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Environmental Performance of the StormPav Permeable Pavement using the Stormwater Management Model (SWMM)

Norazlina Bateni[1,2*], Lukman Mohd Najib[1], Khairisya Roslan[3], Mah Yau Seng[1,2], Inawati Othman[1,2], H. Maseri[4], M. D Mannan[1]

[1]Department of Civil Engineering, Faculty of Engineering,
Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, MALAYSIA

[2]UNIMAS Water Center, Faculty of Engineering,
Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, MALAYSIA

[3]Perunding Optima Sdn Bhd, Jalan Setia Raja, 93350 Kuching, Sarawak, MALAYSIA

[4]Department of Civil Engineering, Faculty of Science and Technology,
I-Cats University College, 93350 Kuching, Sarawak, MALAYSIA

*Corresponding Author

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Abstract: Urban stormwater runoff is contaminated with a variety of pollutants, including total suspended solids (TSS) and total phosphorus (TP), as a result of non-source pollution from transportation, residences, and businesses, as well as sediment from human activities and construction sites. These pollutants are expected to degrade the water quality in local rivers and streams, impairing the quality of marine life and contaminating drinking water supplies. This study evaluates the environmental performance of a permeable pavement system in an urban catchment using the stormwater management model (SWMM). Two pavement systems with different hydraulic designs were compared to reduce runoff, increment of groundwater storage and the environmental parameters assessments on total suspended solids (TSS) and Total Phosphorus (TP). The first system comprises a StormPav, which is the UNIMAS innovated green pavement with subsurface hollow cylindrical micro-detention pond storage of about 70% void content. The second system consists of porous concrete (PC) pavement assembled in a layered of coarse and fine particles to ensure water can infiltrate through, with about 40% void content. The environmental impact assessment was applied at Padungan Commercial Centre in the Kuching City of Malaysia. The case study simulated in low impact development (LID) sub-catchment in SWMM to obtain the runoff, infiltration and environmental quality performance. In the assessment, it was found that, for both pavement systems, higher storms at shorter duration resulted in higher reduction efficiency. The StormPav is more effective in reducing runoff, while presenting a lower value for environmental assessments in removing TSS and TP compared to PC.

Keywords: Stormwater management, StormPav, permeable pavement, SWMM, environmental assessment

Corresponding author: bnorazlina@unimas.my

1. Introduction

Urbanization is the process by which human populations are concentrated into discrete areas. Rapid urbanization has created a slew of perplexing issues, resulting in land being converted to residential, commercial, industrial, and transportation uses. Urbanization implies the danger of deadly flash floods, particularly in densely populated areas. In urban and suburban regions, stormwater runoff is a significant cause of water contamination. It entails a slew of environmental, social, and economic difficulties. Stormwater runoff occurs when rain flows over land or impermeable surfaces such as paved streets, parking lots, and building rooftops. Pollutants such as trash, chemicals, oils, and dirt/sediment are picked up by runoff and endanger rivers, streams, lakes, and coastal waterways. These pollutants have a direct effect on the quality of water.

Increases in stormwater runoff are not only an issue for water quality; they also contribute directly to urban flooding. Urban land use changes as urbanization progresses, increasing the area of impervious surfaces and, as a result, reducing infiltration during storm events and increasing direct runoff, which eventually alters urban hydrologic processes. Stormwater runoff caused by urbanization's impervious surfaces has become a significant source of water pollution, resulting in street flooding and watershed degradation. Cities are frequently the focal point of sustainability efforts, as urban initiatives and efforts determine the quest's relative success. While planning for a development project, stormwater management must strike a balance between environmental protection, economic growth, and social considerations. Stormwater management infrastructure is one strategy to enhance the water quality and mitigate flood issues. Its' encompasses both natural systems and regions of land, as well as techniques that are constructed to replicate natural systems in an urban environment and be integrated into the community, providing aesthetic as well as utilitarian benefits.

A porous urban surface composed of open-pore pavers of porous concrete, or pervious asphalt, or modular unit pavers of permeable interlocking concrete pavers (PICP), with an underlying stone reservoir is referred to as a permeable pavement (PP), are among the commonly applicable stormwater infrastructure. PP collects precipitation and surface runoff, storing it in a reservoir and gradually allowing it to infiltrate into the soil beneath or drain through a drain tile. Furthermore, the PP had also shown its benefit to remove pollutants such as total suspended solids (TSS), chemical or biochemical oxygen demand (COD/BOD), trace metals (Cd, Cr, Cu, Ni, Pb, and Zn), and various species of Nitrogen (N) and Phosphorus (P) with the removal efficiency of about 60% to 97% [1]-[5]. Parking lots, low-traffic roads, sidewalks, and driveways are the most common applications for permeable pavement.

