An overview of the permeable reactive barrier as part of water remediation system in tropical countries

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Abstract. Natural resources are widely used for daily life, but due to poor utilization it can cause natural disasters. Disasters can occur due to several circumstances, such as flooding, which is caused by a malfunction of the drainage system. Floods may contain some bad compounds; therefore, proper solutions are needed to prevent soil pollution. Permeable reactive barrier or PRB can be a solution to this problem. There are various ingredients and benefits of Permeable Reactive Barriers, such as the addition of carbon particles, which will filter water containing petroleum when water passes through PRB. With the help of porous concrete, the water will flow into the permeable reactive barrier and then flow into the bio pores, so that it can make the surrounding soil more fertile. This paper review aims to discuss the use of permeable reactive barriers for soil remediation in tropical countries.

1. Introduction

The environment provides natural resources for us to use. However, sometimes humans use it excessively so that it often causes environmental damage. Environmental conditions change every year either quickly or slowly, this can happen due to many factors and can cause many problems. One of the problems caused by unwise environmental management is flooding. Flood is a natural phenomenon in the form of abnormal overflow of water that can drown a large area so that it can have an impact on the daily life conditions of the people and the environment affected by it [1–4]. Floods every year hit Indonesia, especially metropolitan areas such as Jabodetabek. The rapid rate of urbanization and the ineffectiveness of urban spatial control have resulted in environmental damage. In addition, the rapid population growth that is in line with the increasing need for vacant land encourages the conversion of land which was originally used as a water catchment area to become watertight land, this is the main cause of flooding in urban areas [5,6].

The tropical climate of Indonesia makes Indonesia has high rainfall. The tropical climate of Indonesia makes Indonesia has high rainfall. For example, the results of the analysis of rainfall in February in the Jabodetabek area are more than 300 mm per month where the frequency is included in the category of high monthly rainfall or in the category of above normal rainfall (AN) with a comparison of the characteristic value of rain around 116-150% [7]. The high rainfall is caused by La Nina or a decrease in sea surface temperature which can increase the potential for flooding. BMKG data in February 2021 states that the potential for flooding in the Jabodetabek area has a medium level, which means that it can potentially lead to flooding [8].
High rainfall can lead to reduced availability of clean water. This can happen because the incoming flood can be polluted, so it can cause pollution and water resistance. With the various problems above, efficient solutions are needed to be able to achieve the Sustainable Development Goals (SDGs) targets, namely industry goals, innovation and infrastructure, and life on land goals. The use of a permeable reactive barrier combined with bio pore holes and porous concrete as a rainwater remediation solution in residential areas with tropical climates can be a solution in accelerating the infiltration process to reduce the volume of puddles that can potentially become flooded. Utilization of bio pore holes can help in fertilizing plants around roads so that they can help in creating green open spaces [9]. On the other hand, the use of porous concrete can be a solution in reducing the number of accidents, especially when it rains because the rough texture of the concrete makes the roads not slippery.

This concept is to apply porous concrete to the road in order to increase the soil infiltration process, then the water will be channelled into a permeable reactive barrier (PRB) which functions to remediate rainwater after it is channelled into bio pore holes as a place for water infiltration and to fertilize plants and increase groundwater volume.

2. Research method
This paper using the literature review method to collect the data. The data in this paper also cited from trusted sources. The sources of the data were taken from scientific journal articles and trusted website articles. The flowchart of research methods can be seen in Figure 1.

![Flowchart of research method](image_url)

**Figure 1.** Flowchart of research method

Related to Figure 1, in compiling this paper, it begins by searching for literature related to papers such as weather, porous concrete, water remediation, bio pores, and permeable reactive barriers and continues by reducing the data obtained previously, which focuses on meaning, materials and applications. After the data has been reduced, proceed to the stage of analysing the data and proceed to
its presentation in this article. The last method is to conclude the data obtained and conclude permeable reactive barriers for water remediation for tropical countries.

3. Porous concrete and its application

Porous concrete or pervious concrete is a special type of cementitious material composed of gap graded aggregates, combine with a thin layer of cement paste. Porous concrete is made by continuous voids that will make it into concrete. The gaps that exist in the concrete occur due to the size of the voids [10].

