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ENVIRONMENTAL ASSESSMENT OF STORMPAV GREEN PAVEMENT FOR STORMWATER MANAGEMENT

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Abstract: This study evaluates the stormwater management potential of a green pavement technology for permeable road pavement with subsurface micro-detention storage (StormPav) from a water quality perspective. The system provides integration of permeable pavement with hollow spaces to attenuate peak discharge with design installation using precast products. The environmental assessment was gathered from field experiments to assess the water quality, mosquito breeding capability and infiltration rate in the StormPav. The water quality parameters were determined to assess environmental benefits, which are one of the components of sustainable development. The parameters consist of total suspended solids, pH and alkalinity and they showed identical results to other permeable pavement types. Larvae development was found as early as eight days in stagnant water in the cylindrical hollow section of StormPav. However, the StormPav showed a high permeability rate within 122.45 mm/hr to 168.12 mm/hr at subgrade soil of HSG A soils group with no stagnant water retained in the void section in less than two hours, which nullified the required retention time for larvae development. Hence, StormPav displayed a significant benefit in terms of environmental concern for a sustainable design invention in stormwater management with the presence of subsurface detention storage.

Keywords: Sustainability, permeable pavement, detention pond, stormwater management, environmental.

Introduction

Rapid growth through urban development introduced more impermeable areas as well as a notable reduction of infiltration, groundwater depletion and increment of peak runoff. Therefore, urban growth leads to an increase in sediment and nutrients in water bodies (Osman *et al.,* 2020). Urban runoff is considered to be a significant source of water pollution (Shen *et al.,* 2020) with waste in water resources coming from domestic, commercial, industrial and transportation sources (Czemiel Berndtsson, 2010). It can affect the environment chemically, physically and biologically; hence, contributing to environmental degradation and health risks (Park *et al.,* 2013). Reducing the transport of nutrients to watersheds is important for water pollution control (Osman *et al.,* 2020) towards sustainable urban development. Contaminants in water can affect water quality and consequently, human health. Polluted water is related to disease outbreaks such as diarrhoea, dysentery, cholera, typhoid and guinea worm infection (World Health Organisation [WHO], 2012).

Stormwater management is important in balancing economic growth, social element and environmental protection. One of the major control-at-source measures in stormwater management is the application of green infrastructure. Permeable pavement has been a major consideration in the practice of stormwater management (Scholz, 2013). It is a green approach to the collection, storage, treatment and reuse of stormwater runoff (Imran *et al.,* 2013). Permeable pavement showed a significant achievement in control stormwater pollutions. Studies found a reduction of the pollution build-up consisting of total suspended solids (TSS) of between 28% and 73%, total nitrogen of between 32% and 60%, total phosphorus of between 47% and 60% and heavy metal, including Cd, Cu and Pb, of between 7% and 60% (Bean *et al.,* 2004; Brown *et al.,* 2009; Myers *et al.,* 2011; Beecham *et al.,* 2012). A study showed an improvement of 80% in the removal efficiency of TSS (Selbig & Buer, 2018) and up to 90% of TSS (Li *et al.,* 2017). A study by Myers *et al.* (2009) examined *Escherichia coli* (*E. coli*) survival characteristics in PP base courses, using mineral aggregates (dolomites and calcites) and found significant pathogen depletion rates. Imran *et al.* (2013) conducted a study on faecal matter effects in runoff and the rehabilitation process in permeable pavement and found that the removal rates were 87% for COD and 50% to 90% for BOD.

This paper investigates the performance of a modified permeable pavement with subsurface micro detention storage, StormPav for environmental performance. The StormPav is an innovative product of an on-site micro-detention pond with machine-made concrete blocks. Full-scale studies are vital to ensure that the product is a better alternative for green infrastructure. Previous studies investigated the structural (strength and durability), hydrological performance and hydraulic design of the product as reviewed by Bateni *et al.* (2021). However, the environmental and water quality performances have yet to be explored. Therefore, this study presents the investigation of the environmental evaluation encompassing water quality and health and safety issues, in particular the possibility of mosquito breeding in the micro detention pond storage. The environmental performance was assessed through the experimental study of StormPav with the following objectives, to investigate the parameters and performance in the environmental consideration, comprising water quality parameters, permeability rate and potential of mosquito breeding.