StormPav green pavement system is a new permeable road made up of three precast concrete pieces that form a single modular unit made of Grade 50 concrete. StormPav is a novel green pavement that offers several structural, environmental, and economic benefits over impervious asphalt and concrete pavements **Error! Reference source not found.**. Due to a service inlet in the concrete to drain water, StormPav provides an alternative road design system that reduces flash floods. The system integrates permeable pavement with hollow spaces to slow the rate of clogging, attenuate the peak discharge, and enable rapid production and installation as illustrated in Fig. 1.

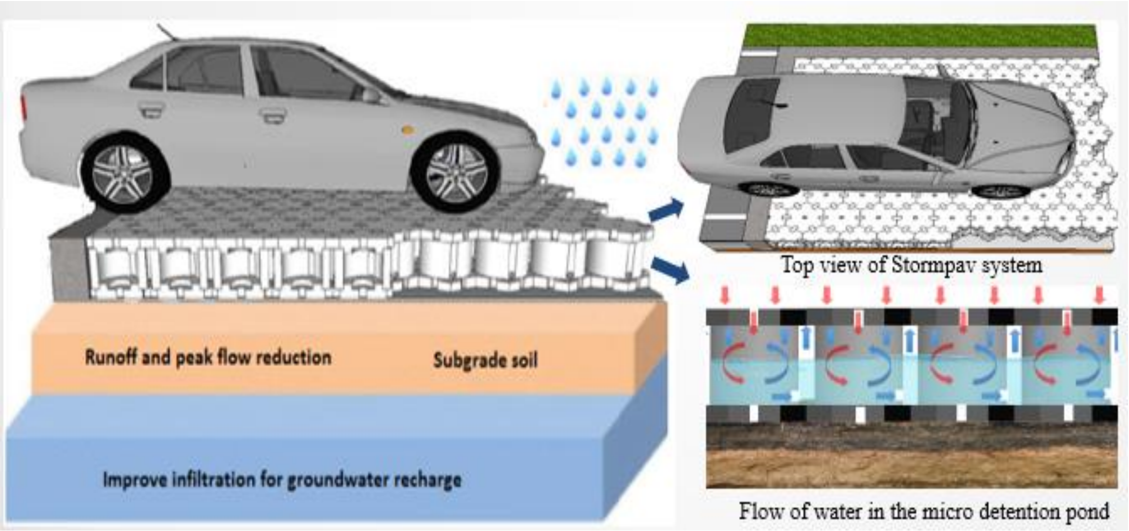
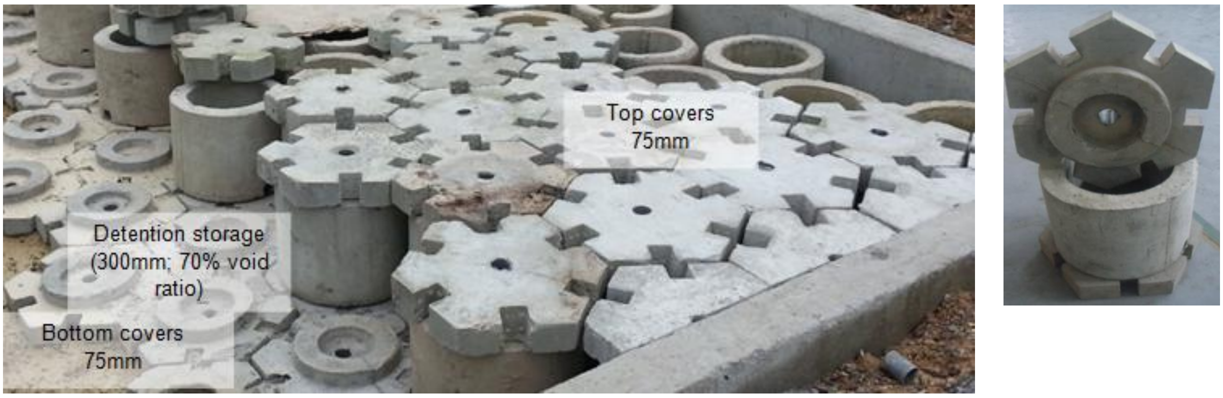
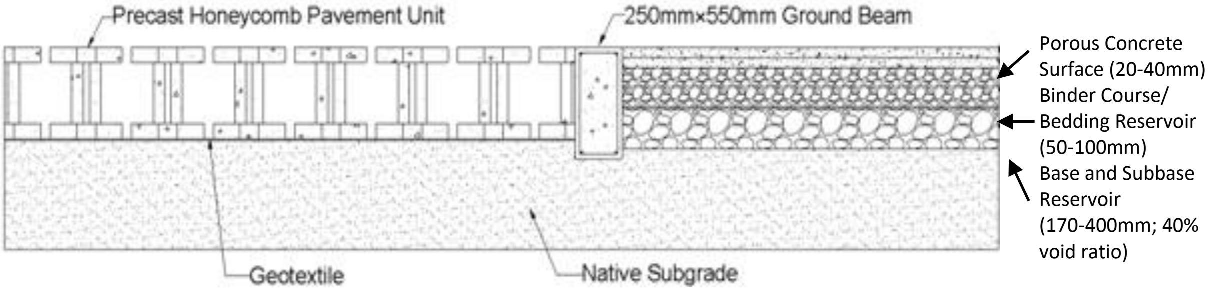