The material that made porous concrete are coarse aggregates, Ordinary Portland cement (OPC), admixtures, and water its similar to the common concrete, but porous concrete just uses coarse aggregates from 9.5 mm to 19 mm various of the size [11]. The strength of the porous concrete is affected by the gap of the voids, aggregate gradation, and the paste aggregate ratio is smaller [12–14]. The aggregate gradation also affected the permeability [14]. Figure 2 show a schematic diagram of porous concrete. The figure shows the gap that occur because the size of the voids that make the concrete [10]. The schematic diagram of porous concrete method can be seen in Figure 2.

![Schematic diagram of porous concrete method](image1)

**Figure 2.** Schematic diagram of porous concrete method [15]

The porous concrete is normally used without any corrosion reinforcement due to the gap in its structure. Porous concrete is usually considered an friendly environmentally pavement [16]. The applications of porous concrete are rigid drainage layers under exterior areas, greenhouse floors, structural walls for better thermal insulation characteristics of lightweight, or both [17]. The water permittivity test can be seen in Figure 3. Figure 3 show the application of porous concrete as interlocking pavement. The interlocking pavement with porous concrete is shows no occurring puddles on the surface. The water is directly absorbed to the blocks whereas in contrast to conventional concrete water will puddles on the surface as seen on Figure 4 [18,19].

![Water permittivity test](image2)

**Figure 3.** Water permittivity test [18]
Figure 4. Porous concrete sample in the passage of sample [19]

4. Current technology on water remediation

One of the biggest challenges of the twenty-first century is to provide safe, clean, and low-cost water. The fast growth of industrialization, increasing population, and changing people's lifestyles have led to increased production. This change leads to improper disposal of hazardous industrial waste in water systems, such as dyes, heavy metals, pesticides, pharmaceuticals, and residues [20]. The demand for clean water continues to increase along with the growth of the human population, but there is water quality deterioration [21]. These contaminants are micro and nano plastic in size [22]. Several attempts have been made to remediate contaminated water by local and international organizations [23]. One of the efforts made for water remediation is water remediation using biosorbents obtained from agriculture and fruits waste [24]. Agricultural waste materials used include bagasse powder (SBP), rice husk ash (RHA), powdered fruit peel waste (WFPP), and powder mixture (PB) were used as fluoride absorbent materials. Bagasse and rice husk ash were obtained from local farmers and rice mills respectively. Skin fruits are waste from the local juice shop. The steps of water remediation using biosorbents obtained from agriculture and fruits waste can be seen in Figure 5.

Figure 5. Water remediation using biosorbents obtained from agriculture and fruits waste [25]

Figure 5 show the steps water remediation using biosorbents obtained from agriculture and fruits waste. All ingredients except rice husk ash cut into small pieces, dried in the sun for 72 hours to remove the moisture content, and then crushed in the grinder separately to become a fine powder. Then the prepared bio-adsorbent powder is stored in a tight container to protect it from moisture. To take notes the pH in the solution that has been treated with bio adsorbent is used as a Microprocessor-Based (Labtronics) pH meter. The experiment was carried out by shaking the fluoride solution with a known fluoride concentration bio adsorbent in a shaker. Then the result is % fluoride removal. After analysis,
it can be concluded that the use of agricultural waste to remove fluoride ions is effective for use in pH range of 4-6 with maximum dose PB to remove 85% of fluoride ions i.e. 1.2 g per 100 mL solution. However, remediation wastewater containing various pollutants will require more research. The suitability of other biomaterials as bio adsorbents should be explored to overcome water pollution [24].

5. Bio pore infiltration process
Bio pores are a method to overcome the problem of decreased water absorption. The bio pore form resembles a synaptic burrow located in the ground and branched and effective for channelling water and air into the soil. In order for bio pore holes to function optimally, the organic matter must be routinely added so that in the hole the process of aerobic composting will still take place by soil microorganisms [26].

