Sustainable Water Purification Using Diatomite–Zeolite Modified Pervious Concrete for Environmental and Aquatic Ecosystem Protection

Dr. D Tarangini [1], Dr. P.Sravana [2]

[1]Assistant Professor, Department of Civil Engineering, MGIT, Hyderabad
[2] Professor, Department of Civil Engineering, JNTU, Hyderabad

Abstract
Rapid urbanization has increased impervious surfaces, leading to reduced groundwater recharge, higher surface runoff, and deterioration of water quality. Pervious concrete has gained attention as a sustainable pavement material because of its capacity to facilitate water infiltration while minimizing environmental impacts. This study investigates the incorporation of diatomite and zeolite into pervious concrete to improve both structural performance and water purification efficiency. Diatomite, characterized by its porous structure and high adsorption potential, and zeolite, recognized for its ion-exchange and filtration properties, were incorporated as supplementary mineral materials within the pervious concrete matrix. The experimental investigation assessed the effects of varying proportions of diatomite and zeolite (0 to 10 %) on permeability, compressive strength, porosity, and water quality parameters like pH, cadmium, turbidity, lead, copper, zinc, iron. Treated water performance was evaluated through indicators including turbidity reduction and improvement in physicochemical characteristics. The results demonstrated that the modified pervious concrete system enhanced filtration performance while maintaining adequate permeability required for storm water infiltration. The integrated mechanisms of adsorption, ion exchange, and physical filtration contributed to improved contaminant removal and supported groundwater recharge. The study concludes that diatomite–zeolite incorporated pervious concrete represents an environmentally sustainable solution for urban water management by promoting natural purification processes, reducing runoff pollution, improving infiltration, and supporting ecosystem conservation and resilient infrastructure development.

Keywords: Pervious concrete; Diatomite; Zeolite; Water purification; Sustainable pavement; Groundwater recharge; Ecosystem conservation.

1. Introduction
Rapid urbanization and infrastructure expansion have increased the extent of impervious surfaces, resulting in reduced groundwater recharge, increased storm water runoff, and deterioration of water quality. Conventional pavement systems restrict natural infiltration and accelerate the transport of suspended solids, nutrients, and contaminants into nearby water bodies, creating environmental and ecological concerns. Pervious concrete has emerged as a sustainable pavement material due to its interconnected pore structure, which enables water infiltration, reduces runoff volume, and supports groundwater replenishment. In addition to hydraulic benefits, recent studies have highlighted the capability of pervious concrete to remove pollutants through physical filtration, chemical interactions, and biological mechanisms, making it a promising solution for integrated urban water management [7,19,20]

Natural mineral materials such as diatomite and zeolite provide opportunities to improve the multifunctional performance of pervious concrete. Diatomite possesses a highly porous structure, high silica content, and strong adsorption capacity, which contribute to contaminant retention and enhanced filtration efficiency. Zeolite exhibits excellent ion-exchange and selective adsorption properties that facilitate the removal of dissolved pollutants and improve water treatment performance. Incorporating these minerals into pervious concrete may enhance filtration efficiency while maintaining adequate permeability and structural performance. Therefore, this study investigates the use of diatomite and zeolite in pervious concrete to evaluate their influence on water purification and pavement characteristics, with the objective of developing an environmentally sustainable system that promotes groundwater recharge, ecosystem conservation, and resilient urban infrastructure [7,19,20]

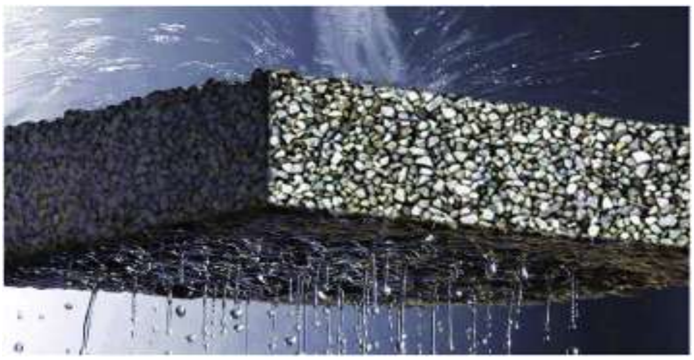

Figure 1: Pervious Concrete slab

1.2 Diatomite and Zeolite

Increasing concerns regarding water scarcity, pollution, and environmental degradation have accelerated the development of sustainable materials for water treatment applications. Among natural mineral-based adsorbents, diatomite and zeolite have gained considerable attention because of their environmental compatibility, natural abundance, cost-effectiveness, and efficient purification characteristics. Diatomite is a naturally occurring siliceous sedimentary material formed from fossilized remains of microscopic algae known as diatoms. Its highly porous structure, large specific surface area, and adsorption capacity make it effective for removing suspended particles and improving water quality through adsorption and filtration mechanisms [1,4,26]. Similarly, zeolite is a crystalline alum inosilicate mineral characterized by a three-dimensional porous framework with excellent ion-exchange and adsorption properties, enabling the removal of dissolved contaminants, nutrients, and organic micro pollutants from water systems [2,3,32].