Materials and Methods

Data for this study were obtained from field and laboratory experiments. The methods of study are depicted in Figure 1. Firstly, the water quality parameters in the StormPav were investigated. Water quality parameters can be classified into three categories; physical, chemical and biological (WHO, 2008). In this study, only the physicochemical properties were analysed. Secondly, mosquito breeding and growth was conducted in standing and stagnant water conditions, an environment assumed to be suitable for the breeding process. Finally, a permeability test was conducted for the StormPav.

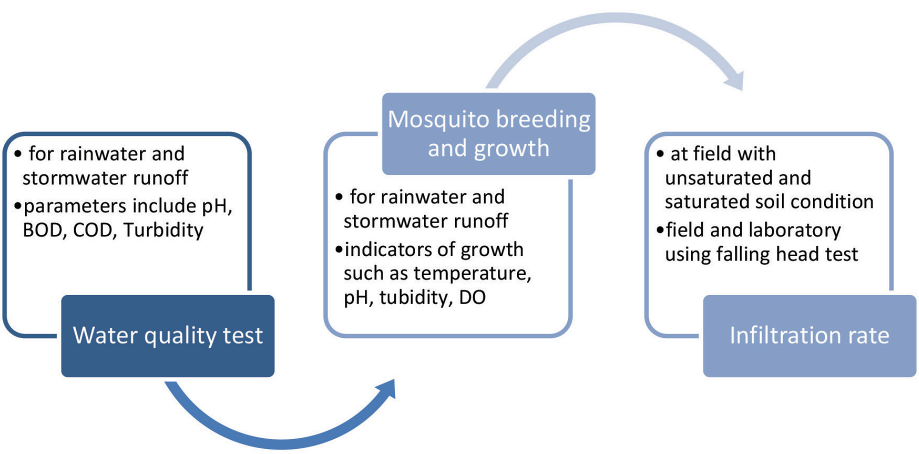

Figure 1: Framework of research method

StormPav Green Pavement

Figure 2 illustrates the StormPav precast structure with dual functions, as road pavement and a subsurface micro detention pond for rainwater storage, an innovative green pavement that provides structural, environmental and economic benefits compared with impermeable asphalt and concrete flooring (Putri *et al.,* 2020). Bateni *et al.* (2019) listed further benefits of StormPav in comparison with conventional types of permeable pavements. The StormPav was a revolutionary product for on-site micro-detention ponds (Yau *et al.,* 2014; Mah *et al.,* 2018; Bateni *et al.,* 2020) with machine-made concrete blocks arranged in sandwiches consisting of three precast concrete parts; top and bottom hexagonal plate and cylindrical hollow section to form a single unit of StormPav (Liow *et al.,* 2019; Yau *et al.,* 2020). The system was built on flat subgrade soil and dry-stacked into an interlocking paver, which provided structural strength, durability and permeability benefits for stormwater management. A lightweight precast honeycomb was also used as a micro-scale detention pond to allow rainfall to percolate down and eventually reach an underlying reservoir. This phenomenon improves groundwater recharge and decreases surface runoff.

Sample Collection

Parameters such as pH, acidity and alkalinity, TSS, chemical oxygen demand (COD), biochemical oxygen demand (BOD), turbidity and conductivity were analysed for each water sample collected in the StormPav to include rainwater and stormwater runoffs. The testing standard was based on the Standard Methods for the Examination of Water and Wastewater, 23rd edition (Baird *et al.,* 2017). The data gathered from each parameter were compared with the standard values set by the WHO and local standards such as National Drinking Water Quality Standard (NDWQS) and other permeable pavements.