Ingredients contained in bio pores are organic waste such as vegetable waste, animal food waste, paper, twig pieces, and grass. The utilization of these microbes can accelerate the process of waste degradation by adding a combined inoculum of four microorganisms such as Saccharomyces, Lactobacillus, Bacillus, and Acetobacter. The combined inoculum has effectiveness in degrading organic waste into compost [26]. There are also several types of bio pores, including root bio pores and earthworm bio pores. Most subsoil carbon (C) turnover occurs in bio pore hotspots such as root channels and earthworm burrows. Bio pores allocate large C amounts into the subsoil, where a vast capacity for long-term C sequestration is predicted. Sufficient content of C inputs creates several years lasting hotspots for preferential root growth and nutrient mobilisation in the subsoil. Concluded that root- and earthworm-derived bio pores are vertical pathways for plant C from the soil surface into the subsoil and for intensive processing of litter C and sequestration of microbial necromass [27].

The use of holes in porous pipes has the aim to improve the infiltration process and help organic waste to have direct contact with air so that air can go in and out along the pipe as well as assist the decomposition process by microorganisms [28]. The benefits produced by the use of bio pores, namely increasing the absorbency of water, converting organic waste into compost, utilizing the role of soil fauna and plant roots, and as a carbon sink to help prevent global warming [26]. The bio pore system methods can be seen in Figure 6.

![Figure 6. Bio pore system [29]](image)

Bio pore made by PVC pipes that have been given hole on each side. Holes in bio pore pipes have a function to increase the rate of infiltration in the soil, it is influenced by aeration factors determined by
porosity and water content of materials. Holes in the pipe can help organic waste to contact directly with the air so that air can go in and out along the bio pore pipe and help the decomposition process by microorganisms [28]. Organic waste applied to bio pores has a function to make the soil more fertile because the waste will undergo a decomposition process by microorganisms and can turn into compost that serves to fertilize the soil [26].

6. Permeable reactive barrier
Permeable Reactive Barrier or what we usually call PRB is a water remediation technology in the form of a vertical wall as a barrier layer that is used to minimize water contamination before being channelled to groundwater [30]. The water will be filtered through the pores on the wall before being channelled to the bio pore so that the water used to fertilize the soil is more hygienic and will then be forwarded to the soil [31].

In the manufacture of Permeable reactive barrier (PRB) there are several materials that can be used which have their respective functions and roles. The materials used include iron, limestone, soil, clay, carbon, and mulch. The material used has a role as a media for filtration, one example is limestone which plays an active role in depositing lead and copper solutions in PRB.

The first step, we will dig a trench for the placement of PRB. Usually, PRBs are placed no more than 50 feet below the ground. Then the trench will be filled with reactive materials such as iron, carbon, mulch, and limestone. These materials can be mixed with sand to make the walls more permeable. The side walls are made of clay to make it watertight so that it is easier to channel water to PRB [31].

When it rains, the water will flow through the ditch to the PRB. Contaminated rainwater will be absorbed (stick) to the surface of the reactive material. For example, carbon particles will filter water containing petroleum when water passes through PRB. Limestone will precipitate metals dissolved in water and cause dissolved lead and copper to settle in PRB [31].

PRB has previously been applied to clean groundwater at a former semiconductor manufacturing site in Sunnyvale, California 1995 [31]. The funnel and gate configuration of PRB can be seen in Figure 7.

![Figure 7. Funnel and gate configuration of PRB](image_url)

When the water will be in the underground channel, before being directed to the bio pore, the water will first pass through the PRB in an arrangement like the picture above where the funnel is made of clay or water-resistant material so that water does not penetrate through the funnel wall and can be channelled into the PRB to filter contaminated water.
7. Project implementation concept

7.1. Layout plan
The layout of the Permeable Reactive Barriers is a planning strategy for design element arrangement relate to the implementation of Permeable Reactive Barriers concept in the road in tropical countries. It is supposed to form an appropriate arrangement and can maximize the work function of the plan elements. The design of permeable reactive barriers and bio pores system can be seen in Figure 8.