Fig. 1 - StormPav application in urban environments and horizontal and vertical flow direction to the ground

StormPav is an Industrialized Building System IBS due to the precast modular product comprise of top and bottom hexagon at 75mm thickness each, that imitate the honeycomb beehive shapes and middle part of hollow cylindrical rain barel tank of 300mm thick, Fig. 2. The hollow cylinder act as micro detention pond, that differentiate the product from other types of conventional PP, which is in layers of fine particles as shown in Fig. 2(b). StormPav products were fabricated in 2015 with a mass production in the following year, which are then tested and investigated for various structural, roadworks, hydraulics and hydrological assessments. This comprises of small-scale field, modelling and laboratory studies on the hydrological performance, hydraulics and flow regime, and structural requirements to include a determination on optimal structure materials and thickness, selection of parameters for model verification, stormwater quantity and field experiment of the water quality **Error! Reference source not found.**. The field experiments to assess the water quality, mosquito breeding capability and the infiltration rate in StormPav pavement had been investigated in **Error! Reference source not found.**. This paper aims to evaluate the environmental benefit of StormPav with comparison of other conventional PP comprise of stormwater runoff pollutant removal efficiency using software modelling, Stormwater Management Model, SWMM 5.1.



(a)



(b)

Fig. 2 - Cross section and properties of (a) StormPav, and; (b) StormPav cross section comparison to porous concrete (PC)

1.1 Stormwater Removal Efficiency of PP

Stormwater quality degradation is related to the changes of land-use due to urbanization and antecedent dry day. Land development contributes to the accumulation of contaminants on the surface of the land that can be caught by stormwater runoff due to heavy rainfall. Major disruption of soil and vegetation during construction increases erosion with increase sedimentation **Error! Reference source not found.**. Removal of permeable surface and modification of the hydraulic conveyance system, which is often related to land use alterations have adversely affected the quality of stormwater runoff. As stormwater flows through impermeable land surfaces, stormwater runoff instantly picks up natural and man-made pollutants that are accumulated during dry days and discharges them to hydraulic conveyance system **Error! Reference source not found.**. Besides, introduce physical, chemical, and biological contaminants due to various anthropogenic activities in the urban areas **Error! Reference source not found.**. In addition, vehicle maintenance consists of drips and spills of oil, coolant and other fluids from the vehicles goes to the roadway and contributes to the stormwater runoff pollution. Table 1 presents the stormwater quality degradation with pollutants loading due to urbanization and land development. From Table 1, the highest amount of pollutant loading is contributed by industrial follows by commercial area. The sources of pollutant are simplified as in Table 2 that include irresponsible human attitude of littering, soil erosion due to land development, and from the traffics and pavement roadway.

Permeable pavement is widely recognized as one of several eco-technologies, for stormwater management infrastructures that can improves the stormwater quality **Error! Reference source not found.**, **Error! Reference source not found.**. PP can reduce the concentration of some pollutants physically (by trapping them in the pavement or soil), chemically (bacteria and other microbes can degrade and consume those pollutants), or biologically (by trapping them in the pavement). Table 3 illustrates the removal efficiency of PP consists of PICP, permeable brick pavers (PBP) and PC from past studies. TSS and TP show the most reduction efficiencies about more than 50% reduction rate when compared to other types of pollutants.

Table 1 - Pollutants loadings of different types of land use collected from past studies

Land-use	Pollutants Loading		
Residential • Area: 3.34 ha • Pervious: 15% • Impervious: 75% • High-density residential area **Error! Reference source not found.**	**Parameters**	**Range (kg/ha)**	**Mean (kg/ha)**
	BOD_5	0.5 – 16.5	4.9
	COD	1.2 – 27.5	9.0
	SS	2.2 – 22	7.5
	NO_3=N	0.001 – 1.5	0.35
	NO_2=N	0.0003 – 0.01	0.004
	NH_3=N	0.013 – 1.2	0.2
	P	0.002 – 0.1	0.05
	Pb	<0.001	0.001
	Parameters	**Pollutant Load (kg/ha)**	
Residential • Area: 9.8 ha • Paved roads; 19% • Residential houses: 68% • Grass and lawns: 13% • Imperviousness: 77% • High-density	TSS	10.98	
	BOD_5	0.69	
	COD	9.38	
	NH_3-N	0.15	
	NO_3-N	0.0031	
	NO_2-N	0.002	
	P	0.10	
	Pb	0.025	
Mixed-use • Area: 41 ha • Impervious: 60% • Pervious: 40% Low density residential and low density industrial **Error! Reference source not found.**	TSS	20	
	COD	2.0	
	BOD_5	2.7	
	TP	0.4	
	Pb	0.02	
	Parameters	**Loading (kg/ha/a)**	
Commercial **Error! Reference source not found.**	TSS	240 – 1780	
	COD	45 – 650	
	TN	7.1 – 10.3	
	TP	1.3 – 2.0	
	Pb	0.04 – 2.01	
	Zn	0.65 – 2.10	
	Cu	0.16 – 0.89	
	Ni	0.09 – 0.14	
Green **Error! Reference source not found.**	TSS	13	
	COD	13	
	TN	4.3	
	TP	0.23	
	Pb	0.003	
	Zn	0.001	
	Cu	0.003	
	Ni	0	
Industrial **Error! Reference source not found.**	TSS	90 – 2100	
	COD	80 – 350	
	TN	1.9 – 10.0	
	TP	0.3 – 2.04	
	Pb	0.001 – 0.21	
	Zn	0.18 – 1.24	
	Cu	0.04 – 0.30	