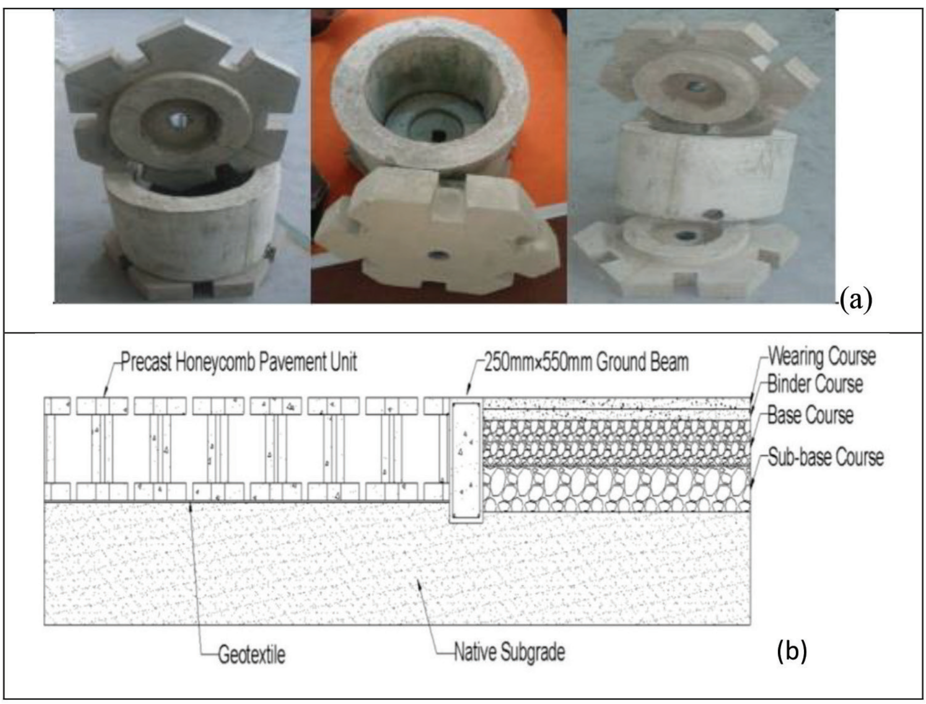

Figure 2: (a) The StormPav green pavement system and (b) comparison of a cross-section of StormPav at the left-hand side and conventional permeable pavement at the right-hand side (Bateni *et al.,* 2021)

Mosquito Growth in StormPav

The StormPav has a net empty space of 0.19 m^3/m^2 in its cylindrical unit and spacing between other StormPav units. Thereby, dirt and debris coming from vehicles will potentially enter the hollow submerged side of the StormPav and provide an ideal situation for mosquitoes to hide while standing water would provide an ideal spot for mosquito breeding. Any standing water such as in flower pots, plants, open containers, open sewer systems, sewer surfaces and trash cans pose a major threat to the population. Mosquitoes are a vector of a variety of arboviruses, including yellow fever virus, bancroftian filariasis, Plasmodium species and turkey pox (Nwoke *et al.,* 2010). Mosquito species differ according to their type of aquatic habitats, based on their location, physicochemical condition and the presence of possible predators (Shililu *et al.,* 2003; Piyaratnea *et al.,* 2005). Although their behaviour and habits are different, they have one thing in common — they need water to hatch. Moreover, the tropical and humid climate conditions in Malaysia, with summer and rainy seasons, create ideal breeding conditions for mosquitoes. Most mosquito eggs hatch within 24 to 72 hours after contact with water. As soon as the eggs hatch, the larvae will appear. The larvae develop for 7 to 10 days before reaching the pupal stage. Mosquito larvae can survive in the water for 4 to 14 days or more, depending on the water temperature. The pupae do not feed, but they spend most of their time in water. The pupal stage lasts for one to three days before the emergence of adult mosquitoes. Bayoh and Lindsay (2003) reported that mosquito larvae required 9.8 to 23.3 days to mature into adults, depending on the temperature. Another laboratory study examined the interval between oviposition and pupation and found that it ranged from 7 to 27 days.

Two StormPav were set to breed the mosquito as shown in Figure 3, using two types of water samples, the rainwater and stormwater runoffs (Figure 3 (b)). Four physicochemical parameters (water temperature, dissolved oxygen [DO], turbidity and pH) were evaluated in this experiment to assess their relationship with mosquito growth. The temperature of the water sample was measured twice a week until the larvae developed (Figure 3 (c)). For each sampling, 200 ml of water was collected from both water samples, using a standard dipper from the sites, where the mosquito larvae were sampled. The water samples were returned to the laboratory for immediate analysis (Figure 3 (d)). In this experiment, the assumptions taken into consideration were that infiltration did not take place, the stormwater was in a stagnant state in the StormPav cylinder and the stormwater was provided in the clear pail to inspect a clear image of mosquito breeding.