Figure 8. Layout plan

Figure 8 shows the layout plan of the installation of PRB and the bio pore system. Porous concrete is installed under the asphalt layer so that rainwater can be absorbed and flowed into the pipe to PRB. After going through PRB, rainwater will go through the pipe again and enter the bio pore system before being distributed to the surrounding soil. Bio pores are made using PVC pipes and covers that have been given holes on each side.

7.2. Detail of permeable reactive barriers and bio pores system
The water will be filtered through the pores on the wall before being channeled to the bio pore so that the water used to fertilize the soil is more hygienic and will then be forwarded to the soil. After that, the water will enter the bio pore system. The use of holes in porous pipes has the aim to improve the infiltration process and help organic waste to have direct contact with air so that air can go in and out along the pipe as well as assist the decomposition process by microorganisms. The detail of permeable reactive barriers and bio pores system can be seen in Figure 9.

Figure 9. Detail of PRB and bio pores system

Figure 9 shows the detail of porous concrete, PRB, and bio pore system. The material that made porous concrete are coarse aggregates, ordinary portland cement (OPC), admixtures, and water its similar to the common concrete, but porous concrete just uses coarse aggregates from 9.5 mm to 19 mm
various of the size. PRB are placed under the pavement filled with reactive materials such as iron, carbon, mulch, and limestone. Ingredients contained in bio pores are organic waste such as vegetable waste, animal food waste, paper, twig pieces, and grass. The utilization of these microbes can accelerate the process of waste degradation by adding a combined inoculum of four microorganisms such as Saccharomyces, Lactobacillus, Bacillus, and Acetobacter.

7.3. The stages of “Permeable Reactive Barriers” implementation
The stage of “Permeable Reactive Barriers” implementation can be seen on Figure 10 and explained as bellows.

- Starting with planning for the implementation of permeable reactive barriers and bio pore systems.
- Water pollution socialization. The first stage is giving socialization for local communities “Permeable Reactive Barriers” discussing the water pollution and how to solve it.
- “Permeable Reactive Barriers” socialization, socialization of permeable reactive barriers, providing an understanding to local communities about permeable reactive barriers and their benefits. Persuade them to help take care after being built.
- License, done by asking a license to government, so that “Permeable Reactive Barriers” can be implemented in the streets of tropical countries.
- Agreement, done by making agreement and signing Memorandum of Understanding (MoU) with government and local communities.
- DED (Detailed Engineering Design) manufacture by collaborating with related departments.
- Study of land for procurement and construction of "Permeable Reactive Barriers".
- Inauguration by the government and local communities.

![Figure 10. The permeable reactive barriers implementation stage](image-url)
7.4. *The Analysis of Effect from Implementing “Permeable Reactive Barriers” for Tropical Countries*

The development of public transportation facilities must have an effect. The analysis of the effects of the construction of Permeable Reactive Barriers as Part of Water Remediation System in Tropical Countries can be seen in Table 1.

| No | Impacted Areas | Explanation |
|----|----------------|-------------|
| 1  | Environment    | The roads are protected from flooding due to puddles of rain. In addition, water enters the canal to PRB and is channelled back to the ground making the soil healthier because of reduced water pollution. Plants also become healthier due to improved water quality. |
| 2  | Economics      | The community's economy increases because the flood barriers on the highway are reduced. After all, rainwater is absorbed by the pore concrete. |

8. **Conclusion**

By stating this idea dealing with problems caused by the lack of water infiltration and the lack of application of water remediation in industrial areas with high rainfall is the use of Permeable Reactive Barriers as a solution for rainwater remediation on the surface of industrial tropical climates. This program has several parts for its application so that it can be carried out optimally. This section consists of, 1) Use of Pervious Concrete for water absorption on roads, 2) Permeable Reactive Barrier as a filter for rainwater contaminated with pathogenic microorganisms, decaying organic waste, toxic chemicals, and hazardous substances from the atmosphere carried by rain, 3) Use of Bio pore as the final reservoir of water which aims to make the soil around the road more fertile, because in the bio pore process the pollutants in the water are reduced so that it can reduce soil pollution.

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