Tajrishy, M. (2017). Evaluation of permeable pavement responses to urban surface runoff. *Journal of En-*

vironmental Management, 187, 43-53. https://doi.org/10.1016/j.jenvman.2016.11.027

Kayhanian, M., Li, H., Harvey, J.T. and Liang, X. (2019). Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences. *International Journal of Transportation Science and Technology*, 8(4), 358-372. https://doi.org/10.1016/j.ijtst.2019.01.001

Kelly, D.A. (2018). Impact of paved front gardens on current and future urban flooding. *Journal of Flood Risk Management*, 11(S1), S434-S443. https://doi.org/10.1111/jfr3.12231

Khankhaje, E., Salim, M.R., Mirza, J., Hussin, M.W. and Rafieizonooz, M. (2016). Properties of sustainable lightweight pervious concrete containing oil palm kernel shell as coarse aggregate. *Construction and Building Materials*, 126, 1054-1065. https://doi.org/10.1016/J.CONBUILDMAT.2016.09.010

Koupai, J.A., Nejad, S.S., Mostafazadeh-Fard, S. and Behfarnia, K. (2016). Reduction of urban storm-runoff pollution using porous concrete containing iron slag adsorbent. *Journal of Environmental Engineering*, 142(2), 1-7. https://doi.org/10.1061/(asce)ee.19437870. 0001025

Kuruppu, U., Rahman, A. and Rahman, M.A. (2019). Permeable pavement as a stormwater best management practice: a review and discussion. *Environmental Earth Sciences*, 78, 327. https://doi.org/10.1007/s12665-019-8312-2

Li, H., Li, Z., Zhang, X., Li, Z., Liu, D., Li, T. and Zhang, Z. (2017). The effect of different surface materials on runoff quality in permeable pavement systems. *Environmental Science and Pollution Research*, 24(26), 21103-21110. https://doi.org/10.1007/s11356-017-9750-6

Liu, Z., Zheng, J. and Li, J. (2009). Utilizing technology of recycled aggregate concrete for pavement construction. *Road Pavement Material Characterization and Rehabilitation*. American Society of Civil Engineers, pp 185-190. https://doi.org/10.1061/41043(350)25

Makepeace, D.K., Smith, D.W. and Stanley, S.J. (2009). Urban stormwater quality: Summary of contaminant data. *Critical Reviews in Environmental Science and Technology*, 25(2), 93-139. https://doi.org/10.1080/10643389509388476

Marcotullio, P.J. (2007). Urban water-related environmental transions in Southeast Asia. *Sustainability Science*, 2, 27-54. https://doi.org/10.1007/s11625-006-0019-0

Nguyen, D.H., Boutouil, M., Sebaibi, N., Leleyter, L. and Baraud, F. (2013). Valorization of seashell by-products in pervious concrete pavers. *Construction and Building Materials*, 49, 151-160. https://doi.org/10.1016/J.CONBUILDMAT.2013.08.017

Nuwanka, M.W. and Gunathilaka, M.D. (2023). Complexities of water pollution: a review of surface water contamination in Sri Lanka. *International Journal of Environment, Engineering and Education*, 5(2), 72-78. https://doi.org/10.55151/ijeedu.v5i2.97

Pilon, B.S., Tyner, J.S., Yoder, D.C. and Uchanan, J.R. (2019). The effect of pervious concrete on water quality parameters: a case study. *Water*, 11(2), 263. https://doi.org/10.3390/w11020263

Qin, Y. (2020). Urban flooding mitigation techniques: a systematic review and future studies. *Water*, 12(12), 3579. https://doi.org/10.3390/w12123579

Rathnayake, U. (2015). Migrating storms and optimal control of urban sewer networks. *Hydrology*, 2(4), 230-241. https://doi.org/10.3390/hydrology2040230

Rathnayake, U.S. and Tanyimboh, T.T. (2011). Optimal control of combined sewer systems using SWMM 5.0. *WIT Transactions on the Built Environment*, 122, 87-96. https://doi.org/10.2495/UW120081

Sambito, M., Severino, A., Freni, G. and Neduzha, L. (2021). A systematic review of the hydrological, environmental and durability performance of permeable pavement systems. *Sustainability*, 13(8). https://doi.org/10.3390/su13084509

Shade, C., Kremer, P., Rockwell, J.S. and Henderson, K.G. (2020). The effects of urban development and current green infrastructure policy on future climate change resilience. *Ecology and Society*, 25(4), 37. https://doi.org/10.5751/es-12076-250437

Siriwardhana, K.D., Jayaneththi, D.I., Herath, R.D., Makumbura, R. K., Jayasinghe, H., Gunathilake, M.B., Azamathulla, H. Md., Tota-Maharaj, K. and Rathnayake, U. (2023). A simplified equation for calculating the water quality index (WQI), Kalu River, Sri Lanka. *Sustainability*, 15(15), 12012. https://doi.org/10.3390/su151512012

Teymouri, E., Mousavi, S.F., Karami, H., Farzin, S. and Hosseini Kheirabad, M. (2020). Municipal wastewater pretreatment using porous concrete containing fine-grained mineral adsorbents. *Journal of Water Process Engineering*, 36, 101346. https://doi.org/10.1016/j.jwpe.2020.101346

West, M., Wenzel, M., Schwieiss -Mpca, B., Flynn, L., Smith, T., Erickson, A., Moon, K., Skowronek, G., Moore, A., Gaffey, T., Pruchnofski, C., Boeck, C., Burman, J., Chamberlain, Z., Connell, J., Duncanson, D., Grigor, L., Hauger, J., Jakes, D., Rantala -Metropolitan, J. (2015). *Minnesota Pollution Control Agency Industrial Stormwater Best Management Practices Guidebook Version 1.1.* Editing and Graphic Design, pp 1-163.

Yahia, A. and Kabagire, K.D. (2014). New approach to proportion pervious concrete. *Construction and Building Materials*, 62, 38-46. https://doi.org/10.1016/J.CONBUILDMAT.2014.03.025

Yang, J. and Jiang, G. (2003). Experimental study on properties of pervious concrete pavement materials. *Cement and Concrete Research*, 33(3), 381-386. https://doi.org/10.1016/S0008-8846(02)00966-3

Yong, C.F., Deletic, A., Fletcher, T.D. and Grace, M.R. (2010). The drying and wetting effects on clogging and pollutant removal through porous pavements. *7th International Conference on sustainable techniques and strategies for urban water management*, Lyon, France, pp. 1-10.

Zhang, R., Kanemaru, K. and Nakazawa, T. (2015). Purification of river water quality using precast porous concrete products. *Journal of Advanced Concrete Technology*, 13(3), 163-168. https://doi.org/10.3151/jact.13.163

Zheng, M., Chen, W., Gao, Q., Liu, S., Deng, C., Ma, Y. and Ji, G. (2022). Research on the reduction performance of surface runoff pollution through permeable pavement with different structures. *Water, Air, and Soil Pollution*, 233, 147. https://doi.org/10.1007/ s11270-022-05619-4