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Groundwater Recharge through Permeable Pavement

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ABSTRACT

Rapid urbanization has led to increased impervious surfaces such as conventional concrete and asphalt pavements, which prevent natural infiltration of rainwater into the ground. This results in groundwater depletion, surface runoff, and urban flooding. Permeable pavement is an innovative and sustainable solution that allows rainwater to pass through its surface and infiltrate into the underlying soil layers, thereby recharging groundwater. This paper studies the concept, working mechanism, components, and benefits of groundwater recharge through permeable pavements. The study highlights how permeable pavements can reduce runoff, improve water quality, and support sustainable urban water management. A simple model is also proposed to demonstrate the working of permeable pavement systems. This paper presents a detailed study on the concept, components, and working mechanism of groundwater recharge through permeable pavements. The benefits of this system, including runoff reduction, water quality improvement, and sustainable urban water management, are discussed. Additionally, a simple physical model is proposed to demonstrate the functioning of permeable pavement systems for educational and practical understanding.

Keywords: *Permeable Pavement, Groundwater Recharge, Infiltration, Stormwater Management, Sustainable Infrastructure.*

INTRODUCTION

Groundwater is one of the most important sources of fresh water for domestic, agricultural, and industrial use. However, due to rapid urban development, natural land surfaces are being replaced by impervious pavements, buildings, and roads. These surfaces prevent rainwater from infiltrating into the ground, causing a decline in groundwater levels and an increase in surface runoff and flooding. Permeable pavements are designed to overcome this problem by allowing water to pass through the pavement surface into the soil below. This system not only helps in groundwater recharge but also reduces pressure on stormwater drainage systems. In recent years, permeable pavements have gained attention as a sustainable solution for urban water management. The consequences of this change include declining groundwater levels, frequent urban flooding, and excessive burden on stormwater drainage systems. Traditional drainage approaches focus on quickly removing runoff rather than allowing infiltration. Permeable pavements are designed to address these challenges by enabling rainwater to infiltrate through pavement surfaces into the ground. This system not only enhances groundwater recharge but also supports sustainable stormwater management, making it a promising solution for modern urban infrastructure.

LITERATURE REVIEW

Several researchers and organizations have studied the performance of permeable pavements as an effective method for groundwater recharge and stormwater management. Their findings confirm that permeable pavements significantly improve infiltration and reduce urban runoff.

Bean, Hunt, and Bidelspach (2007) evaluated different permeable pavement installations and observed that these systems were capable of infiltrating a major portion of rainfall directly into the ground. Their study showed that permeable pavements reduced surface runoff by more than 70–90% compared to conventional pavements. They also reported improvement in water quality due to filtration through aggregate layers.

A. Permeable Surface Layer

The surface layer is the topmost layer and is made from materials such as pervious concrete, porous asphalt, or permeable interlocking concrete blocks. This layer allows water to pass through its pores while providing sufficient strength to support pedestrian or vehicular loads. The surface layer also plays a role in reducing surface runoff and improving skid resistance.

B. Bedding Layer

The bedding layer is a thin layer of coarse sand or fine aggregates placed below the surface layer. It provides uniform support to the pavement surface and facilitates the movement of water into the lower layers. This layer also helps in leveling the surface and distributing loads evenly.

C. Base and Sub-base Layer

The base and sub-base layers consist of open-graded aggregates with high void content. These layers serve as a temporary storage reservoir for rainwater and provide structural stability. The stored water is slowly released into the subgrade soil, preventing sudden runoff and reducing peak flow rates.

D. Subgrade Soil

The subgrade soil is the natural soil beneath the pavement structure. It plays a critical role in groundwater recharge by allowing infiltrated water to percolate deeper into the ground. The permeability of the subgrade soil significantly influences the effectiveness of the permeable pavement system.

METHODOLOGY/DESIGN

The methodology adopted in this study focuses on understanding the performance of groundwater recharge through permeable pavement by designing a small-scale physical model and observing the infiltration behavior of water through different pavement layers. The procedure includes site analysis, material selection, model preparation, and performance evaluation. Initially, the concept of permeable pavement structure was studied and the suitable layer arrangement was finalized based on standard pavement practice. A rectangular transparent container was selected to visually demonstrate the movement of water through the layers.

A. Study Approach

The project follows an experimental demonstration approach rather than numerical simulation. A small-scale physical model is prepared to represent the real pavement layers. Water is poured over the surface to simulate rainfall and the infiltration behaviour is observed. The rate of percolation and storage of water within layers is visually examined to verify the groundwater recharge mechanism.

The methodology mainly focuses on restoring the natural hydrological cycle which is disturbed due to conventional impervious pavements. Instead of allowing water to flow into drainage systems, the designed structure allows infiltration and storage before gradual percolation into soil.