Infiltration Rate

The infiltration rate testing on StormPav was performed to simulate a continuous surface runoff situation in the field as shown in Figure 4 (a). The StormPav cylindrical unit was filled in with water to a depth of 25 mm which is equivalent to 14 L of water. The time, depth and duration were measured and recorded. The testing was performed in dry and submerged conditions. The infiltration rate in mm/hour was determined

(a) (b) (c) (d)

Figure 3: Mosquito growth experiment

by dividing the amount of water infiltrated (mm) by the time interval (hour) recorded. Next, the falling head test was carried out at the laboratory as shown in Figure 4 (b). The soil was taken near the StormPav field experiment. Then, the soil sample was submerged for at least one day to make sure the soil was in a saturated condition before the falling head test was performed. In addition, the soil classification test by particle size analysis was also conducted based on soil type.

Results and Discussion

Data from the experimental study was analysed and further discussed in terms of water quality performance, infiltration rate capability and the relationship with mosquito reproduction in the StormPav system.

Water Quality Results

The results involving water quality parameters are shown in Table 1. Water samples from the StormPav showed that the rainwater contained 40 mg/L of suspended solids, while stormwater runoff contained 68 mg/L of suspended solids. The average pH for rainwater and stormwater were 6.6 and 7.6, respectively. This indicated that the rainwater was slightly acidic than the stormwater water runoff. Next is the acidity in the water sample by observing the $CaCO_3$ value. The $CaCO_3$ of rainwater was 38 mg/L while the stormwater was 54 mg/L which required more neutralisers to react with. The alkalinity, meanwhile, showed a lower value at 8 mg/L for both water types. The BOD was slightly lower in rainwater compared with stormwater runoff at 0.97 mg/L and 1.13 mg/L, respectively. A higher BOD means that the water was more polluted with more organic matter and bacteria working to decompose the waste. The COD value in the rainwater sample was 20 mg/L while the stormwater runoff was at 32 mg/L. A COD value of below 25 mg/L require extensive treatment as the amount of oxygen reduction was considered high and is harmful towards higher aquatic life forms. The optimum dosage of coagulant required to remove the turbidity of the water sample taken from the StormPav was also determined. The turbidity for rainwater was 0.94 NTU while for stormwater runoff, it was 1.78 NTU. The results were simplified using the

Figure 4: Infiltration rate test, (a) field experiment and (b) falling head laboratory experiment

Water Quality Index (WQI) to determine their water quality standard. From Table 1, the WQI obtained from the StormPav is Class III with a rating of about 66% on average, indicating that the stormwater was slightly polluted and unsuitable for human consumption without treatment. The StormPav was also compared to studies by Drake (2013) which consist of Permeable Interlocking Concrete Pavement such as AquaPave® and Eco-Optiloc®, pervious concrete and traditional asphalt. The results were in the range of other permeable pavement types, which shows the significant environmental benefit of the StormPav.

Mosquito Breeding

Table 2 summarises the physicochemical composition of the water sample in the mosquito breeding experiment. The stormwater runoff recorded a lower pH range, higher turbidity and DO value, indicating that it was more polluted compared with the rainwater. Larvae developed at day 8 and day 15 in the stormwater runoff and rainwater, respectively (Figure 5). The differences in the larvae development rate suggested different physicochemical characteristics of the water samples. In this study, temperature was recorded twice a week for both water samples and their values were found to be similar for both water samples during the sampling process. The temperature recorded were in the range of 26^{o}C to 34^{o}C throughout the experiment and the pH of both water samples were almost similar. However, stormwater runoff averaged at 6.93 while rainwater sample averaged at 7.23. This may have a slight contribution to the breeding conditions

Table 1: Physicochemical parameters of water samples in the StormPav and its comparison with other permeable pavement types