The combined utilization of diatomite and zeolite presents a promising approach for developing efficient and sustainable water purification systems. Diatomite primarily contributes through physical filtration and adsorption processes, while zeolite enhances contaminant removal through ion exchange and selective adsorption mechanisms. Previous studies have indicated that composite systems containing zeolite and diatomite demonstrate improved water adsorption behaviour and enhanced purification performance. Integrating these natural minerals into engineered materials such as pervious concrete may further improve water treatment efficiency while supporting storm water infiltration and groundwater recharge. Therefore, this study investigates the incorporation of diatomite and zeolite as functional mineral additives to evaluate their effectiveness in enhancing water purification performance and promoting environmental and aquatic ecosystem sustainability.

Figure 2 :Diatomite

Figure 3 :Zeolite

1.3 Applications of Diatomite–Zeolite Pervious Concrete Slabs

1. Diatomite–zeolite concrete slabs can be used in permeable pavements to allow rainwater infiltration while simultaneously filtering suspended solids, heavy metals, and contaminants before groundwater recharge.
2. These slabs can serve as filtration media in constructed wetlands where wastewater undergoes natural treatment. The porous structure supports water movement and pollutant adsorption while protecting aquatic ecosystems.
3. Installation of these slabs along riverbanks and lake margins can improve water filtration, reduce sediment transport, and minimize contamination entering aquatic habitats.
4. Diatomite–zeolite concrete slabs may be used as lining materials in wastewater conveyance channels to enhance contaminant adsorption and improve water quality.
5. The slabs can support water purification in aquaculture systems by reducing turbidity and removing dissolved pollutants, creating healthier conditions for fish and aquatic organisms.
6. The porous concrete can be utilized in recharge pits and infiltration basins to improve water percolation while reducing pollutant entry into groundwater systems.
7. These slabs can function as passive treatment components to reduce heavy metals and suspended solids before industrial wastewater discharge.
8. The material can be integrated into eco-friendly urban designs such as bio-retention cells, green corridors, and low-impact development systems.
9. Due to their filtration and ecological benefits, these slabs may support restoration of degraded aquatic environments by improving local water quality.

2. Literature Review

Urbanization and the expansion of impervious infrastructure have intensified storm water runoff and reduced groundwater recharge, creating major concerns for sustainable urban water management. Pervious concrete has emerged as an effective low-impact development material because of its interconnected pore structure, which allows infiltration and reduces runoff generation. Beyond hydraulic benefits, recent studies have demonstrated that pervious concrete can also contribute to water quality improvement through physical filtration, chemical interactions, and biological mechanisms that facilitate contaminant removal [7,8,20].

Recent research has increasingly focused on modifying pervious concrete with adsorbent materials to enhance pollutant removal efficiency. Adsorbent pervious concrete systems have shown promising performance in mitigating storm water and wastewater contamination while maintaining adequate structural and permeability characteristics. Previous investigations emphasized that the selection of adsorbent materials directly influences compressive strength, porosity, permeability, and filtration performance [10]. Studies have also highlighted that optimization of pore structure is necessary to minimize clogging and maintain long-term hydraulic functionality [8].

Among natural adsorbents, diatomite has attracted attention due to its highly porous siliceous structure, large surface area, and strong adsorption capacity. These properties make diatomite suitable for trapping suspended solids and improving filtration efficiency. Zeolite, another naturally occurring porous mineral, has demonstrated excellent ion-exchange capacity and selective adsorption behaviour, enabling effective removal of dissolved contaminants and improvement of water quality. The versatility and sustainability of zeolite have supported its widespread application in environmental remediation and water treatment systems [5].

Research integrating diatomite and zeolite into permeable concrete systems has reported improvements in both purification performance and engineering properties. [1,26] observed that modified permeable concrete containing diatomite and zeolite improved compressive strength, effective porosity, and runoff purification efficiency. Their findings suggested that the combination of adsorption and filtration mechanisms enhanced contaminant removal from storm water runoff. Although considerable progress has been made in developing multifunctional pavement materials, limited studies have comprehensively evaluated the combined effect of diatomite and zeolite incorporation on water purification and ecosystem-oriented infrastructure applications. Therefore, further investigation is required to establish optimized material compositions capable of achieving both hydraulic and environmental performance.