B. Design Considerations

While designing permeable pavement system, the following factors are considered:

1. Rainfall Intensity

The pavement must be able to absorb water during moderate rainfall without generating surface runoff. The void ratio of surface and base layer should be high enough to allow quick infiltration.

2. Soil Permeability

The effectiveness of groundwater recharge depends on subgrade soil type. Sandy and silty soils allow faster recharge, whereas clayey soils reduce infiltration rate. For the model, medium permeability soil is selected.

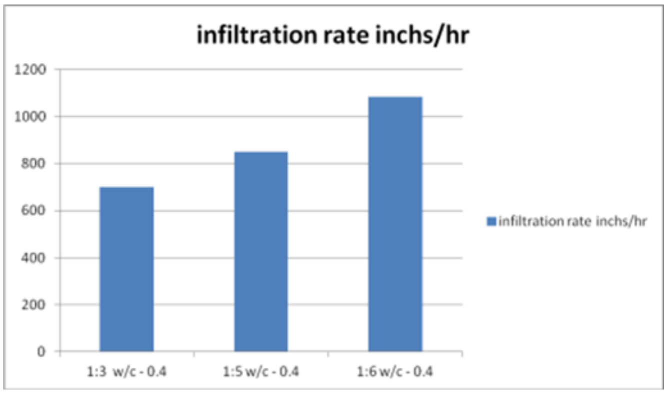
3. Load Bearing Requirement

The pavement should support light pedestrian or vehicle load. Hence interlocking paver blocks or porous concrete blocks are used at the top layer.

4. Storage Capacity

The aggregate base layer acts as a temporary reservoir. Its thickness is designed such that it can store water during rainfall and release it slowly to soil.

Layer	Material Used
Surface Layer	Permeable paver blocks / porous concrete
Bedding Layers	Coarse sand
Base Layer	Gravel (10–20 mm aggregate)
Sub-base Layer	Larger stones (20–40 mm)
Subgrade	Natural soil
Container	Transparent acrylic box



APPLICATIONS

Parking Areas and Driveways – Used in parking lots, residential driveways, and commercial parking spaces to reduce waterlogging and allow rainwater to seep into the ground.

Footpaths and Pedestrian Walkways – Installed in sidewalks, gardens, and pathways to prevent surface runoff and maintain natural groundwater recharge.

Residential and Low-Traffic Roads – Suitable for colony roads and streets where traffic load is low to moderate, helping control urban flooding.
Parks, Campuses, and Open Spaces – Used in public parks, school/college campuses, and recreational areas to manage stormwater and maintain soil moisture naturally.
Airports and railway stations – helps manage large stormwater runoff from wide paved areas and prevents water accumulation.
Industrial areas and warehouses – controls runoff pollution and reduces load on drainage systems in heavy paved zones.
School and college campuses – supports sustainable infrastructure and groundwater recharge in large open paved spaces.
Commercial complexes and shopping malls – minimizes waterlogging in parking and entrance areas during heavy rainfall.

FUTURE SCOPE

The use of permeable pavements has a wide future potential in sustainable urban development and water resource management. With increasing urbanization and climate change, cities are facing serious problems such as groundwater depletion, urban flooding, and water scarcity. Permeable pavement systems can be integrated with modern smart city planning to improve rainwater harvesting and reduce dependence on conventional drainage systems. In future, advanced materials with higher strength and durability can be developed so that permeable pavements can also be used on medium and heavy traffic roads.
In the future, advanced materials with higher strength and permeability can be developed to allow use on high-traffic roads and highways. The system can also be combined with rainwater harvesting tanks, sensors, and IoT monitoring systems to measure infiltration rate and groundwater recharge efficiency in real time. Government policies and building regulations may include permeable pavements as a mandatory feature in parking areas, residential layouts, and commercial complexes.
Further research can focus on improving clogging resistance and maintenance techniques to increase the lifespan of the pavement. Integration with sensors and monitoring systems can help measure infiltration rate, groundwater recharge quantity, and water quality in real time. Governments and municipalities can adopt this technology in highways, parking areas, and public infrastructure projects as a compulsory green infrastructure component.I

CONCLUSION

Groundwater recharge through permeable pavements is an effective and sustainable solution to overcome the problems caused by rapid urbanization such as waterlogging, surface runoff, and declining groundwater levels. By allowing rainwater to infiltrate through specially designed pavement layers, this system restores the natural hydrological cycle that is otherwise disturbed by conventional impervious pavements. The permeable pavement structure not only recharges groundwater but also improves water quality through natural filtration and reduces the load on stormwater drainage systems. It helps in minimizing urban flooding, conserving water resources, and promoting environmentally friendly infrastructure development. The demonstration model further proves the working principle in a simple and understandable manner.@

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