Ni	0.03– 0.16

Table 2 - Sources and pollutants in urban area

Source	Pollutants	References
Road Abrasion	TSS, PAHs, Microplastics	**Error! Reference source not found.**
Pedestrian debris	TSS, hydrocarbon	
Vehicle wear tires	TSS, Cd, Cu, PAHs, Microplastics	**Error! Reference source not found.**
Littering	BPA and polybrominated diphenyl ethers (PBDEs), and metals	**Error! Reference source not found.**
Soil Erosion	TSS and TP	**Error! Reference source not found.**

Table 3 - Pollutant Removal Efficiency of PICP, PC and PBP

Type of PP	Pollutants						References
	TSS	TP	TN	Zn	Cu	Pb	
Permeable Interlocking Concrete Pavers (PICP)	70%	64%	30 - 40%	-	-	-	**Error! Reference source not found.**, **Error! Reference source not found.**
Porous Concrete (PC)	80%	50%	25%	88%- 90%	2%	30% - 47%	**Error! Reference source not found.**, **Error! Reference source not found.**
Permeable Brick Pavers, PBP	93%	71%	34%	-	-	-	**Error! Reference source not found.**

2. Methodology

The Storm Water Management Model (SWMM) of the US EPA, SWMM 5.1 was launched in 2014, after several updates to include a case study on water quality issues [22]-[24] and evaluate the environmental performance of the Stormwater Management Infrastructure **Error! Reference source not found.**, **Error! Reference source not found.**. In example, S. Gülbaz **Error! Reference source not found.** compare five pollutants parameter (Zn, Cu, Pb, TN and TP) with and without PP in the SWMM LID control. While, Chow et al. **Error! Reference source not found.** and Rezaie et al. **Error! Reference source not found.** simulate the TSS , TN and TP water quality parameters to investigate the difference on water quality with and without LID control within the sub catchment study boundary. In this study, SWMM 5.1 was used to simulate three scenarios on water quality performance comprised of existing conditions of asphalt road pavement, porous concrete (PC) and StormPav. The parameter of pollutants covers TSS and TP to evaluate the environmental performance.

The SWMM model requires numerous data layers and parameters to simulate runoff and pollutant loads in the watershed. Table 4 shows the parameters applied in the water quality and water quantity module of SWMM. By using build-up and wash-off equations, SWMM is capable of simulating pollutant distribution. It is necessary to correctly parameterize the equation for various land uses to use the full potential of SWMMM. The equations consist of three equations of build-up (power, exponential and saturation) and three equations of wash off (exponential, rating curve, and event mean concentration. The pass study frequently mentions exponential build-up and wash-off equation parameters. Therefore, this project considered only parameters of the exponential build-up and wash off equations, so the results are comparable. The equations are as follows:

$$\text{Buildup} = C_1.\left(1-\exp\left(-C_2.t\right)\right) \tag{1}$$

$$\text{Washoff } = C_3.\text{Runoff}^{C_4}.\text{Buildup} \tag{2}$$

In Eq. (1), on the left-hand side, the buildup term is the pollutant buildup in mass per unit area or unit curb length, and the number of previous dry weather days is on the right-hand side. In Eq. (2), the left-hand wash-off term is the wash-off load in the mass unit per hour, the right-hand runoff term is the runoff rate per unit area (inches/h or mm/h) and build up is the accumulation of contaminants in total mass units. C1 is the maximum potential buildup (mass per unit area or unit curb length), C2 is the constant buildup rate regulating pollutant speed of pollutant build-up (1/days), C3 is the wash off coefficient, and C4 is the wash off exponent. Table 4 shows the exponential functions for this case study. The pollutant removal efficiency of each permeable pavement is determined by comparing pollutant load with and without LID Practice implementation. Table 5 illustrates the two Low Impact Development (LID) case scenarios in this study, StormPav and Porous Concrete (PC).

