CAN POROUS PAVEMENT BE A SUSTAINABLE SOLUTION FOR THE NEWLY EXTENDED PART OF DHAKA IN TERMS OF SOLVING WATER LOGGING ISSUES AND GROUNDWATER LEVEL RECLAMATION?

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ABSTRACT

This paper highlights an urban planning proposal for the newly extended portion of Dhaka city like Purbachal, Jalshiri Residential Project Area, etc. The planning emphasizes two basic needs of the expanding part of the city: reducing the water logging problem and replenishing groundwater levels. The solution proposed in order to reach the goal is installing permeable pavement instead of asphalt concrete in the residential areas of the newly planned portion of the city. Both the benefits and limitations of installing the porous pavement in Dhaka have been assessed. Based on the soil quality of the study area, the most efficient form and design of porous pavement was attempted to identify. From the hydrological aspect, the rate of increased infiltration and runoff reduction volume anticipated from the proposed design is estimated based on soil quality, rainfall volume and temperature of Dhaka. Furthermore, this paper outlines the environmental benefits of porous pavement, such as its ability to filter polluted municipal runoff water in the city containing heavy metals. Additionally, it discusses the pros and cons of porous pavement installation. Constraints are identified as a result of the high cost of initial construction, the dearth of experienced, skilled workers, and the shortage of imported foreign raw materials for construction. Additionally, since porous pavement can support a lighter load than concrete asphalt pavement, the number and varieties of permitted vehicles must be scrutinized in residential zones with porous pavement. Finally, the feasibility of constructing and maintaining porous pavement in Dhaka is analysed, and a set of prerequisites was identified that will determine the sustainability of porous pavement installation in Dhaka's new residential zones.

Keywords: *Permeable pavement, water logging, groundwater. feasibility*

1. INTRODUCTION

Dhaka, Bangladesh's capital city, is undergoing continual urban expansion. The Dhaka Metropolitan Development Plan (DMDP) 1995-2015 suggested new urban development standards for the twenty-first century. The DMDP suggests that the metropolis expand outward into rural and agricultural areas (Zaman & Lau, 2002). Integrated into this plan, different residential and commercial places are being constructed beside Dhaka. Purbachal New Town Project is one of these. Under this project, a residential area of 62000 apartments over 25 km^2 is being built (Rajuk, 2023). Another urbanisation project similar to the previous one is the "Jalshiri Abashon Project". This one is being constructed 1.3 km south of the Purbachal New Town Project (Bangladesh Army, 2023). The principal issues with the newly extended area of the city are the same difficulties that existed in the old part of the city owing to a lack of adequate planning. The main two problems which made the life of dwellers of present-day Dhaka complex are the water logging issue and the decline of groundwater level. Dhaka experiences considerable water logging during the monsoon season (May to October) (Mowla et al., 2013). One of the leading causes of this problem is that stormwater couldn't find a path to infiltrate the ground as most of the city is already heavily paved with asphalt concrete pavement. The city's stormwater couldn't be run-offed as well due to the filling of the surface reservoir or marshy lands of its catchment. So, stormwater drainage facility fails here significantly after heavy precipitation. The second issue, the declining groundwater level, is also alarming for Dhaka. To accommodate the city's expanding water demand, the Dhaka Water Supply and Sewerage Authority (DWASA) and private customers accelerated the abstraction rate by establishing deeper tubewells. Since the rate of groundwater recharge is slower than the rate of abstraction, the groundwater level is heavily affected (Bhattacharjee et al., 2019). Groundwater levels decreased throughout the city, ranging from 0.6 to 2.4 m/year (Moshfika et al. 2022). Because of the gradual reduction of rechargeable areas due to the expansion of the urban regions and infrastructures (including impermeable pavements), natural water recharge to aquifers has been unable to keep pace with water demand during the previous two decades (Chowdhury, 2018). So, a common impediment, heavy installation of impermeable asphalt pavement, has been identified that is limiting the resolution of these two problems in Dhaka. In these circumstances, low impact development (LID) is an increasingly accepted approach for solving the issues of stormwater design and management. LID is a design philosophy incorporating planning strategies and stormwater management technology to reduce runoff and waterlogging problems of urban stormwater, degradation of groundwater and surface water quality (Coffman, 2000; Dietz, 2007; CVC & TRCA, 2010). Porous pavement (PP) is a vital LID technique that increases the volume of infiltrating stormwater through subsurface storage and groundwater recharge. The porous pavement allows stormwater to penetrate through its porous concrete layer. As Dhaka is facing a huge waterlogging issue, if a portion of the stormwater can be diverted to the groundwater table through infiltration, then impressive progress in floodwater management can be expected. Additionally, it will add to the declining groundwater table of Dhaka. Moreover, the porous pavement surface can filter pollutants from the stormwater, predominantly high in Dhaka's floodwater. Eventually, this will reduce groundwater pollution without introducing any other artificial groundwater pollution attenuation mechanism, which will also be economically profitable. Finally, utilizing construction material for permeable pavement sourced from various renewable sources can minimize the adverse environmental effects associated with the production of bitumen used in traditional pavements, which will address another sustainable development aspect of the City.