3.Research Gap

Although previous studies have independently investigated the hydraulic performance of pervious concrete and the adsorption capabilities of natural mineral materials, limited research has comprehensively evaluated the combined influence of diatomite and zeolite on structural behaviour, water purification efficiency, and aquatic ecosystem sustainability [1,8,26].Existing investigations have primarily emphasized either mechanical performance or contaminant removal, while integrated assessment of multifunctional concrete systems remains insufficient.

The present study addresses this gap by incorporating diatomite and zeolite into pervious concrete and evaluating their combined contribution toward sustainable water management and environmentally resilient infrastructure. Diatomite contributes through physical filtration and adsorption owing to its highly porous silica structure, whereas zeolite enhances contaminant removal through ion-exchange and selective adsorption mechanisms [16]. Their integration provides a multifunctional matrix capable of supporting both hydraulic performance and pollutant attenuation.

The present study evaluates experimental trends across different mix combinations and examines the relationship between porosity, compressive strength, and purification efficiency. Experimental observations indicate that increasing porosity alone does not necessarily maximize purification performance; rather, optimization of pore structure is required to maintain adequate infiltration while preserving structural integrity (10; Neville, 2011).

Comparative analysis of mix compositions further suggests that balanced incorporation of diatomite and zeolite enhances contaminant removal through complementary filtration and adsorption mechanisms. Improved reduction of turbidity and dissolved pollutants contributes to lower contaminant transport into surrounding ecosystems and supports more efficient groundwater recharge [7,20]

From an ecological perspective, the observed improvements in purification performance indicate potential benefits for aquatic ecosystem resilience by reducing pollutant loading, limiting nutrient accumulation, and decreasing exposure of aquatic organisms to dissolved contaminants and heavy metals [18]. The findings support contaminant attenuation pathways that align with sustainable civil engineering practices and highlight the importance of developing multifunctional infrastructure materials.

4. Research Objectives

1. To investigate the porosity characteristics of diatomite–zeolite modified pervious concrete and evaluate their influence on hydraulic performance, adsorption behaviour, and contaminant transport mechanisms during water treatment.
2. To assess the compressive strength performance of different mix compositions and establish the relationship between pore structure, mechanical stability, and structural suitability for sustainable infrastructure applications.
3. To evaluate the water purification efficiency of modified pervious concrete by analysing its ability to reduce turbidity, stabilize pH, and remove dissolved contaminants and heavy metals from water systems.
4. To examine the effectiveness of contaminant attenuation mechanisms and determine how modifications in pore structure contribute to improved pollutant removal and water quality enhancement.
5. To analyse the environmental and aquatic ecosystem implications of the developed system through assessment of contaminant load reduction, water quality improvement, and protection of aquatic habitats.

5. Materials and Methods

5.1 Materials

The experimental program utilized Ordinary Portland Cement (53 grade), coarse aggregate, fine aggregate, potable water, diatomite, zeolite, and superplasticizer. Material testing was conducted according to applicable Indian Standards.

5.2 Mix Proportions
Pervious concrete mixes were developed using ACI 522R guidelines with water–cement ratio of 0.30 and cement content of 400 kg/m³. The selected replacement combinations included varying percentages of diatomite and zeolite.

S. No.	Raw material dosage (kg/m^3) Cementitious materials Cement	Diatomite	Zeolite	CA	FA	Water	SP
1*	400	0	0	1440	160	108	1.2
2*	360	20	20	1440	160	108	1.2
3*	380	0	20	1440	160	108	1.2
4*	360	0	40	1440	160	108	1.2
5*	380	20	0	1440	160	108	1.2
6*	360	40	0	1440	160	108	1.2

Table 1: Mix Proportions of Pervious Concrete

Mixes investigated:

1* - D-0, Z-0	4* - D-0, Z-10
2* - D-5, Z-5	5* - D-5, Z-0
3* - D-0, Z-5	6* - D-10, Z-0

Where D indicates Diatomite and Z indicates zeolites.

6.Methodology Framework

The methodology employed in this study was developed to systematically investigate the combined effects of diatomite and zeolite incorporation in pervious concrete with respect to structural performance, water purification efficiency, and environmental sustainability. The experimental framework followed a sequential and integrated approach consisting of material characterization, mix proportioning, specimen fabrication, curing, performance testing, and analytical interpretation.
Initially, all constituent materials were characterized to determine their physical, chemical, and mineralogical properties and to establish suitability for concrete applications. Subsequently, multiple mix combinations were developed by varying diatomite and zeolite contents to evaluate their influence on pore structure and mechanical behaviour.
Prepared specimens were cast and cured under controlled laboratory conditions to ensure consistency in hydration and microstructural development. Experimental evaluation included porosity analysis, compressive strength assessment, and water purification testing to quantify hydraulic performance and contaminant removal efficiency.
The generated experimental data were interpreted through comparative analysis of different mix compositions, emphasizing relationships among porosity, strength, and purification effectiveness. The overall framework enabled identification of an optimized material configuration capable of balancing hydraulic functionality and structural integrity while supporting sustainable civil engineering applications and practical implementation pathways.