Table 4 – TSS and TP parameters input in LID SWMM

Parameter	B_{min}	B_{exp}	W_c	W_{exp}
TSS	15	0.8	1.4	0.9
TP	0.5	0.1	0.4	1

Table 5 – PC and StormPav properties input in LID SWMM

Pavement Types	Surface Layer	Surface Thickness (mm)	Surface Void Ratio	Impervious Surface Fraction	Permeability (mm/hr)	Reservoir Storage Thickness	Void Ratio
PC	933	80	0.15	0.85	200	300	0.4
StormPav	1.6/unit	75	0.11	0.88	220	300	0.7

The study area is at Padungan, Kuching, Sarawak (Fig. 3). The area is a commercial business center consists of shophouses, pubs and restaurants, as well as an open market selling fruits and flowers. The continuous development causes stormwater runoff pollution to carry considerable quantities of pollution. The study site is kept within two rows of shophouses only where the StormPav is applied in the backstreet behind the shophouses due to low traffic activities.

Fig. 3 - Study area, Padungan commercial centre and stormwater runoff at the outlet drainage [40]

The rainfall data were obtained from Hydrological Procedure (HP) 26, Department of Irrigation and Drainage, Sarawak, Malaysia and then used to construct the intensity–duration–frequency (IDF) curves for the area. The analysis is performed for various types of rainfall intensities of 2 and 10 yrs average recurrence interval (ARI) with duration of 15 minutes and 1 hour as shown in Table 6. The return period of 2 yrs and 10 yrs were chosen because permeable pavements are only effective at reducing pollutants for low rainfall depths and intensities following Chow et al. [23], that conventional permeable pavements are unable to handle the surcharge amount of runoff in urban areas for return periods of more than 10 years and rainfall depth amounting to 90 mm.

Table 6 - Design Storm for 2-yr and 10-yr return period

Intensity (mm/hr)	Depth (mm)	Return Period (yr)	Duration (hr)
155.11	38.78	2	0.25
64.1	64.1	2	1
164.04	41.01	10	0.25
87.45	87.45	10	1

3. Results

The LID control in SWMM model simulation is used to evaluate the performance of StormPav pollutant removal efficiency at Padungan, Kuching, Sarawak, Malaysia.

3.1 Sources of Pollution

Fig. 4 illustrates the various factors that have contributed to the pollution observed at Padungan Commercial Centre. The sources of pollution are primarily attributed to anthropogenic activities, which result in contamination through mechanisms such as soil erosion, improper waste disposal, road abrasion, pedestrian debris, and tire wear from vehicular traffic. Littering exhibits the most significant proportion, approximately 40%, whereas road abrasion and vehicle tire wear account for approximately 25% and 20%, respectively. In contrast, the factors of pedestrian debris and soil erosion are responsible for a maximum of 10% of the overall impact. The findings are in agreement with **Error! Reference source not found.**, littering has been identified as the cause of approximately 60% of water pollution. It releases decomposes of chemicals and microparticles, which are not native to the environment and a variety of issue such as a cigarette butt. The cigarette butts contain toxins of arsenic and formaldehyde that can enter the soil and freshwater sources, affecting both humans and animals.

Next, is the road abrasion and vehicle wear tires. Road covers approximately 40% of the sub catchment. Road abrasion is a significant source of particles of TSS **Error! Reference source not found.**, PAHs **Error! Reference source not found.**, and microplastics **Error! Reference source not found.**. The abrasion process is enhanced by the use of studded tyres and grit in road maintenance. Vehicle tyres grind grit particles on the pavement, producing fine particles that can be washed away or integrated into pavement pores **Error! Reference source not found.**. Microplastics may be derived from bitumen used in road pavement construction as well as road marking paints.

Traffic-related pollution is heavily influenced by factors such as traffic intensity (ADT) and composition (i.e., passenger cars vs. trucks), driving patterns such as speed and brake use, and pavement type. For example, the rate of brake wear is heavily influenced by the composition of the brake lining as well as the manner of driving in which the brakes are applied **Error! Reference source not found.**. Several investigations, as summarised by Loganathan et al. **Error! Reference source not found.**, revealed that sediments deposited on road portions with high braking, accelerating, and decelerating activity included higher metal concentrations than other areas along the road. Huber et al. **Error! Reference source not found.** determined that roads with high annual ADT have the highest metal runoff concentrations due to braking and acceleration activity at traffic signals. According to the same research study, concentrations in parking lot runoff varied greatly depending on the principal use of the parking lot (i.e., the frequency of entrances and departures, the presence of heavy vehicles, and so on). In agreement, Revitt et al. **Error! Reference source not found.** mentioned that a rougher surface in car park areas, as well as pavement abrasion from higher frequency of vehicle stopping and starting, would result in larger sized particles discharged from the pavement. Increased speed and traffic density were found to increase pollutant concentrations in road dust, owing to higher exhaust emissions and increased road abrasion **Error! Reference source not found.**, with vehicle speed being more influential than traffic density **Error! Reference source not found.**. Increased motor activity also contributed to greater PAH concentrations in runoff **Error! Reference source not found.**. On the other hand, metal concentrations in road dust were higher for concrete highway pavements than for asphalt-concrete combinations, owing to stronger abrasion in the former instance **Error! Reference source not found.**.