So apparently, replacing the use of asphalt pavement with pavement made with porous material in the newly expanding urban areas can be a better option to avoid the waterlogging and groundwater declination-related issues already arising in the existing portion of the city. Citizens in this city are already considering this particular approach (Dhaka Tribune, 2019). However, the question here is whether the solution will be sustainable for the future. This study highlights both the costs and benefits of installing porous pavement in extending portions of Dhaka.

2. METHODOLOGY

To accomplish its goals, this study depends on secondary data. By reviewing the literature, the required information on the desired field was obtained. A brief discussion was carried out on the different components of a porous pavement. Following that, the general advantages of porous pavement were discussed first. This segment encompassed both the theoretical benefits of stormwater management and the real-world success stories of porous pavement projects across the world. Then, the possible advantages of implementing the idea of porous pavement installation at the study area of the Purbachal residential area, Dhaka, were projected. Within this context, pertinent information regarding the geology, particularly the soil type of the study area, was identified. Based on the site condition, the most appropriate design of porous pavement for the study area was suggested. The subsequent section addressed challenges related to the feasibility of installing porous pavement in the study area from various perspectives. In conclusion, the paper presents a set of recommendations to address and overcome these challenges.

2.1 Porous pavement

Porous pavements are a stormwater management technology that can be used in low vehicular volume avenues to reduce stormwater runoff volume while increasing rainfall water infiltration. According to Elvidio V. Diniz, porous pavement consists of 4 layers:

a) Minimally compacted subbase with uneven soil distribution
b) A base course of crushed stones with a diameter of 1-2 inches. The site's runoff storage capability determines the thickness of this layer.
c) A 2-inch-thick layer of aggregate with a 0.5-inch diameter to stabilise the base course.
d) First and foremost, a porous asphalt concrete surface. The thickness of the layer is determined by the vehicle load (Diniz, 1980).

Porous asphalt pavements comprise a relatively thin layer of open-graded asphalt mix on top of a deep layer of large-sized crushed stones. Water can be easily infiltrated through the porous asphalt layer and held in the crushed stone base until it percolates into the subbase or drains laterally. For water collection purposes, auxiliary drainage systems like French drain pipes are constructed in the subbase. Thus, extra runoff volume can be reduced using such technology and infiltration volume can be increased. Concrete lattice blocks and a porous concrete mix are two other types of porous pavement. Ultimately, the resulting pavement has a coarse surface roughness and a high void space ratio (Field, 1982). Figure 1 illustrates the cross-section of a porous pavement.

2.2 General advantages of porous pavement

The materials used to cover impermeable pavements have the potential to seal surfaces, repel water, and prevent precipitation and other water from infiltrating soils. They also allow stormwater to flow over them, resulting in enormous amounts of runoff followed by comparatively dry circumstances shortly afterwards. Pollutants would build up on such impervious surfaces as well (Barnes et al., 2000). On the contrary, by reducing peak water flow via drainage channels and minimizing flooding, the porous pavement has the ability to capture initial rainfall and allow it to soak into the soil (Thorpe, 2020). Damodaram et al. (2010) showed that permeable pavements were better at preventing flooding than other technologies, such as green roofs and collecting rainwater. A study conducted in Jurong, China observed a reduction of 24.7% in the peak flow of a specified five-year recurrent rainfall event following the introduction of permeable pavements in a tourist village (Xie et al, 2017). Moreover, as demonstrated by Huang et al. (2014), the introduction of permeable pavements in the campus of Tianjin University, China, resulted in a notable decrease of around 35.6% in total runoff and 28.7% in peak flow. It is also stated that permeable concrete increases groundwater and aquifer recharge by collecting rain and allowing it to penetrate the soil. Furthermore, other purported benefits of this material include reduced solar radiation absorption due to the light colour of concrete pavements compared to darker materials and less heat storage due to the relatively open pore structure of permeable concrete. It is also believed to provide better tree protection than other surfaces (Tennis et al., 2004). Permeable concrete pavement systems can also help manage the number of pollutants in waterways by lowering or eliminating runoff and allowing for pollution remediation. Such treatment takes place as a result of absorbing initial rainfall and allowing it to percolate into the ground, allowing soil chemistry and biology to naturally "treat" polluted water, which will reach the groundwater table eventually (Thorpe, 2020).