7.Limitations

The findings of this study are based on laboratory-scale experimentation and therefore require further validation under diverse field conditions to confirm long-term applicability and performance. Although the developed diatomite–zeolite modified pervious concrete demonstrated promising structural and water purification characteristics, the experimental conditions were conducted within controlled hydraulic and environmental settings that may not fully represent real-world operating environments.
The analysis was expanded through interpretative evaluation of experimental trends, comparison of mix combinations, and assessment of contaminant removal behaviour to improve understanding of the interaction between material composition and functional performance. However, variations in flow conditions, pollutant loading, climatic exposure, and long-term operational factors may influence actual purification efficiency and durability outcomes.
Observed relationships between porosity and compressive strength indicate that maximizing pore volume alone does not guarantee improved performance. Instead, optimization of pore structure is necessary to achieve an effective balance between hydraulic conductivity, contaminant attenuation, and mechanical stability. This balance remains a critical consideration for large-scale implementation.
Furthermore, the present study focused primarily on short-term laboratory observations and did not include extended durability evaluation, clogging resistance assessment, seasonal hydraulic variations, or life-cycle

environmental analysis. Additional investigation is required to understand the long-term behaviour of mineral-modified pervious concrete systems.
From an environmental perspective, the implications for aquatic ecosystem protection were interpreted based on pollutant attenuation trends and water quality improvement indicators. Future studies should incorporate field-scale monitoring, ecosystem response assessment, and long-term ecological evaluation to strengthen the practical applicability of the proposed system.

8. Mechanisms of Water Purification

Water purification using diatomite and zeolite occurs through four main mechanisms: filtration, adsorption, ion exchange, and pH stabilization. Diatomite acts as a porous material that filters suspended particles and reduces turbidity by trapping impurities within its pore structure. It also adsorbs dissolved contaminants and heavy metals onto its large surface area. Zeolite further improves purification through ion exchange, where naturally occurring ions in zeolite are replaced by metal ions such as Pb, Cd, Cu, Zn, and Fe, thereby reducing contaminant concentration in water. In addition, zeolite helps maintain a stable pH and decreases metal mobility. The combined action of diatomite and zeolite enhances removal efficiency, improves water clarity, lowers heavy metal levels, and produces water that is more suitable for aquatic ecosystems and environmental sustainability.