Finally, pedestrian debris, contributed to approximately 10% of the runoff pollutions especially solid contaminants such as TSS. Despite soil erosion being responsible for a relatively small proportion (5%) of runoff pollution in this region, its environmental impact remains observable. This is due to the fact that commercial centers are unlikely to experience significant soil erosion. Soil erosion is a common occurrence in the event of heavy precipitation. First, the water begins to dissolve the soil, scattering the components of its constituent elements. Rainwater runoff usually affects lighter materials like silt, organic debris, and finer sand particles, but under heavy rain, it can also affect larger particles. Soil erosion usually has a negative impact on plant development, agricultural productivity, water quality, and recreation **Error! Reference source not found.**. Severe soil erosion that results in excessive silt export to rivers or reservoirs through stormwater runoff causes life disturbances in water bodies as well as a reduction in environmental quality.

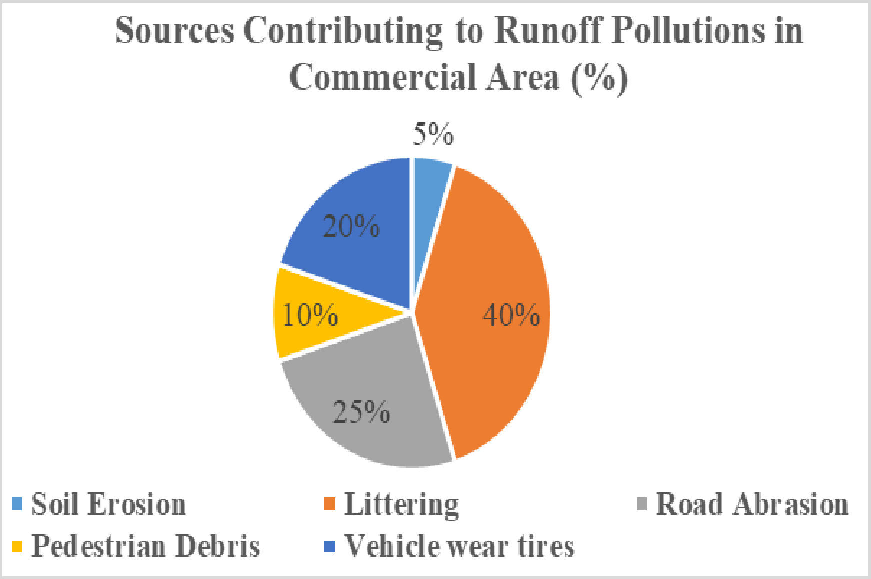
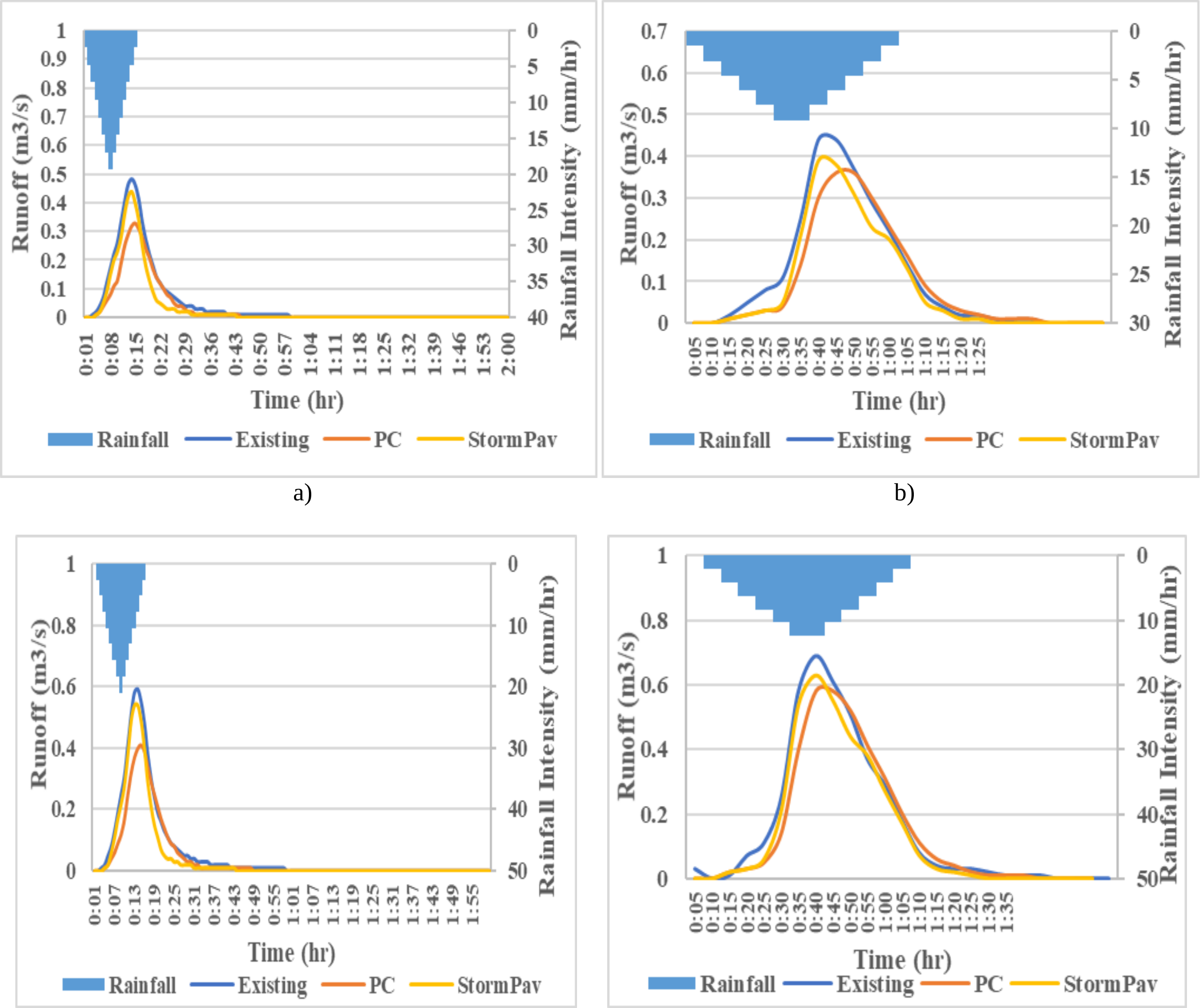