Parameters	Rainwater	Stormwater Runoff	NDWQS Class; Limits	WHO Limits	ASH	AP	EO	PC
pH	6.64	7.62	IIA,I;6.5-8.5	6.5-9.2	7.4-8.1	7.8-9.7	7.8-9.4	8.1-12
Alkalinity (mg/L $CaCO_3$)	38	54	-	-	17-95	49-164	58-150	93-421
Acidity (mg/L $CaCO_3$)	8	8	-	-	-	-	-	
Total Suspended Solid (mg/L)	40	68	IIB,III;-	25	12-313	3-34	3-45	1.3-101
Dissolved Oxygen (mg/L)	5.54 (67%)	6.30 (76%)	III,IIB;1000	1000	-	-	-	-
Biochemical Oxygen Demand (mg/L)	0.97	1.13	I,IIA;-	-	-	-	-	-
Chemical Oxygen Demand (mg/L)	20	32	IIB,III;-	10	-	-	-	-
Turbidity (NTU)	0.94	1.78	I;-	5	-	-	-	-

as mosquitoes prefer to breed in water that is slightly acidic compared with alkaline water (Hemme *et al.,* 2009). The turbidity value was higher in the stormwater runoff at 4.52 NTU compared with only 2.10 NTU in the rainwater. Turbid water serves as an ideal environment for mosquito larvae, compared with clear water (Paaijmans *et al.,* 2008; Ibrahim Elmalih *et al.,* 2018). In the rainwater, the DO level was lower at 5.54 and about 6.30 for the stormwater runoff. These results were supported by Silberbush *et al.* (2015) where lower DO leads to a decrease in the survival rate of mosquito larvae, but an increase in the development time.

Infiltration Rate

The infiltration rate was investigated in both the field and laboratory. Based on the particle size analysis, the soil was classified as well-graded sand with less than 15% gravel. A sand-type soil is classified under group A in the hydrological soil group to include deep sand with very little silt and clay. Figure 6 (a) depicts the infiltration rate at dry soil and saturated condition. The results show a higher infiltration rate at dry soil compared with saturated soil. In the studies by Mangala *et al.* (2016) and Sihag *et al.* (2017), the infiltration rate capacity of soil decreased after a period of time as the soil became water-saturated. From Figure 6 (a), the average infiltration rate decreased from 181.82 mm/hr on dry soil to 122.45 mm/hr on saturated soil. Figure 6 (b) shows the results obtained from the falling head permeability laboratory test and its comparison to the field test. The falling head method showed a permeability measurement higher than the field test in the StormPav. The average permeability rate calculated in the falling head test was 168.12 mm/hr while the field test on saturated soil, the permeability was measured at 122.45 mm/hr. The difference was less than 20%, which is acceptable. The infiltration rates measurements obtained using the falling head method were usually higher than those obtained during field tests due to the difference in the principles of measurement (Li *et al.,* 2013; Qin *et al.,* 2015; Valeo & Gupta, 2018). The differences between the constant head and falling head methods were subjected to the incorporation of the pavement thickness into the falling head calculation. The falling head method calculated a saturated hydraulic conductivity that assumed water was not free-flowing into the pavement, which requires the thickness value of the pavement layer (Li *et al.,* 2013). In this study, the pavement was not saturated and water was free-flowing. Therefore, the use of the full pavement thickness in the calculation may

Table 2: Physicochemical parameters of water samples in the StormPav

Parameters	Temperature (ºC)	pH	Turbidity (NTU)	Dissolved Oxygen (DO)	Larvae Development (days)
Rainwater	26-34	7.23	2.10	5.54	15
Stormwater runoff	26-34	6.93	4.52	6.30	8

Figure 5: Larvae development, (a) at day 8 and (b) adult mosquito

skew the measurement. The resulted infiltration rate rests in group A soil, which was within the typical range of permeability of sandy soil, where the runoff potential was moderately low. The result is in agreement with Bateni *et al.* (2021), in which the StormPav can use subgrade soil of hydrologic soil groups (HSG) A and B to control the flood for rainfall events of 10-year ARI by providing a detention duration within 24 to 72 hours.