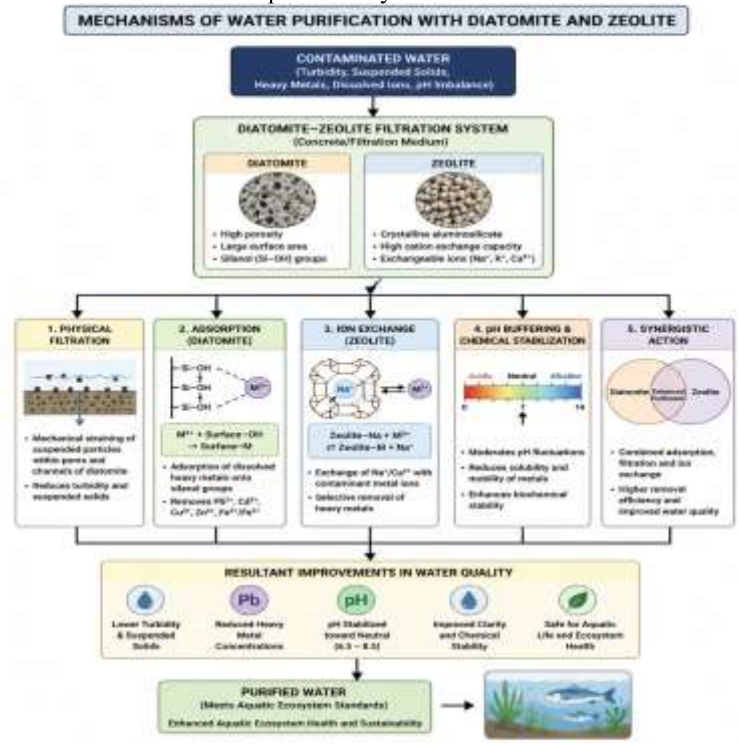

Figure 4: Flowchart representing water purification

9.Results and Discussions

Porosity was determined using the Archimedes method following ASTM standard procedures, which estimate the open pore volume through measurements of dry, saturated, and immersed specimen masses. The method is widely used for assessing pore structure and water absorption characteristics of porous materials and cement-based composites (ASTM C642, 2021). Water purification performance was assessed based on the material's ability to remove contaminants from water through mechanisms such as adsorption, filtration, ion exchange, and surface interaction, which are influenced by porosity and microstructural characteristics [11,12,16].
The highest porosity observed in Mix 3* suggests greater potential for water infiltration and purification performance, which may enhance contaminant removal and create conditions favorable for aquatic organisms. However, excessively high porosity may reduce structural durability and affect long-term performance. In contrast, the lower porosity observed in Mix 6* indicates a denser matrix with improved mechanical stability but potentially lower permeability and reduced filtration efficiency. The porosity characteristics influence the efficiency of water filtration and contaminant removal. Materials with an optimized pore structure provide greater surface area for adsorption and facilitate water flow, improving the removal of suspended particles, nutrients, and dissolved pollutants.

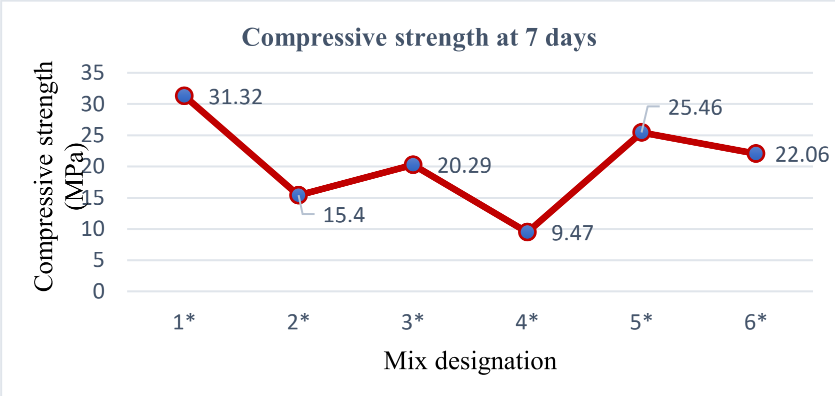

Figure 5: Graph showing compressive strength of modified pervious concrete

From the perspective of aquatic life, materials with suitable porosity contribute to healthier aquatic environments by reducing contaminant loading into rivers, lakes, and groundwater systems. Improved filtration decreases nutrient accumulation that can otherwise cause eutrophication, leading to algal blooms, reduced dissolved oxygen, fish mortality, and habitat degradation [17]. Cleaner water conditions support aquatic organisms by maintaining suitable habitats and reducing stress caused by poor water quality [16].
Additionally, natural filtration materials such as diatomite and zeolite can remove heavy metals and pollutants through adsorption and ion exchange mechanisms, reducing contaminant accumulation in aquatic food chains and contributing to healthier freshwater ecosystems [18].

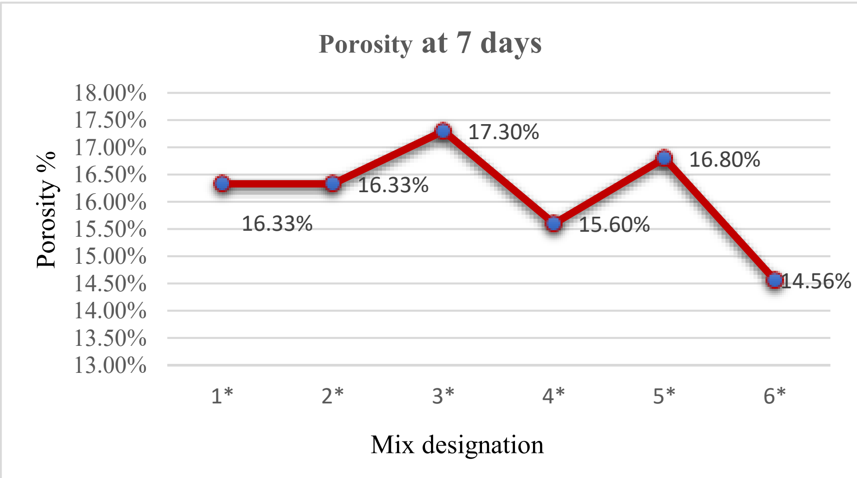

Figure 6 Graph showing porosity of modified pervious concrete

Table 2: Test results of Modified Pervious Concrete

Mix Designation	**Porosity %**		**Compressive Strength (MPa)**		**ACI Recommended Porosity Range (%)**	**Compliance**
	7 Days	**28 Days**	**7 Days**	**28 Days**		
1*	16.33	15.60	31.32	34.64	15–35	Within limit
2*	16.33	15.80	15.40	20.04	15–35	Within limit
3*	17.30	16.20	20.29	25.37	15–35	Within limit
4*	15.66	15.10	9.47	11.98	15–35	Within limit
5*	16.80	16.40	25.46	36.82	15–35	Within limit
6*	14.56	14.30	22.06	27.80	15–35	below lower practical range