Fig. 4 - Percentage of Non source pollution in Padungan commercial centres

3.2 Runoff Reduction and Pollutant Removal Efficiency of PC and StormPav

In this study, various storm events were simulated for three different scenarios comprising of existing condition (typical impermeable concrete road of asphalt road pavement), porous concrete (PC) and StormPav using SWMM. Fig. 5 illustrates the runoff responses of porous concrete (PC) and StormPav for four different rainfall events. Both StormPav and PC managed to reduce the peak flow rate of the runoff. Fig. 5(a) and Fig. 5(c) demonstrate that the emergence of runoff in stormwater passing through PC and StormPav is observed at approximately 4 minutes following the onset of rainfall, whereas in the current state, runoff is detected at 3 minutes after the commencement of rainfall. Fig. 5(b) and Fig. 5(d) demonstrate that the runoff is observed at approximately 12 minutes following the onset of rainfall, whereas for the current state, the runoff is detected one minute earlier. The findings indicate that Stormpav and PC possess the capability to retard the onset of runoff by an estimated duration of one minute through the uninterrupted assimilation of stormwater via the interstitial voids within the pavement stratum, subsequently allowing the stormwater to percolate into the underlying storage system. The phenomenon of runoff occurs after the saturation of all available spaces by precipitation. The efficiencies for PC and StormPav are higher during small storm events with volume below

50mm. The efficiency decreased from 33% to 14% for PC and 16% to 8% for StormPav as the rainfall volume increased from 38.78 mm to 87.45 mm. PC is better at reducing peak runoff compared to StormPav for all rainfall events.



a)

b)

c)

d)

Fig. 5 – The runoff responses at 2 and 10 yrs ARI: (a) Runoff responses for 15 min, 2 yr storm event; (b) runoff responses for 1 hr, 2 yr storm event; (c) runoff responses for 15 min, 10 yr storm event, and; (d) runoff responses for 1 hr, 10 yr storm event

Table 7 presents that, the implementation of porous concrete (PC) and StormPav resulted in a reduction of runoff by as much as 40% for rainfall depths of 64.1 mm and 41.01 mm, respectively. The runoff reduction efficiency of the two LID controls exhibited a decrease of less than 40% when subjected to volumes or depths exceeding 50mm. This finding indicates that as the duration and return period increase, the effectiveness of reduction decreases. The hydrological response of PC and StormPav was observed to be more effective in reducing runoff during a 15-minute rainfall event with a 2-year return period, as compared to a 1-hour rainfall event with the same return period. In order to quantify this viewpoint, it was observed that PC and StormPav, both of which encountered a 15-minute precipitation event with a recurrence interval of 2 years, exhibited a runoff reduction of 56% and 49%, respectively. The permeable pavements exhibited a reduction in efficiency to 29% and 37%, respectively, in response to an increase in rainfall duration from 15 minutes to 1 hour. The observed pattern exhibits similarity over a 10-year period. In comparing the return periods, it was observed that the LID controls exhibited a greater reduction in runoff for a 2-year return period of 15 minutes as opposed to a 10-year return period of the same rainfall duration. The results indicate that PC and StormPav exhibited runoff reduction efficiencies of 56% and 49%, respectively, when subjected to a 15-minute rainfall event with a 2-year return period. For a 10-year return period of rainfall, the PC and StormPav exhibited reduced efficiency levels of 49% and 44%, respectively. The pattern remains consistent for durations of one hour. As the depth of rainfall increased, the effectiveness of the permeable pavements declined. The efficiency of both the PC and StormPav experienced a decline from 56% to 20% and 49% to 25%, respectively, with an increase in the volume of rainfall from 38.78 mm to 87.45 mm. In both instances, there was a notable decrease in productivity observed during instances of more substantial storm occurrences. The reason for this phenomenon is that as the depth of rainfall intensifies, the pavement layer composed of PC and StormPav may become excessively saturated with water, leading to surface flooding. This, in turn, results in the complete filling up of the void spaces between the layers, thereby impeding the infiltration of excess runoff into the pavement layer. This phenomenon may occur in cases where the infiltration rate of the uppermost layer is less than the intensity of the rainfall. In such scenarios, the capacity of permeable pavements to absorb stormwater may become compromised, despite the fact that the underlying stratum remains unfilled [37]. The findings suggested that the minimum reduction efficiency for both scenarios was observed at a precipitation magnitude of 87.45 mm.