The findings revealed that the proposed StormPav exhibited its potential to immediately transmit and bypass water into the soil in less than two hours to infiltrate 14 L of water. The StormPav can fully release and discharge the inflow water with none retained in the system within 66 minutes in dry soil and 98 minutes in saturated soil. Nonetheless, the duration of water infiltration in the StormPav detention storage area relied on the infiltration capabilities of subgrade soils. The result is supported by Zhang (2006) where the infiltration depended heavily on soil conditions. This study showed that the StormPav provided a high permeability rate and bypasses water immediately to the ground with sand as subgrade soil. Sandy soils were known to have a high permeability rate, which resulted in a high infiltration rate and good drainage. Furthermore, the high permeability rate of HSG soil groups A and B may result in no potential growth of mosquitoes as the duration mosquito larvae took about eight days to develop.

Conclusion

The StormPav green pavement with sustainability characteristics has shown that it can play a significant role in stormwater management, allowing the system to be incorporated into green infrastructure to preserve environmental sustainability while reducing the occurrences of disasters. Environmental preservation can be achieved through pollutant control, optimal stormwater collection and prevention of any biodiversity in the hollow submerged side of the system. The water quality experiment showed that runoff from the StormPav was not suitable for secondary use. Experiments on the effect of water quality on the rate of mosquito breeding in stagnant water found that mosquito breeding was possible in the hollow section of the system. The ecological parameters observed in this study indicated that the mosquitoes exhibit concerning physicochemical nature of the environment. The mosquitoes were examined to be able to develop in high turbidity and high dissolved oxygen content with slightly acidic pH environment. However, from the infiltration rate test, the StormPav showed a high permeability rate and bypass water immediately to the ground. Therefore, no potential for mosquito growth would be expected in the examined soil conditions. This research can be further extended with different types of soil as subgrade at field experiments. The infiltration capacity of the on-site native soil has a considerable impact on the subgrade reservoir capacity, hence affecting

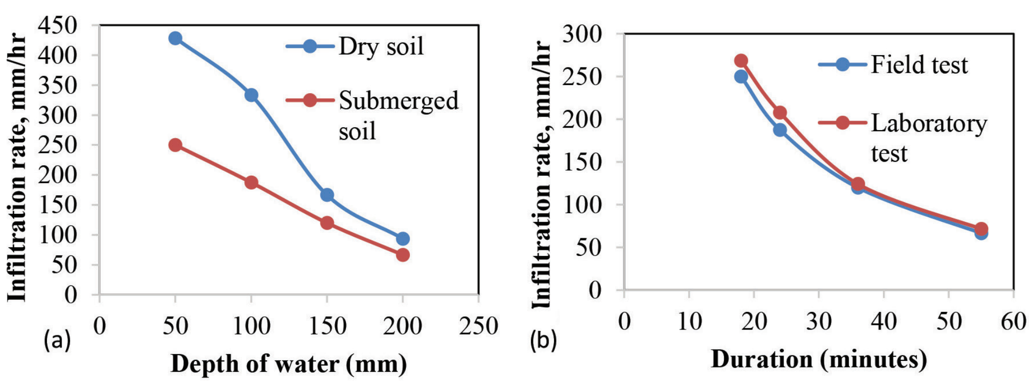

Figure 6: Infiltration rate (a) field test at dry and saturated conditions and (b) comparison on the infiltration rates at the field (saturated soil) and laboratory

the effectiveness of the StormPav. On the other hand, the rate of sedimentation and fine particles accumulation in the hollow section of the StormPav should also be considered to ensure the effectiveness of the system in Malaysia's climate.