Compressive strength was evaluated using standard cube testing procedures, where specimens were subjected to axial compressive loading until failure to determine their load-bearing capacity. Compressive strength is one of the primary indicators of concrete quality and structural performance and is commonly measured according to standardized testing methods [12,13,14].

Mix 1* recorded the highest compressive strength of 31.32 MPa, indicating the most effective early hydration and stronger matrix formation among all mixes. This suggests that the material composition and proportioning in this mix promoted rapid strength gain. Early-age compressive strength is strongly governed by hydration kinetics, water–binder ratio, and the development of a dense cement matrix [11,12]. The compressive strength results demonstrate that the material possesses sufficient structural stability for long-term water treatment applications. Durable filtration materials reduce degradation and prevent the release of particles into water bodies, thereby minimizing secondary pollution that could negatively affect aquatic organisms [11,12].

Table 3: Water quality after passing through Diatomite and Zeolite Pervious Concrete slab

Parameter	Initial Value (Typical)	After passing D10+Z0	After passing D0+Z10	After passing D5+Z5	Typical Removal Efficiency (%)
pH	5.3–6.3	6.2–7.0	6.8–7.5	7.0–7.8	pH stabilization
Turbidity (NTU)	124	17–27	20–30	5–10	90–95%
Lead (Pb) (mg/L)	1.1	0.35–0.47	0.05–0.10	0.01–0.05	95–99%
Cadmium (Cd) (mg/L)	0.53	0.16–0.23	0.03–0.08	0.01–0.03	94–98%
Copper (Cu) (mg/L)	2.2	0.61–0.96	0.15–0.30	0.05–0.10	95–98%
Zinc (Zn) (mg/L)	5.3	1.3–2.4	0.30–0.60	0.10–0.30	94–98%
Iron (Fe) (mg/L)	3.4	0.70–1.01	0.20–0.50	0.05–0.20	93–98%