2.3 Possible advantages of installing porous pavement in Dhaka:

Porous pavements have been proven in numerous studies to reduce stormwater flows by reducing the volume and frequency of stormwater flows, lowering and delaying peak flow rates, and lengthening flow durations. Stormwater quality can be improved by lowering stormwater temperature, pollutant concentrations, and loadings of suspended particles, heavy metals, polyaromatic hydrocarbons, and certain nutrients (Drake, 2013). These general benefits might be predicted if porous pavements are placed in Dhaka's growing new residential areas.

Firstly, a thorough examination of the Purbachal residential city revealed that the land primarily comprises sandy soil despite a silty clay layer of 4.5m thickness at the start (Sayed et al., 2015). The average annual rainfall volume in this zone is 2400mm (Shishir et al., 2020). For similar boundary conditions with such soil quality parameters, a particular type of porous pavement, pervious geopolymer concrete (PGC) pavement, has been found to be the most effective. PGC is a porous, non-slip pavement concrete that enables water to pass through. Here, biomass aggregate (BA) manufactured by burning palm oil biomass is used to replace natural aggregate (NA) (Arafa et al., 2021). A four-month study found that installing PGC pavements under drainage systems over an existing layer of clay soil reduced direct runoff volume by about 93% (Dreelin, 2006). Another advantage of PGC pavement is its compressive strength of 13.7 MPA, over 51% higher than the compressive strength of ordinary Portland cement pervious concrete with natural aggregate. PGC pavement has an average water permeability of 2.1 cm/s, up to the mark (Arafa et al., 2021). Moreover, with increased temperature, the viscosity of the stormwater is supposed to be decreased as well. So, the comparatively warmer temperature of Dhaka than Western countries will also catalyse the infiltration amount of stormwater to increase. Even the factor of warmer temperatures can increase the rate of infiltration by 56% in some cases (Braga et al., 2007). So, a good outcome can be expected if such types of porous pavement are installed in the Purbachal residential area. Furthermore, multiple human activities impact the groundwater quality of a city (Kumar et al., 2013, 2017; Hossain et al., 2018). In Dhaka, trace metals from industrial effluents, traffic emissions, brick kilns, and terrestrial runoff are polluting its groundwater through seepage or natural recharge (Rahman et al., 2014; Islam & Azam, 2015; Islam & Huda, 2016; Rahman & Islam, 2016). In particular, the presence of Lead (Pb) was identified in a higher concentration in Dhaka's precipitation, which has several possibilities to percolate the groundwater table of the city (Mohuya, F. A. et al. 2010). Traces of other heavy metals like Cd, Fe, Zn, Mn, and NI have been identified in the city's groundwater as well (Bodrud-Doza, M., 2019). Porous pavement functions efficiently as a filter media for removing suspended solids and heavy metals from stormwater (Legret & Colandini, 1999). Furthermore, as stormwater infiltrates through the pavement into the soil, soil chemistry and biology work to remove pollutants before the water reaches the groundwater table (Thorpe, 2020). Table 1 illustrates the results of a four-year study to compare the volume of suspended solids and heavy metals identified in runoff water and infiltrating water through porous pavement in a study region. Lastly, regarding maintenance expenses, hot mix asphalt has the lowest initial construction costs, whereas permeable pavements are significantly less expensive than impermeable pavements. When stormwater treatment costs are considered, permeable pavements are more cost-effective over a 20-year and 30-year timeframe analysis (Rehan et al., 2018). Therefore, this section can be concluded by saying that installing porous pavement in Dhaka's newly expanding areas has various potential benefits.

2.4 Major challenges of installing porous pavement in Dhaka:

There are possible concerns with permeable concrete pavement, such as the potential for clogging with muddy runoff under certain conditions (Delatte et al., 2007), which can reduce the water permeability of the pavement significantly. It's also essential to carefully plan and implement their mix design and construction details (Tennis et al. 2004). So, skilled labour is another challenge, as constructing porous pavement is uncommon in Bangladesh. As from the previous chapter, PGC-type porous pavement has been found to be most efficient for the study area. The PGC with Fine Aggregate (FA)/Coarse Biomass Aggregate (CBA) ratio of 1:7, with a CBA size of 5–10 mm cured for 24 h at 80 °C, gave optimum compressive strength of 13.7 MPa. However, according to AASHTO T 325 in Table 1 of Article 1020.04, the concrete mixture shall obtain a minimum compressive strength of 22.1 MPa to allow vehicle movement. Heavy vehicles, including single and tandem axle trucks, are obstacles to using such porous pavements (Young, 2013). Therefore, heavy vehicles are still a challenge for these pavements. A study conducted in Illinois, USA, found that the initial construction cost of porous pavement is almost 25% more than the construction cost of traditional asphalt pavement (Rehan et al., 2018). However, in the case of Bangladesh, the initial cost may be higher because there is no biomass aggregate manufacturing plant from palm oil biomass, which is required for PGC pavement.