References

Baird, R. B., Eaton, A. D., & Rice, E. W. (2017). *Standard methods for the examination of water and wastewater*. (L. L. Bridgewater, Ed.) *American Public Health Association, American Water Works Association & Water Environment Federation* (23rd ed.). Washington DC: American Public Health association, American Water Works Association & Water Environment Federation. http://doi.org/10.1016/B978-0-12-382165-2.00237-3

Bateni, N., Lai, S. H., Ahmad Bustami, R., Mannan, M. A., & Mah, D. Y. S. (2021). A review on green pavement hydrological design and recommended permeable pavement with detention storage. *IOP Conference Series: Materials Science and Engineering*, *1101*(1), 12014. http://doi.org/10.1088/1757-899x/1101/1/012014

Bateni, N., Lai, S. H., Putuhena, F. J., Mah, D. Y. S., Mannan, M. A., & Chin, R. J. (2019). Hydrological Performances on the Modified Permeable Pavement with Precast Hollow Cylinder Micro detention Pond Structure. *KSCE Journal of Civil Engineering*, *23*, 3951-3960. http://doi.org/10.1007/s12205-019-2271-8

Bayoh, M. N., & Lindsay, S. W. (2003). Effect of temperature on the development of the aquatic stages of Anopheles gambiae sensu stricto (Diptera: Culicidae), 375-381. http://doi.org/10.1079/BER2003259

Bean, Eban Z., Hunt, W. F., Bidelspach, D. A., & Smith, J. T. (2004). *Study on the Surface Infiltration Rate of Permeable Pavements*.

Beecham, S., Pezzaniti, D., & Kandasamy, J. (2012). Stormwater treatment using permeable pavements. *Proceedings of the Institution of Civil Engineers: Water Management*, *165*(3), 161-170. https://doi.org/10.1680/wama.2012.165.3.161

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

Czemiel Berndtsson, J. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering*, *36*(4), 351-360. http://doi.org/10.1016/j.ecoleng.2009.12.014

Drake, J. (2013). *Performance and Operation of Partial Infiltration Permeable Pavement Systems in the Ontario Climate*. University of Guelph.

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

Hemme, R. R., Tank, J. L., Chadee, D. D., & Severson, D. W. (2009). Acta Tropica Environmental conditions in water storage drums and influences on Aedes aegypti in Trinidad, West Indies, *112*, 59-66. http://doi.org/10.1016/j.actatropica.2009.06.008

Ibrahim Elmalih, E. B., Almugadam, B. S., G Tamomh, A., & Mohamed Hassan, S. (2018). Influence of Environmental Factors on Breeding Habitats of Mosquito Species in Kosti City, White Nile State, Sudan. *Health Science Journal*, *12*(4). http://doi.org/10.21767/1791-809x.1000577

Li, H., Kayhanian, M., & Harvey, J. T. (2013). Comparative field permeability measurement of permeable pavements using ASTM C1701 and NCAT permeameter methods. *Journal of Environmental Management*, *118*, 144-

152. https://doi.org/10.1016/j.jenvman. 2013. 01.016

Liow, C. V., Mah, D. Y. S., & Malek, M. A. (2019). Flow characteristics of stormpav green pavement system. *International Journal of Innovative Technology and Exploring Engineering*, *8*(8), 1288-1292.

Mah, D. Y. S., Loh, S. L., Mannan, M. A., & Wan Ibrahim, W. H. (2018). Modelling of surface permeation in multiple-orifice permeable road. *International Journal of Engineering and Technology (UAE)*, *7*(3), 40-43. http://doi.org/10.14419/ijet.v7i3.18.16670

Mah, D.Y.S., Ong, J., Mannan, A. (2020). *2020 International Journal of Emerging Trends in Engineering Research.* Available online at http://www.warse.org/IJETER/static/pdf/file/ijeter17822020.pdf Modelling of Compartmentalized Household Storm water Detention System using SWMM5, *8*(2), 344-349.

Mah, D.Y.S., Putuhena, F. J., & Azalina, N. (2014). Environmental Technology: Potential of Merging Road Pavement with Stormwater Detention, *1*(1), 1-8.

Mangala, S., Toppo, P., & Ghoshal, S. (2016). Study of Infiltration Capacity of Different Soils. *International Journal of Trend in Research and Development*, *3*(2), 2394-9333.