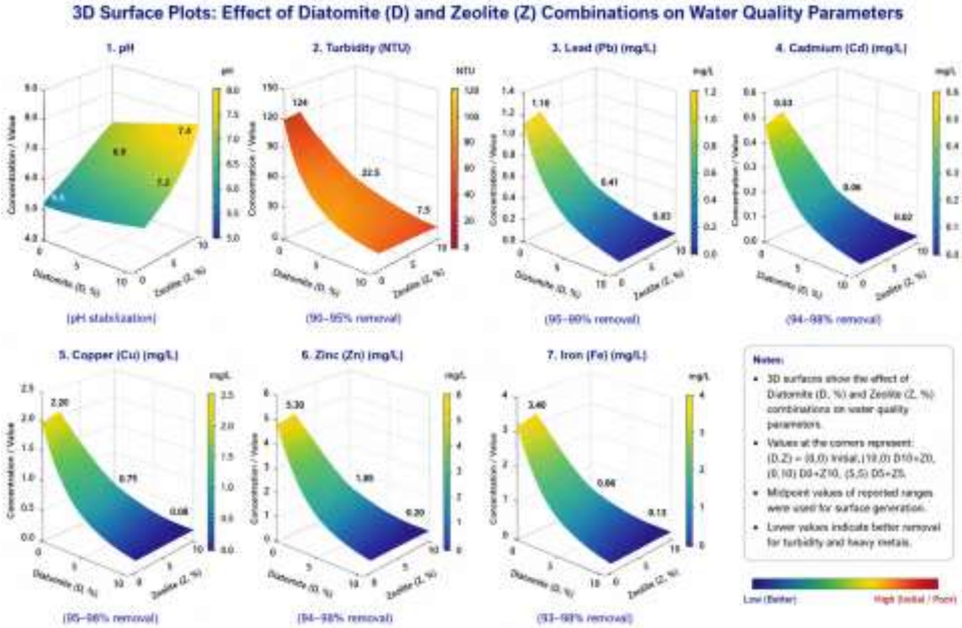

Figure 7: 3D Surface Plots showing water quality parameters

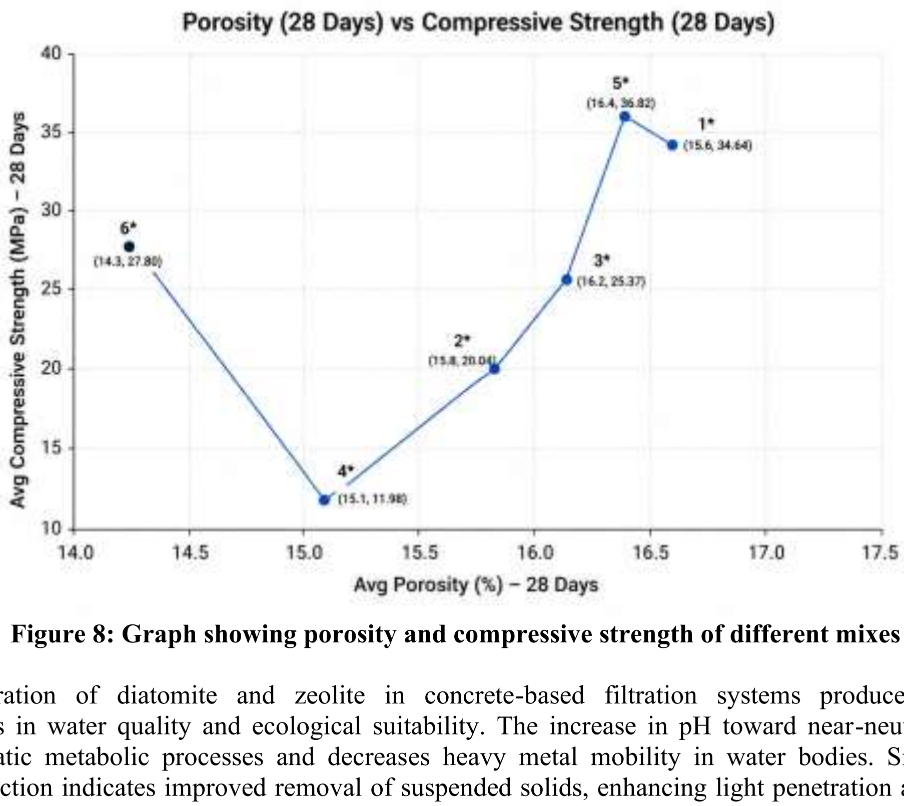

Figure 8: Graph showing porosity and compressive strength of different mixes

The incorporation of diatomite and zeolite in concrete-based filtration systems produced measurable improvements in water quality and ecological suitability. The increase in pH toward near-neutral conditions supports aquatic metabolic processes and decreases heavy metal mobility in water bodies. Simultaneously, turbidity reduction indicates improved removal of suspended solids, enhancing light penetration and promoting photosynthetic activity necessary for aquatic primary productivity and ecosystem sustainability [4,2]. Diatomite has been widely recognized as an effective adsorbent because of its high porosity, large surface area, and abundant active adsorption sites that facilitate contaminant removal from aqueous environments.

Among the investigated combinations, D5+Z5 demonstrated superior overall performance, indicating that balanced mineral incorporation enhances both adsorption and filtration mechanisms. The porous silica-rich structure of diatomite contributes to physical adsorption, whereas zeolite provides ion-exchange capability and structural stability that promote contaminant capture and water quality improvement [2,3]. The combined action of these materials likely improved the retention of dissolved pollutants and supported efficient treatment performance.

The observed reductions in dissolved heavy metals including lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and iron (Fe) indicate successful contaminant attenuation through adsorption and ion-exchange processes. Previous studies have shown that both natural and modified diatomite and zeolite materials exhibit strong affinity toward metal ions and can substantially reduce heavy metal concentrations under optimized treatment conditions [3,33].

Heavy metal attenuation is environmentally significant because these contaminants can accumulate in aquatic organisms and transfer through trophic levels, resulting in long-term ecological impacts. Therefore, lowering metal concentrations toward aquatic ecosystem standards contributes to improved ecological resilience, reduced toxic stress, and enhanced sustainability of aquatic environments. These findings support the application of diatomite–zeolite concrete systems as environmentally compatible filtration materials for water remediation and aquatic ecosystem protection [2,33].