Table 7 - Summary of runoff removal efficiency

Intensity (mm/hr)	Depth (mm)	Return Period (yr)	Duration (hr)	PC (%)	StormPav (%)
155.11	38.78	2	0.25	56.58	49.98
64.1	64.1	2	1	29.65	37.23
164.04	41.01	10	0.25	49.96	44.78
87.45	87.45	10	1	20.09	25.10

Table 8 shows the pollutants removal efficiency for PC and StormPav. It can be observed that as rainfall intensity increased, the pollutant removal efficiency decreased. For Porous concrete (PC), the TSS removal efficiency decreased from 99% to 98% as intensity increased from 64.1 mm/hr to 164.04 mm/hr while the TP removal efficiency decreased from 98% to 91%. StormPav showed the same trend that as the rainfall intensities increased, the TSS and TP removal efficiency reduced from 99% to 63% and 87% to 45% respectively. The change in pollutant removal effectiveness over time is primarily influenced by the intensity of rainfall and the nature of the rainwater pollutants. The permeable pavement relies mostly on pollution removal and adsorption and has little biological effects in a short period of time. Permeable pavement will continue to capture pollutants in internal water as rainfall intensity rises. Pollutants will accumulate on permeable pavement; as rainfall intensity increases, some pollutants will be washed away; as the concentration of pollutants in the water permeable pavement increases, the removal rate decreases **Error! Reference source not found.**. The permeable pavement will continually intercept pollutants as rainfall intensity increases. Some pollutants will be washed out as a result of the constant rainfall, and the rate of pollution removal will decrease. This is in accordance with **Error! Reference source not found.**, where for low and high rainfall intensities, the pollutant load removal performances of permeable pavements for TSS and TP all dropped as the intensity of the rainfall rose. The other reason could be as the intensity of the rainfall increased, the permeable pavements became quickly saturated, giving pollutants less time to enter, adsorb, and retain, resulting in insufficiency of the pollutant removing process in the permeable pavements. Meanwhile more particles were trapped on the surface of the permeable pavements during lower intensity rainfalls, resulting in high removal efficiencies for TSS and sediment-associated components.

Table 8 - TSS and TP removal efficiency for PC and StormPav

Intensity (mm/hr)	Depth (mm)	Porous Concrete		StormPav	
		TSS (%)	TP (%)	TSS (%)	TP (%)
155.11	38.78	98.18	91.72	65.12	47.93
64.1	64.1	99.95	98.18	99.33	87.88
164.04	41.01	98.23	92.40	63.52	45.61
87.45	87.45	99.87	97.60	97.60	83.23

At low rainfall intensity, both PC and StormPav had a high TSS removal efficiency of 99% each while 98% and 87% respectively for TP removal efficiency. However, as the rainfall intensity increased, StormPav saw a huge decline in efficiency, reducing as low as 63% for TSS and 45% for TP while the PC remained consistent with only a slight drop in efficiency despite the increase of rainfall intensity. PC performed better at reducing pollutants compared to StormPav. This is due to the fact that the porous concrete is designed in layer to provide the removal benefit and slowly trapping the pollutants through the permeable pavement materials compared to StormPav that is design in hollow cylindrical of rain barrel shaped, suited for detention pond storage.

4. Conclusion

StormPav provides stormwater management characteristics in environmental aspects. The water quality modelling in SWMM 5.1 shows the reduction of runoff and pollution removal from StormPav. The system allows water to store the micro detention storage to slowly reduce the peak flow runoff as well as trapping the pollutants in the hollow cylindrical set. Besides, the system provides the pollutants removal of the stormwater runoff through the design innovation by providing the reservoir to collect the pollutant rather than releasing it to the conveyance system. Significant achievement in environmental preservation is contributed through the stormwater collection in detention storage and the stormwater pollutant control of the hollow submerged part of the system. This research can be further extended to include the sediment accumulation in the system for clogging investigation. The rate of clogging will affect the effectiveness of the permeable pavement service life.

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