Myers, B., Beecham, S., & van Leeuwen, J. A. (2011). Water quality with storage in permeable pavement base course. *Proceedings of the Institution of Civil Engineers: Water Management*, *164*(7), 361-372. https://doi.org/10.1680/wama.2011.164.7.361

Nwoke, E.A., Ukaga, C.N., & Nwachukwu, M. (2010) Epidemological characteristics of Bancoftian filariasis and the Nigerian Environment. *Journal of Public Health and Epidemiology* Vol. *2*(6), pp. 113-117, September 2010. Available online at http://www.academicjournals.org/jphe

Osman, M., Takaijudin, H., Yusof, K. W., Goh, H. W., & and A Ab Ghani. (2020). The use of treatment train for stormwater quality control in urban areas in Malaysia: A short review. http://doi.org/10.1088/1755-1315/476/1/012090

Paaijmans, K. P., Jacobs, A. F. G., Takken, W., Heusinkveld, B. G., Githeko, A. K., Dicke, M., & Holtslag, A. A. M. (2008). Observations and model estimates of diurnal water temperature dynamics in mosquito breeding sites in western Kenya, *4801*(July), 4789-4801. http://doi.org/10.1002/hyp

Park, D., Asce, A. M., Song, Y., Roesner, L. A., & Asce, F. (2013). Effect of the Seasonal Rainfall Distribution on Storm-Water Quality Capture Volume Estimation, (February), 45-52. http://doi.org/10.1061/(ASCE)WR.1943-5452.0000204.

Piyaratne MK, Amerasinghe FP, Amerasinghe PH, Konradsen F. Physico-chemical characteristics of Anopheles culicifacies and Anopheles varuna breeding water in a dry zone stream in Sri Lanka. *Journal of Vector Borne* Dis. 2005 Jun;42(2):61-7. PMID: 16161702.

Putri, E. E., Yuliet, R., Hoo, S. C., Mannan, M. A., Silas, L., Ibrahim, W. H. W., … Tasnim, S. (2020). StormPav Green Pavement the environmentally friendly pavement. *E3S Web of Conferences*, *156*, 3-8. http://doi.org/10.1051/e3sconf/202015605008

Qin, Y., Yang, H., Deng, Z., & He, J. (2015). Water permeability of pervious concrete is dependent on the applied pressure and testing methods. *Advances in Materials Science and Engineering*, *2015*, 1-7. https://doi.org/10.1155/2015/404136

Scholz, M. (2013). Water quality improvement performance of geotextiles within permeable pavement systems: A critical review. *Water (Switzerland)*, *5*(2), 462-479. http://doi.org/10.3390/w5020462

Shen, W., Zhang, L., Li, S., Zhuang, Y., Liu, H., & Pan, J. (2020). Science of the Total Environment A framework for evaluating county-level non-point source pollution: Joint use of monitoring and model assessment. *Science of the Total Environment*, *722*, 137956. http://doi.org/10.1016/j.scitotenv.2020.137956

Sihag, P., Tiwari, N. K., & Ranjan, S. (2017). Estimation and inter-comparison of infiltration models. *Water Science*, *31*(1), 34-43. http://doi.org/10.1016/j.wsj.2017.03.001

Silberbush, A., Abramsky, Z., & Tsurim, I. (2015). Dissolved oxygen levels affect the survival and developmental period of the mosquito Culex pipiens Scientific Note Dissolved oxygen levels affect the survival and developmental period of the mosquito Culex pipiens, (December). http://doi.org/10.1111/jvec.12186

Selbig, W. R., & Buer, N. (2018). Hydraulic, water-quality and temperature performance of three types of permeable pavement under high sediment loading conditions. *U.S. Geological Survey Scientific Investigations Report 2018–5037*, 44. https://pubs.er.usgs.gov/publication/sir20185037

Valeo, C., & Gupta, R. (2018). Determining surface infiltration rate of permeable pavements with digital imaging. *Water (Switzerland)*, *10*(2). https://doi.org/10.3390/w10020133

WHO. (2008). *WHO Guidelines for Drinking-Water Quality*. *World Health Organization* (Volume 1). Geneva.

WHO. (2012). Water quality and health strategy 2013-2020. *World Health Organization*, 1-15. Retrieved from http://www.who.int/water_sanitation_health/publications/2013/water_quality_strategy/en/

Zhang, J. (2006). *A laboratory scale study of infiltration from Pervious Pavements*. RMIT University.