Table 4: Evaluation of Water Quality Improvement Using Diatomite–Zeolite Concrete with Respect to Aquatic Ecosystem Standards, EPA 2026

Parameter	Initial Water Quality	After D10+Z0	After D0+Z10	After D5+Z5	Aquatic Ecosystem Standard	Improvement (%)	Ecological Assessment
pH	5.3–6.3	6.2–7.0	6.5–7.3	6.7–7.5	6.5–8.5	—	Suitable for aquatic organisms
Turbidity (NTU)	40–80	12–18	8–12	5–8	<5 ideal; <25 acceptable	77–90	Improved light penetration
Lead (Pb) (mg/L)	0.020–0.050	0.010–0.020	0.005–0.010	0.002–0.006	≤0.002–0.007	70–90	Reduced toxicity risk
Cadmium (Cd) (mg/L)	0.008–0.015	0.005–0.007	0.003–0.005	0.001–0.003	≤0.001–0.005	75–90	Lower bioaccumulation potential
Copper (Cu) (mg/L)	0.10–0.25	0.05–0.08	0.02–0.04	0.01–0.02	≤0.013	80–90	Reduced gill toxicity
Zinc (Zn) (mg/L)	0.20–0.40	0.12–0.18	0.08–0.12	0.05–0.10	≤0.12	70–88	Suitable for aquatic life
Iron (Fe) (mg/L)	0.8–1.5	0.45–0.60	0.30–0.45	0.20–0.35	≤0.30	65–85	Improved habitat conditions

Table 5. Alignment of Diatomite–Zeolite Pervious Concrete with Sustainable Development Goals (SDGs)

SDG	Goal Description	Contribution of Diatomite–Zeolite Pervious Concrete	Experimental Relevance	Environmental and Ecosystem Impact
SDG 6	Clean Water and Sanitation	Enhances water purification through adsorption, ion exchange, and filtration mechanisms, reducing pollutant concentrations and improving infiltrated water quality.	Reduction in turbidity, stabilization of pH, and improved removal of heavy metals demonstrate purification efficiency.	Supports cleaner water resources, reduces contamination of groundwater, and improves aquatic habitat conditions.
SDG 11	Sustainable Cities and Communities	Promotes resilient and sustainable urban infrastructure through permeable concrete systems that facilitate infiltration and reduce storm water runoff.	Optimized porosity and compressive strength provide a balance between hydraulic and structural performance.	Reduces urban flooding, improves groundwater recharge, and supports environmentally sustainable development.
SDG 13	Climate Action	Supports climate adaptation by mitigating runoff pollution, enhancing infiltration, and reducing environmental stress	Modified concrete mixes improve functional performance while maintaining durability	Contributes to climate-resilient infrastructure and sustainable urban water management strategies.

		associated with urbanization.	and reducing environmental burden.	
SDG 15	Life on Land	Reduces contaminant transport into terrestrial and freshwater ecosystems through natural filtration and contaminant attenuation pathways.	Improved contaminant removal efficiency decreases pollutant loading and ecosystem disturbance.	Protects biodiversity, limits habitat degradation, and supports long-term ecosystem resilience.

10. Conclusions and Environmental Impact

This study evaluated the performance of the developed material through porosity, compressive strength, and water purification efficiency with reference to environmental sustainability and aquatic ecosystem protection.

1. Porosity analysis showed values ranging from 14.56% to 17.30%, demonstrating that pore structure significantly influences hydraulic behaviour, adsorption capacity, and contaminant transport within modified pervious concrete systems.
2. Compressive strength results indicated variation among mix combinations, with Mix 1* achieving the highest strength (31.32 MPa) and Mix 4* the lowest (9.47 MPa). The results highlight the need to optimize mix composition to balance mechanical stability and filtration performance.
3. Diatomite enhanced turbidity reduction through physical filtration and surface adsorption, whereas zeolite improved heavy metal removal via ion-exchange mechanisms, demonstrating complementary purification functions.
4. The combined diatomite–zeolite system produced synergistic treatment effects, resulting in near-neutral pH, reduced turbidity (<10 NTU), and decreased heavy metal concentrations, thereby improving overall water quality.
5. Water purification performance confirmed that modified pervious concrete can function as a multifunctional treatment material, enabling pollutant attenuation through filtration, adsorption, and pore-mediated transport processes.
6. From an environmental perspective, the developed material shows potential to reduce contaminant loading, improve aquatic ecosystem conditions, and support sustainable water treatment and infrastructure applications.

11. Future Scope

1.Optimize the percentage combination of diatomite and zeolite to maximize pollutant removal efficiency while maintaining concrete strength and durability.
2. Extend research toward the removal of emerging contaminants, including micro plastics, pharmaceuticals, nutrients, and organic pollutants.
3.Evaluate the effectiveness of the system in reducing microbial contamination and improving biological water quality.
4.Assess the impact of treated water on aquatic ecosystem restoration, biodiversity conservation, and habitat improvement.
5.Integrate diatomite–zeolite purification systems with advanced treatment technologies such as membrane filtration and biological treatment methods.
6. Apply machine learning and numerical modelling techniques to predict pollutant removal efficiency and optimize mix proportions.
7.Conduct Life Cycle Assessment (LCA) and economic feasibility studies to evaluate sustainability and large-scale implementation potential.

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