3. FIGURE AND TABLE:

3.1 Figure

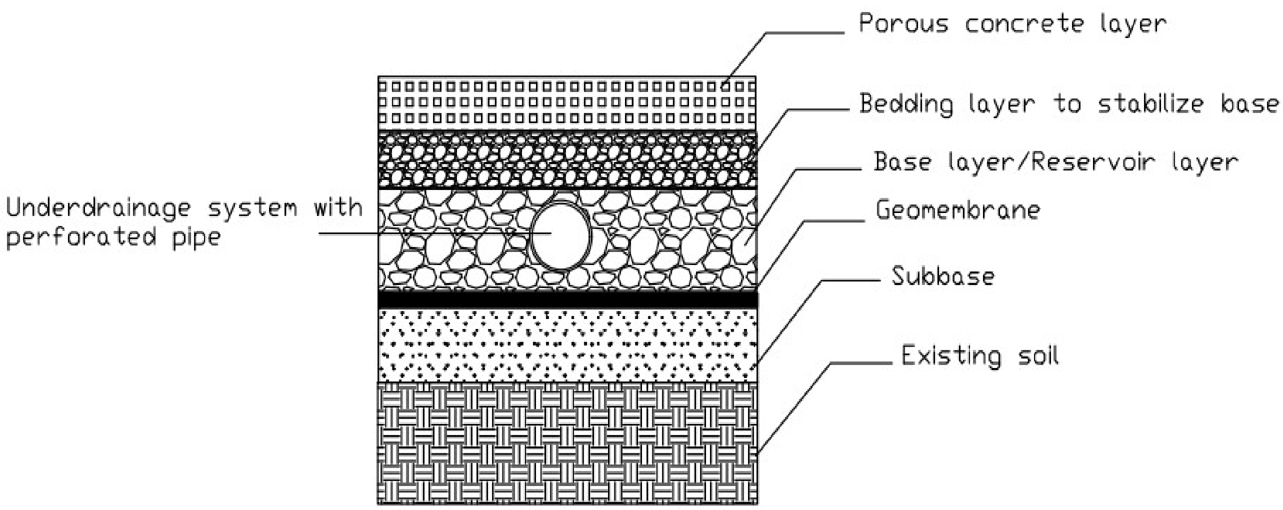

Fig.1: Cross section of Porous Pavement.

3.2 Table

Table 1: Heavy metal removal capacity of porous pavement (Legret & Colandini, 1999)

Infiltrated water through porous pavement	Suspended solids (kg/ha)	Pb (g/ha)	Cd (g/ha)	Zn (g/ha)
Minimum	0.32	0.17	0.001	3.2
Maximum	20.9	3.6	0.27	29.9
Mean	3.5	0.88	0.08	11.3
Runoff water collected from the catchment	Suspended solids (kg/ha)	Pb (g/ha)	Cd (g/ha)	Zn (g/ha)
Minimum	1.3	1.9	0.11	34.1
Maximum	26	16.7	0.88	58.5
Mean	8.5	5.6	0.35	41.8

4. CONCLUSION

Water logging problem after heavy rainfall has become a significant concern for Dhaka residents. The growing portions of the city still under construction require careful planning to avoid such issues. Furthermore, the regions where the town is intended to be extended are more vulnerable to waterlogging because most were previously marshy territory where runoff water from catchments gathered. As a result, the central city's runoff water is now posing a potential hazard to these residential zones. Another concern of the town is the decline of the groundwater level, as the city is heavily reliant on underground water. The impediment formed in stormwater infiltration caused by impermeable roadway pavement is a common cause of these two distinct issues. As a result, an attempt to construct a unique porous pavement known as "PGC pavement" in the streets of these new residential zones could be a viable approach to reducing, if not completely eliminating, these concerns. The already defined design of PGC pavement provides various advantages, including high water permeability, greater strength than most porous pavement types, the ability to clean up polluted precipitation water, and benefits from a sustainable building standpoint. On the contrary, constructing such a pavement in Bangladesh's streets has substantial barriers as well. For example, high primary construction costs, sophisticated design and building procedures, a shortage of manufacturing facilities to produce raw materials, clogging of pores after muddy rainfall, substantial barriers to heavy vehicle access, and so on. As a result, the initiative's success is contingent on several criteria. If the government initially subsidises the project to reduce the cost of initial construction for investors, the import tax on raw materials can be waived, strict monitoring of vehicle permits to use the pavement can be ensured, and finally, proper maintenance and observation will help the new idea be effective in terms of sustainable development.

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